WELL WATER QUALITY IN SAN MIGUEL DE ALLENDE
Phase I: Results and Conclusions

Prepared for:

Municipio de San Miguel de Allende

Dirección de Medio Ambiente y Ecología

Dirección de Desarrollo Urbano y Ordenamiento Territorial Municipio de Allende

SAPASMA
Sistema de Agua Potable y Alcantarillado de San Miguel de Allende

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Message from the Director

Ecosystem Sciences Foundation (ESF) is an international, non-profit, non-governmental organization dedicated to improving people's lives by restoring and improving management of environmental resources. Water is the most fundamental resource and its quality is of the greatest importance to the health of humans. Because of the threat of contamination from fluoride, arsenic, and coliform bacteria in community wells throughout the San Miguel de Allende Municipality, ESF, Dirección de Medio Ambiente y Ecología, Dirección de Desarrollo Urbano y Ordenamiento Territorial, and Sistema de Agua Potable y Alcantarillado de San Miguel de Allende (SAPASMA) established a collaborative team to test wells and determine those villages most at risk for polluted drinking water. The next phase, to be undertaken by Mexican partner organization Ciencias del Ecosistema, A.C., is to demonstrate alternative low-technology, potable water sources for high risk villages. ESF donated the bulk of the water testing equipment and materials, set-up a laboratory and provided the training for Dirección de Medio Ambiente y Ecología, Dirección de Desarrollo Urbano y Ordenamiento Territorial, and SAPASMA personnel. Sociedad Audubon de México, A.C. generously provided use of their laboratory incubator, used in coliform screening. ESF then compiled and analyzed all data using GIS technology. The water testing project represents a significant monetary contribution from ESF as well as a substantial contribution of manpower and time by the Municipality of San Miguel de Allende. ESF is proud to have developed a partnership with the Municipality for a project of such fundamental importance to the people of San Miguel de Allende. Please visit our website, www.ecosystemsciences.com, to learn more about what Ecosystem Sciences Foundation does and please consider contributing to our efforts.

Mark Hill
Foundation Director

Abstract

Community wells in rural areas of the San Miguel de Allende Municipality were tested between September 2005 and February 2006 to determine contamination from arsenic, fluoride, and coliform bacteria. Other water quality parameters such as pH, hardness, and alkalinity were also tested. Of the 101 water samples analyzed, 20 exceeded the Mexican government drinking water standard permissible limits for fluoride levels and 69 tested positive for coliform; no fecal coliform was detected. The arsenic levels at all sites sampled were below the Mexican government drinking water standards and do not pose a health risk. More than 100,000 people reside in the rural areas where testing was conducted and they all depend upon groundwater for their drinking water. As the groundwater supply in this region diminishes due to overuse, the contaminant concentrations increase, putting users at greater risk of suffering health effects. Adverse health effects as a result of exposure to excessive fluoride concentrations and coliform bacteria are well documented. This study employed water quality testing and GIS analysis to identify rural communities at greatest risk of exposure to contaminants so that treatment strategies can be prioritized and implemented to reduce that risk. Treatment options include providing education and training in identifying contamination sources (for coliform), providing trucked water, and implementing rain water harvesting systems in areas with the highest fluoride concentrations. These strategies will be employed during subsequent phases of the project.

Introduction

A partnership between Ecosystem Sciences Foundation, Ciencias del Ecosistema, A.C., the San Miguel de Allende Municipal Government Department of Environment and Ecology (‘Dirección de Medio Ambiente y Ecología’), Department of Urban Development (‘Dirección de Desarrollo Urbano y Ordenamiento Territorial’), and Drinking Water and Sanitation System (‘Sistema de Agua Potable y Alcantarillado de San Miguel de Allende’) (SAPASMA), collected and analyzed groundwater samples in rural communities of the municipality from August 2005 to February 2006. One hundred twenty rural water (see Figure 1) were selected for sampling to determine contamination from fluoride, arsenic, and coliform bacteria; measures of other water quality parameters such as pH, alkalinity, and hardness were also determined. Other pertinent data regarding well depth, water distributions systems, and storage of water were also collected, which will provide Ciencias del Ecosistema, A.C. and the municipal government departments with the necessary information to conduct the next phase of the project. This next phase entails providing communities that have fluoride contamination problems with alternative drinking water sources in order to reduce the health risks from contamination.

More than 100,000 people reside in the rural areas where testing was conducted and they all depend upon groundwater for their drinking water. The health effects as a result of exposure to excessive fluoride concentrations and coliform bacteria are well documented (WHO 2006, United States Environmental Protection Agency [EPA] 2003, Connett 2001, Kennedy 2001). In Mexico, thirteen million inhabitants do not have access to safe, potable water.

The water quality results indicate the presence of coliform in almost three quarters of the samples and high fluoride concentrations in approximately 20% of the samples; arsenic levels are below the Mexican government health standards. The water quality results were entered into a GIS and displayed on maps to show concentration levels (or presence/absence in the case of coliform) at each site (see Figures 6 - 11). Well systems in the moderate to high-risk categories for fluoride levels will be retested and then prioritized for treatment during phase II of this project. Sites showing coliform presence will also be re-sampled and communities will receive training on how

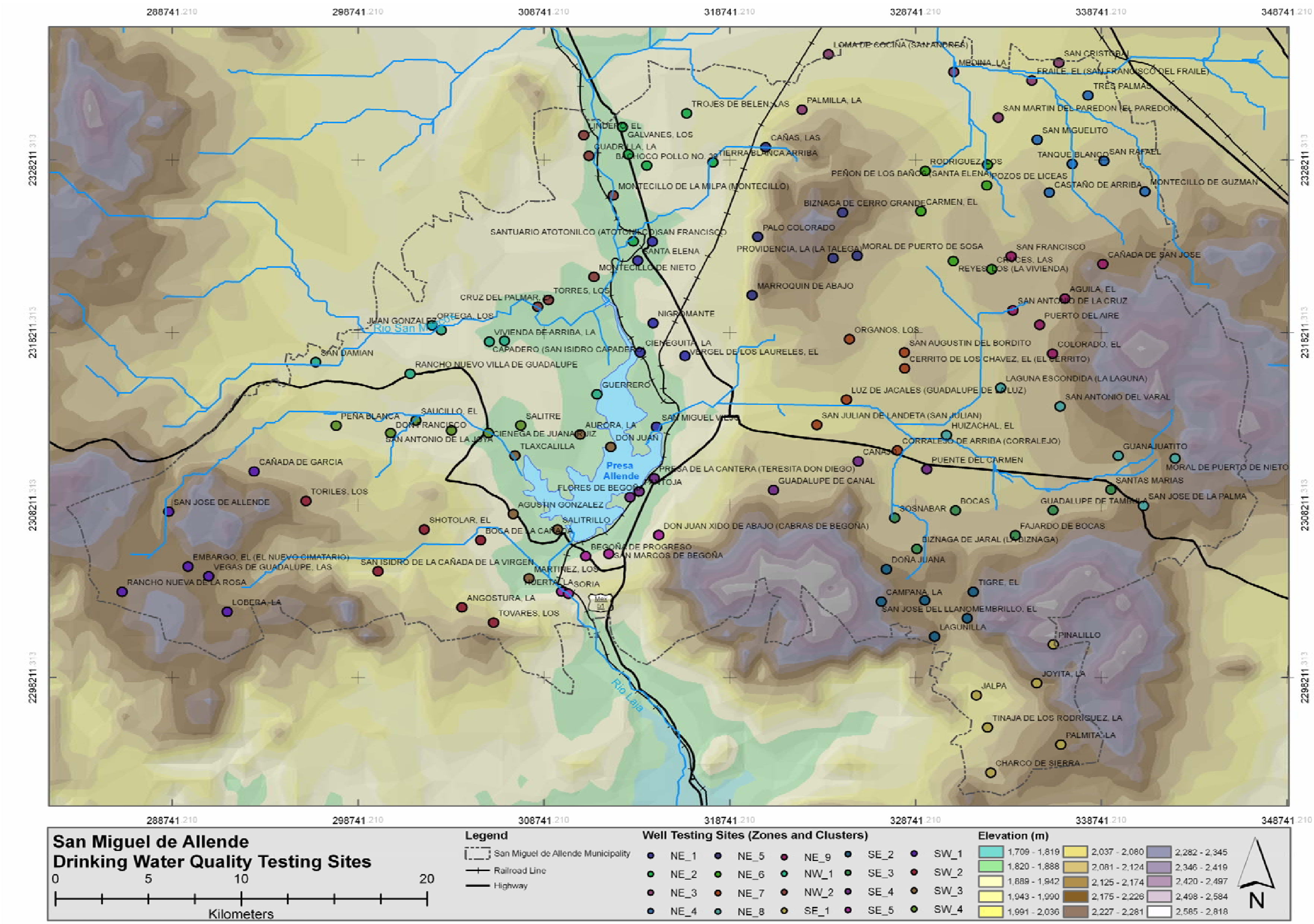

Figure 1. Original sample locations map (ESF 2005).

to identify contamination sources and prevent future contamination; replacement water distribution materials may also be provided, depending on funding availability.

Background
The population and economy of rural San Miguel de Allende Municipality, Mexico depends upon groundwater for drinking and irrigation needs. The Independence Aquifer ('Acuífero de la Independencia'), which underlies this municipality and much of the state of Guanajuato provides fossil groundwater for these purposes. Recent research suggests that the rate of depletion of this aquifer is increasing and not sustainable, and also reports that the quality of this aquifer water does not meet acceptable drinking water standards, in particular locations of the aquifer (Ortega-Guerrero et al. 2002).

While high-quality drinking water is a human necessity, each human society has its own culturally defined standards of acceptability. Particular techniques to acquire and treat drinking water may be acceptable for one society, but not others. In the same way, utilization of a resource is addressed differently by different cultures. In order to implement strategies to acquire, protect, and/or restore drinking water quality, these strategies must be sensitive to the subject societies. This project attempts to investigate the scientific and medical dimensions of drinking water while also researching and considering the impact of culture; for this reason, participation of the San Miguel de Allende Municipal Government Departments is and important component.

Independence Aquifer
The Independence Basin is an area of approximately 7,000 square kilometers that includes the Municipality of San Miguel de Allende in Central Mexico. Groundwater is the main water source for agricultural (85% of use), urban, and industrial uses (15% of use combined) in the basin (Ortega-Guerrero *et al*. 2002). The groundwater resources in the Independence Basin are part of the Independence Aquifer, a large underground reservoir of ancient water. Recent research suggests that the rate of depletion of this aquifer is increasing and is not sustainable (Ortega-Guerrero 2004). Because groundwater pumping (extraction) has exceeded recharge for many years, the aquifer is diminishing (Castellanos *et al*. 2002). Studies also show that the groundwater quality in the aquifer does not meet acceptable drinking water standards in some locations, specifically as a result of high arsenic concentrations (Ortega-Guerrero et al. 2002, Ortega-Guerrero 2004). Dissolved salts and metals naturally exist in groundwater. However, as the amount of water in the aquifer diminishes the concentration of salts and metals increases. Excessive concentrations of these salts and minerals can have adverse health effects that have already been documented in the San Luis de la Paz area (Ortega-Guerrero *et al*. 2002) and the San Luis Potosi area (Deogracias 2006).

The probability is increasing that any individual well delivers water of diminished quality is increasing as more water is pumped from the Independence Aquifer. Inefficient irrigation practices, overgrazing, deforestation, soil erosion, and population increases within the basin are all contributing to the depletion of this essential natural resource. Without proper watershed and aquifer management practices, the water quality in this aquifer will continue to decrease along with the quantity of water available for human use (Ortega-Guerrero *et al*. 2002).

Drinking water
Exposure through drinking water to excessive amounts of arsenic, a naturally occurring mineral, is known to cause cancer of the skin, lungs, urinary bladder, and kidney, as well as other skin changes such as pigmentation and skin thickening (hyperkeratosis) (WHO 2005a). The concentrations of arsenic sampled in some areas of the Independence Basin have exceeded the Maximum Contaminant Level for arsenic suggested by the Mexican Department of Health and

the World Health Organization (WHO) (Ortega-Guerrero *et al.* 2002, Ortega-Guerrero 2004, WHO 2005a).

Excessive amounts of fluoride are known to cause bone disease and mottling of children's teeth (United States Environmental Protection Agency 2003). Fluoride is also known to exist in the Independence Aquifer at concentrations above the Maximum Contaminant Level (Ortega-Guerrero *et al*. 2002, Ortega-Guerrero 2004, WHO 2005a).

Coliform is a family of bacteria. The coliform bacteria *Escherichia coli* (known commonly as *E. coli*) comes from mammal feces and is known to cause dysentery in humans. Screening for coliform reveals information concerning potential contamination of the water source and supply system.

Alkalinity, pH, and hardness in water can impact water quality for human consumption and agricultural use. When found in certain concentrations and combinations, alkalinity, pH, and hardness can increase the incidences of heart disease and other ailments (WHO 2005b). The increased concentrations of sodium, alkalinity, and pH in the groundwater from the Independence Aquifer in the past two decades have affected soil fertility, and consequently, soil productivity (Ortega-Guerrero *et al*. 2002).

To address these water quality issues, Ciencias del Ecosistema, A.C. and the San Miguel de Allende Municipal Government Department of Environment and Ecology entered into a partnership to investigate drinking water quality in rural communities within the San Miguel de Allende municipality. This document presents the initial results of the first stage (Phase I) of this joint effort to investigate and improve drinking water quality for rural inhabitants of San Miguel de Allende municipality.

Purpose

The purpose of this reconnaissance-level water quality testing project is to identify the communities in the San Miguel de Allende Municipality at greatest risk of exposure to groundwater contaminants. Risk categories for the different contaminants were established and the results displayed on maps in order to prioritize treatment for the next phase of the project, which involves providing a short-term and long-term alternative water source in order to reduce the health risks from the contaminated groundwater.

Table 1. List of the ten urban wells of San Miguel de Allende sampled, February 2006, with identification codes.

ID	SAPASMA Well Name
134	Pozo No. 6, Guadalupe
135	Pozo No. 11, Mexiquito II
136	Pozo San Luis Rey II
137	Pozo No. 3, San Antonio I
138	Pozo No. 4, Villa de los Frailes
139	Pozo No. 13, La Lejona
140	Pozo 7 Insurgentes I
141	Pozo Landeta II
142	Pozo La Luz
143	Pozo de Tirado

Methods

The original list of 120 rural community water sources was modified during the course of the project, based on logistical constraints and the acquisition of new information such as multiple communities sharing the same well. In the end, 101 rural water sources within the San Miguel de Allende Municipality were sampled and analyzed (see Table 2). Finally, ten urban wells from the city of San Miguel de Allende were sampled and analyzed (see Table 1). Because of the disparity of need as well as between well systems and existing treatment techniques, the two datasets, rural and urban, are treated separately in this document.

Table 2. List of the 101 rural wells of San Miguel de Allende Municipality sampled.

ID	Sample Location; Pueblo Name
1	La Cieneguita
2	San Francisco
3	San Miguel Viejo
4	Vergel de los Laureles
5	Fraccionamiento El Nigromante
6	Santa Elena de la Cruz
7	Galvanes
8	Trojes de Belén
9	San Martin de la Petaca
10	Bachoco Pollo No. 34
11	Tierra Blanca de Arriba
12	Santuario de Atotonilco
14	Loma de Cocina (San Andrés)
15	La Medina
16	La Palmilla
18	San Martín del Paredón
21	San Miguelito
24	Tres Palmas
25	Biznaga del Cerro Grande
26	Las Cañas
27	Marroquin de Abajo
28	Moral de Puerto de Sosa
29	Palo Colorado
30	La Talega
31	El Carmen
32	Peñón de los Baños
34	Los Reyes (La Vivienda)
35	Los Rodríguez
36	Las Cruces
38	Corralejo de Arriba
41	San Julián de Landeta
42	San Agustín del Bordito
44	El Huizachal
45	Laguna Escondida
46	Moral de Puerto de Nieto
47	San Antonio del Varal
48	San José de la Palma
53	Cañada de San José
55	San Isidro Capadero
56	Guerrero
57	Juan González
58	San Damián
60	Rancho Nuevo Villa de Guadalupe
62	Cruz del Palmar
63	La Cuadrilla
64	El Lindero
65	Montecillo de la Milpa (Montecillo)
66	Montecillo de Nieto
67	Los Torres
69	Jalpa
70	La Joyita
72	Pinalillo
73	Tinaja de los Rodríguez
74	La Campana
75	Doña Juana
77	El Membrillo
81	Bocas
82	Fajardo de Bocas
83	Guadalupe de Támbula
85	Santas Marías
86	Cañajo
88	Guadalupe de Canal
90	Puente del Carmen
93	Don Juan Xidó de Abajo (Cabras de Begoña)
94	La Huerta
95	San Marcos de Begoña
97	Cañada de García
98	La Lobera
99	San José de Allende
100	El Embargo (Nuevo Cimatario)
101	Las Vegas de Guadalupe
102	Rancho Nuevo de la Rosa
103	La Angostura
104	Boca de la Cañada
105	San Isidro de la Cañada
106	Xotolar
107	Los Toriles
108	Los Tovares
109	Agustín González
110	Don Juan
111	Los Martínez
112	Tlaxcalilla
113	La Aurora
114	Salitrillo
115	Ciénega de Juana Ruiz
116	Don Francisco
117	Peña Blanca
118	Salitre
119	San Antonio de la Joya
121	La Palma
122	San José de Gracia
123	Elvira
124	Corral de piedras de Arriba
125	La Calera
126	Puerto de Nieto
127	San José de la Amistad
128	Don Diego
129	Estancia de San Antonio
130	Castaño de Abajo
131	Tierra Blanca de Abajo
133	Loma de Magueyes

Sampling and Data Collection

One hundred and one rural water systems were sampled between September 2005 and February 2006 (see Table 2). Generally, two field technicians collected three samples daily three times a week. The field effort was two-fold: community and water source description acquisition and sample collection. Field technicians first made contact with the Delegado, an elected representative and appointed government contact person, at each community. From the Delegado, technicians solicited various information about the primary community water source, and completed a two page field form (Appendix A) at each site. Information detailed included water source type, well depth, type of distribution system, information about the community, the contact person's name, GPS location information, and well system information and descriptions and existence and type of treatment methods used. If the Delegado was unavailable, then technicians directed their efforts to the community school, and interviewed school teachers to collect well and community information. One or more digital photo was taken of the well and associated apparatus at each site. Samples were collected as near to the well as possible, and risk of contamination was minimized by utilizing standard sample collection strategies. Samples were held in clean polyethylene bottles and "Whirl-Pak" sampling bags, and packaged in a cooler with ice for transportation to the laboratory.

Laboratory Sample Analysis

Fluoride concentrations were measured colorimetrically using the SPADNS AccuVac Method 4500-F (APHS 1998a). Arsenic levels were tested using Arsenic Test Kit Reagent Set (HACH 2000), and coliform samples underwent the Bromcresol Purple Acidity Method of Presence/Absence with MUG (APHS 1998b, HACH 2005b). Other water quality parameters such as total chlorine, free chlorine, total hardness, total alkalinity, and pH were evaluated using AquaCheck 5-in-1 test strips (HACH 2005a).

Because of the length and detail involved in the laboratory process, protocols specific to each parameter and task are provided in Appendix B. Protocols were provided to technicians in both Spanish and English.

Data Transfer and Analysis

Data sheets were filled out by hand by technicians, and delivered to project office staff (located in San Miguel de Allende) for entry into a pre-prepared Adobe Acrobat Form. The Form was configured to deliver the data in digital form via email to project staff in Boise, Idaho, USA. Hard copies of the data forms, as entered by office staff, were printed and archived at the San Miguel de Allende office. Digital data were assessed for comprehensiveness and consistency and compiled on a backed-up server at the Boise office until completion of the sampling process.

Field and laboratory data were analyzed separately in various ways to identify potential patterns in well characteristics and water quality. Simple, non-parametric statistics were performed for all water quality parameters and well characteristics to roughly characterize each data set. Lastly, analysis and summary of the qualitative data from the field data were performed.

Although potentially beyond the scope of this reconnaissance level investigation, a more rigorous statistical evaluation, ordination, was performed for all water quality parameters with sample collection and environmental variables. Ordination allows researchers to identify patterns in the results that may be linked to environmental variables and/or sampling techniques. Results from this effort could help guide future efforts with regard to site selection, project design, and sampling techniques.

Grid Creation for Parameter Concentration Maps

Grids depicting the range in water quality pollutant levels throughout the San Miguel de Allende Municipality were created in ArcGIS 9.1, using the Spatial Analyst Extension (see Figures 6, 7, 9 - 11). Grids were created for the following variables: Alkalinity, Arsenic, Hardness, Fluoride, and pH. An associated grid was not created for coliform since results were categorized into the two groups of presence and absence.

Grids were interpolated using the Inverse Distance Weighted (IDW) function in Spatial Analyst. IDW is a grid interpolation technique that functions under the assumption that points close to one another are more alike than those farther apart. To predict a value for any unmeasured location, IDW uses measured values surrounding the unmeasured location. Those measured values closest to the unmeasured location will have more influence on the predicted value than those farther away. For each water quality pollutant grid, unmeasured locations were calculated using the six closest measured locations. Thus, IDW assumes that each measured point has a local influence that diminishes with distance. The method emphasizes the points closer to the unmeasured location greater than those farther away, hence the name Inverse Distance Weighted (ESRI 2006).

The latitude and longitude of each sample site was collected using a GPS receiver. This coordinate data was used as the specific geographic location within the San Miguel de Allende Municipality for each water quality pollutant point. One hundred and one water quality sample points were used as the data to interpolate each grid.

The grid creation function of ESRI's Spatial Analyst outputs a grid whose aerial extent is equal to a rectangle encompassing the interpolated point data. This output grid is larger than the project area and loses accuracy towards its margins. Therefore, final grids were clipped, using the San Miguel de Allende Municipality shapefile, to reflect the actual project area and to ensure accurate results.

Results

The original list of 120 sites was amended during the course of the project, often because more than one community shared the same water source for their drinking water. A total of 111 samples were taken and analyzed during the course of the study, from September 2005 through February 2006. Ten of the samples were taken from the urban wells of San Miguel de Allende (see Table 1), while 101 were taken from the rural sites (see Table 2). Since the urban wells are all treated with chlorine and monitored frequently by SAPASMA (Municipal agency responsible for water supply and sanitation), these ten samples are analyzed apart from the rest and results are presented separately from the rural samples.

Results are presented in two sections: the first summarizes data collected during the sampling effort about the water source and storage and distribution systems; the latter section presents and summarizes the results of the water quality data.

Results: Well Systems

During the data collection phase of this study, field technicians made contact with Delegados in each community to obtain the water samples and collect data about the water source, water delivery systems, water storage, treatment methods, and water availability. The well depth data was incomplete; most Delegados did not know the depth of the well systems; of the well sites sampled, 83 (63%) did not have well depth data. Of the well depths provided, the most frequently recorded value was 200 meters; the average depth was 208 meters with the deepest well reported at 350 meters, and the shallowest well at 50 cm, which indicates a spring. Sixteen communities' water source are springs and one was a pond (see Figure 2.1).

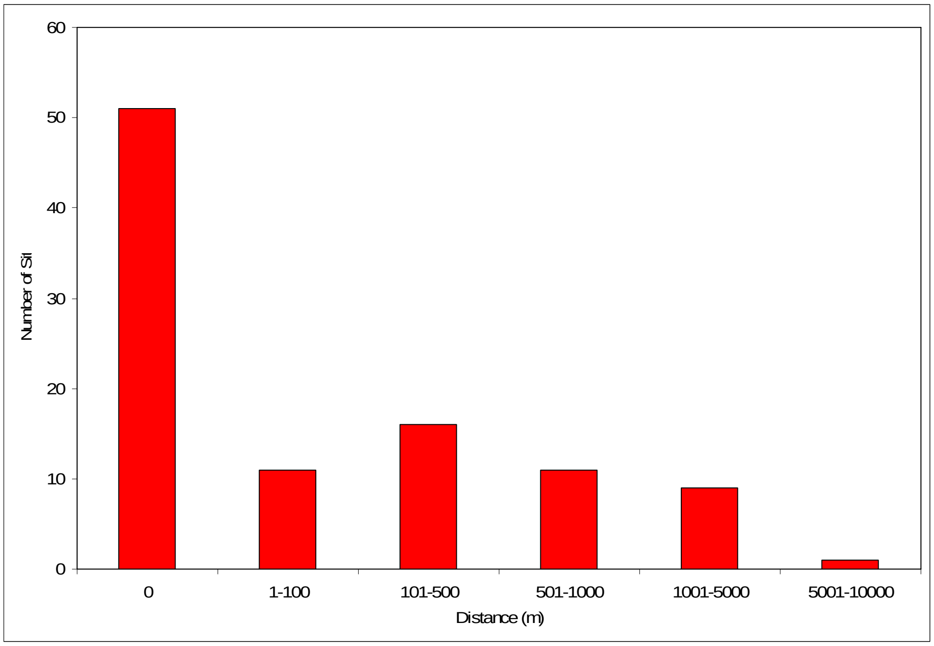

Figure 2. Distance between sample site and well locations, San Miguel de Allende Municipality.

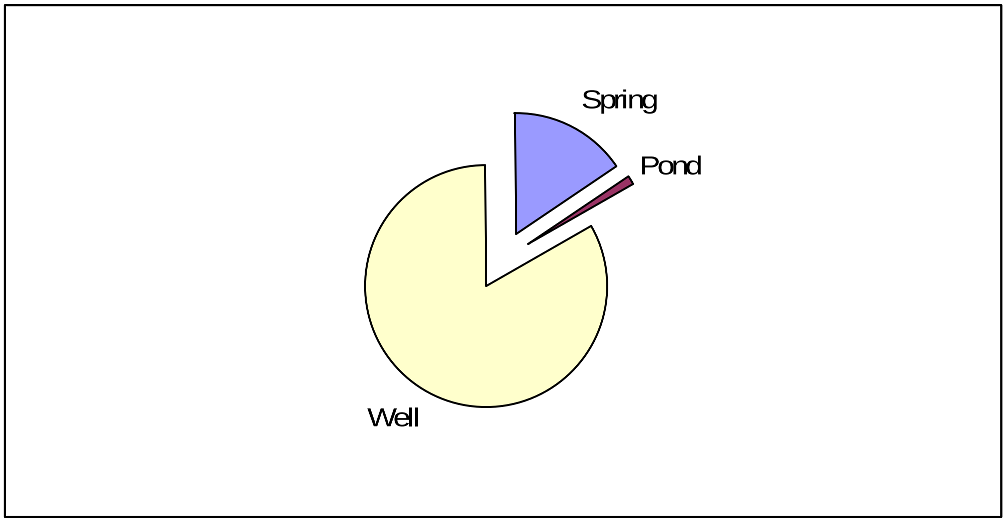

Figure 2.1. Distribution of drinking water sources tested for various water quality parameters in San Miguel de Allende Municipality.

In order to control for variation in sampling techniques, technicians recorded the distance between the location of the sample site from the actual well that withdraws water from the underground aquifer. As displayed in Figure 2, approximately half of the samples were taken directly from the well, and the rest approximately evenly distributed across distance categories.

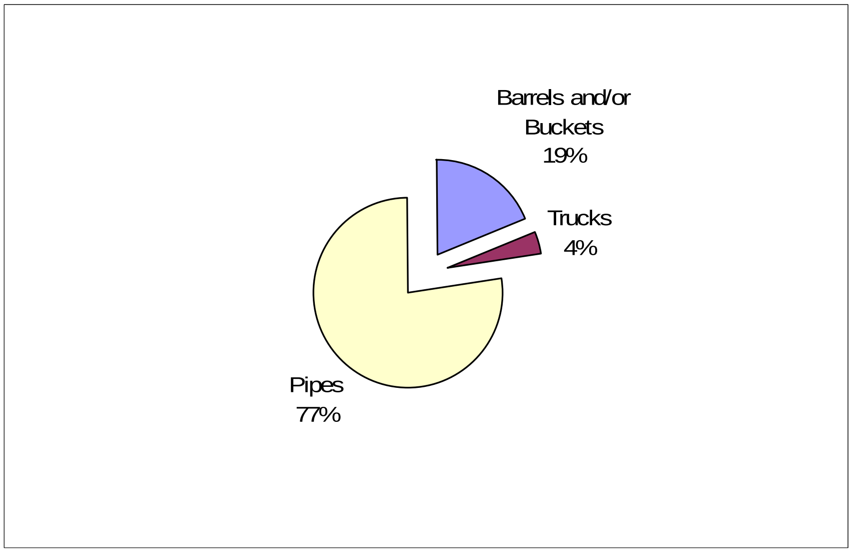

Figure 3. Distribution of three types of water transfer methods among sampled, rural systems in the San Miguel de Allende Municipality.

Technicians investigated at each sample site the method of water transport between wells and sample location. As displayed in Figure 3, the majority of sites simply used closed pipes to move water from well to tap. Trucks with water containers (‘pipas’) accounted for 4% of sampled methods of transport, and the use of barrels (‘tambos’) and buckets (‘cubetas’) to transport water accounted for the remaining 19% of sampled systems.

Technicians recorded how drinking water is stored in between the well and the distribution system. The most common type of storage container sampled (38%) was the ‘mampostería,’ which is a covered, masonry structure. Closed, raised structures, such as water towers, were the second most commonly sampled (27%). Open containers, including wells without covers, accounted for 19% of the samples, while 3% of sites sampled utilized barrels and buckets to store water (see Figure 4).

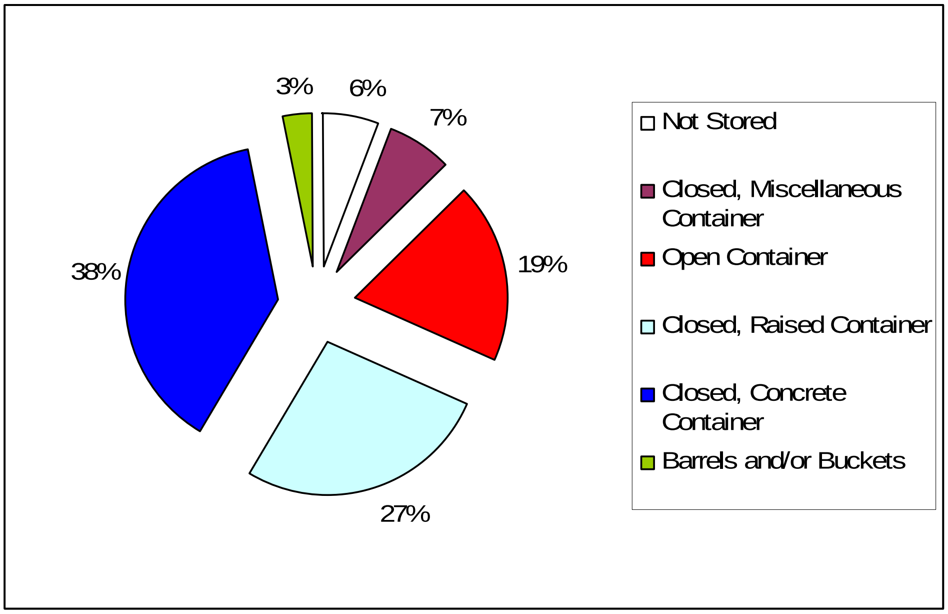

Figure 4. Distribution of sampled drinking water storage types in San Miguel de Allende Municipality.

The ten urban wells of San Miguel de Allende are all treated. As well, they all utilize pumps and pipes for transport from well to distribution system. Lastly, all ten of the urban wells are reliable year-round.

Of the rural water systems tested, most of them (82%) had no functioning water treatment systems. While three-quarters of these had no treatment infrastructure in place, purification equipment was in place at the remaining quarter, yet was either in disrepair or had simply been disconnected (see Figure 5). Of the sampled systems, only 17 communities use water treatment equipment. Water treatment methods include the uses of sodium hypochlorite, chlorine, chlorine gas, and acetic acid (to soften water). Various reasons were provided for not repairing and/or utilizing existing water treatment equipment, and this issue is addressed in the Discussion section.

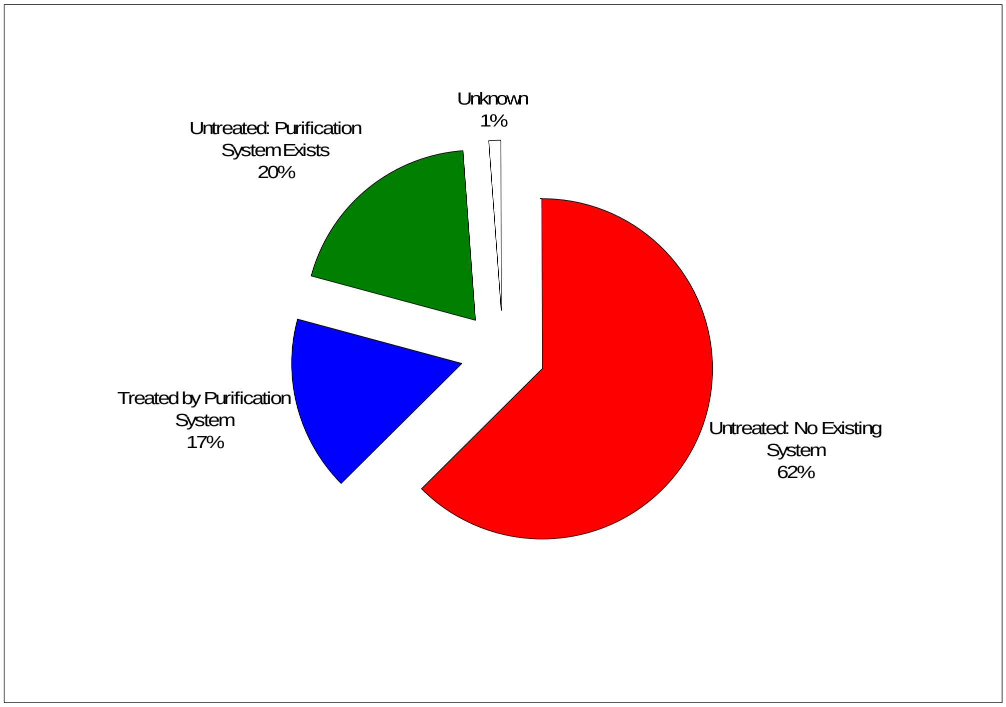

Figure 5. Existence of functional and dysfunctional water purification systems among sampled rural water systems, San Miguel de Allende Municipality.

Of the 101 sampled sites, 79 used pumps to draw water from wells. Of these, at least 15 were submergible pumps ('bomba submergible'). At 21 sites the water is not pumped. 'Cubetas' are the most common method of withdrawing water (when the method is specified) other than a pump. The method of withdrawal was not determined for one site.

Technicians inquired as to seasonal or temporal variation in water availability with respect to sampled wells. Delegados and representatives provided some information, and the few responses obtained demonstrate that water is available year-round for most wells. The most common reason provided for unavailability of water was that the lack of consistency supply of electricity for the water pumps. Seven wells were reported to go dry at one point or another during the year. For three of these wells, accessible water levels return within hours after pumping is stopped, but another three go dry for at least three months every year, returning to an accessible level only when the rain season begins in July. One well was reported to go dry whenever a nearby agricultural well is in operation, only returning to an accessible level two days after the agricultural well is shut off.

Results: Water Quality

Overall, results indicate that water quality throughout the municipality poses no acute immediate danger to the inhabitants. However, several wells contained contaminant levels that exceed Mexican governments maximum allowable standards (NORMA Official Mexicana, NOM-1276-SSA1-1994) and pose both short and long term health hazards. Results from the water quality testing reveal fluoride concentrations in excess of Mexican government permissible limits and the presence of coliform in almost three-quarters of the samples taken. The results for each contaminant are discussed below in more detail, along with the findings for the other water quality parameters. It should be noted, again, that water quality testing was performed as a reconnaissance effort, and future efforts should include water quality testing to confirm results and monitor temporal trends.

Fluoride

Results show that of the 101 rural samples analyzed, 20 have fluoride levels above the Mexican government drinking water standard of 1.50 mg/L. Concentrations vary from 0.0 mg/L to 4.0 mg/L with a mean of .88 mg/L. Any levels above 1.5 mg/L in drinking water pose serious health hazards to humans (WHO 2006). Risk categories were established in order to prioritize treatment for a follow up phase to the project; communities that fall into the Moderate or High-risk categories should acquire alternative water sources.

Concentrations at or above 2.2 mg/L are considered high risk; eight communities have levels in this category (see Table 3). Two of these sites located at Guerrero and Agustin Gonzalez have concentrations of 4.0 mg/L, more than twice the allowable limit and above drinking water standards around the world. Twelve communities have fluoride concentrations in the moderate risk category (1.5 - 2.2 mg/L). The twenty communities that tested Moderate or High-Risk represent a total population of 6,293 people. Ten sites have levels in the low risk category (1.0-1.4 mg/L), which are currently below the Mexican government permissible limits. One of the urban wells of San Miguel de Allende, ID 143, "Pozo de Tirado" was found to have a fluoride concentration of 1.9 mg/L, placing it in the Moderate Risk Category.

Table 3. Sampled rural community water sources in the San Miguel de Allende Municipality with fluoride levels in excess of Mexican government standards (>1.5 mg/L), categorized by risk level, with population values (SIGOET 2004).

ID	Community Name	Fluoride Concentrations (mg/L)	Risk Category	Population
56	Guerrero	4.0	High	190
109	Agustín Gonzàlez	4.0	High	515
113	La Aurora	3.2	High	24
66	Montecillo de Nieto	2.8	High	220
67	Los Torres	2.4	High	335
110	Don Juan	2.4	High	103
2	San Francisco	2.2	High	172
5	Fraccionamiento El Nigromante	2.2	High	1126
3	San Miguel Viejo	2.1	Moderate	471
104	Boca de la Cañada	2.1	Moderate	286
4	Vergel de los Laureles	2.0	Moderate	189
14	Loma de Cocina	2.0	Moderate	283
60	Rancho Nuevo Villa de Guadalupe	1.9	Moderate	114
114	Salitrillo	1.8	Moderate	276
118	Salitre	1.8	Moderate	119
119	San Antonio de la Joya	1.8	Moderate	208
12	Santuario de Atotonilco	1.8	Moderate	609
64	El Lindero	1.7	Moderate	171
1	La Cieneguita	1.7	Moderate	875
6	Santa Elena de la Cruz	1.6	Moderate	7
			Total	**6293**

Community locations are displayed in Figure 1. Figure 6 depicts the estimated fluoride levels in groundwater throughout the municipality, based on the data collected during this investigation. Fluoride levels were highest in communities closest to Presa (Ignacio) Allende and along the main stem of the Rio Laja upstream of the reservoir.

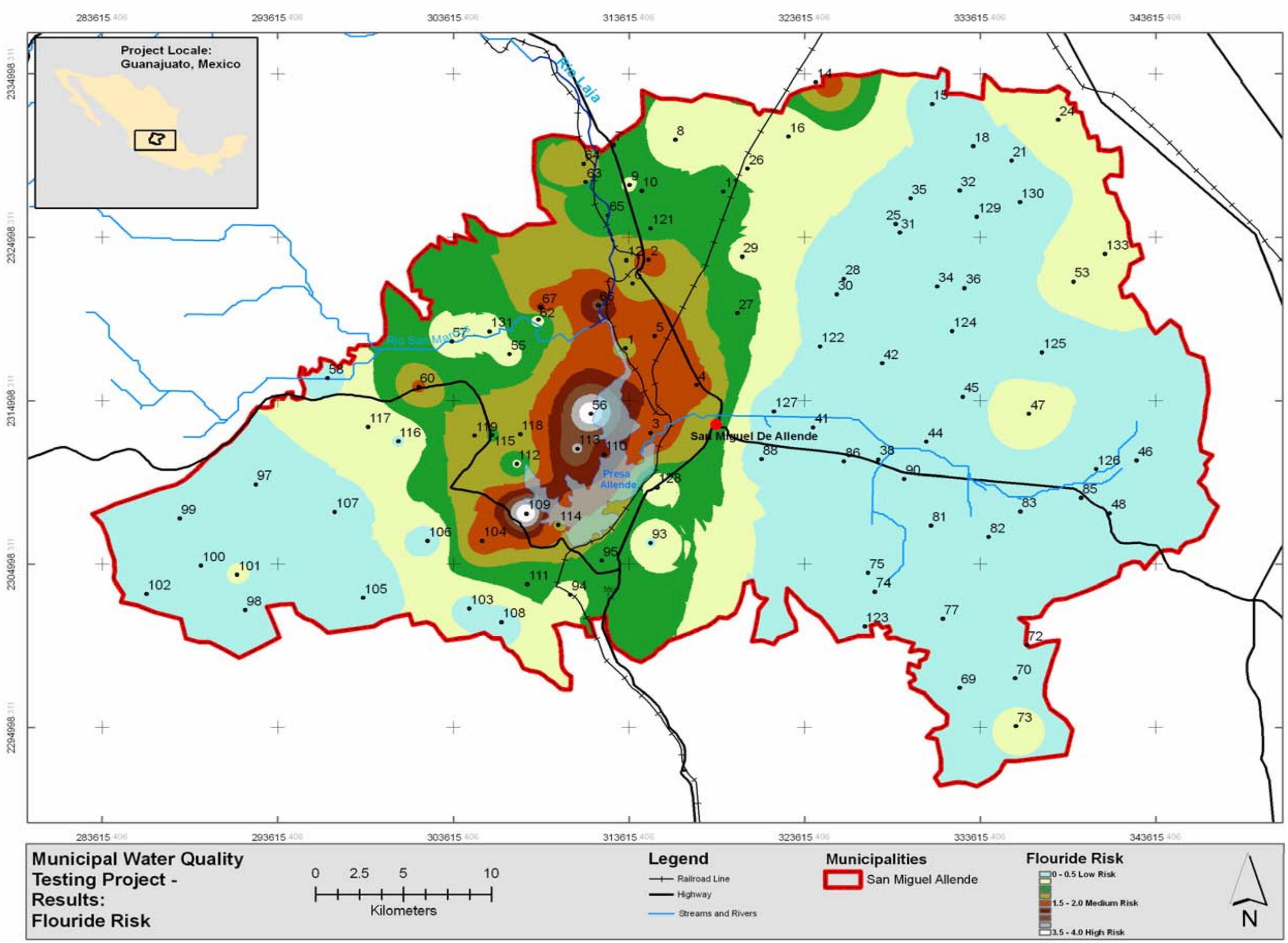

Figure 6. Map of fluoride concentrations interpolated from well water tested in San Miguel de Allende Municipality sampling effort.

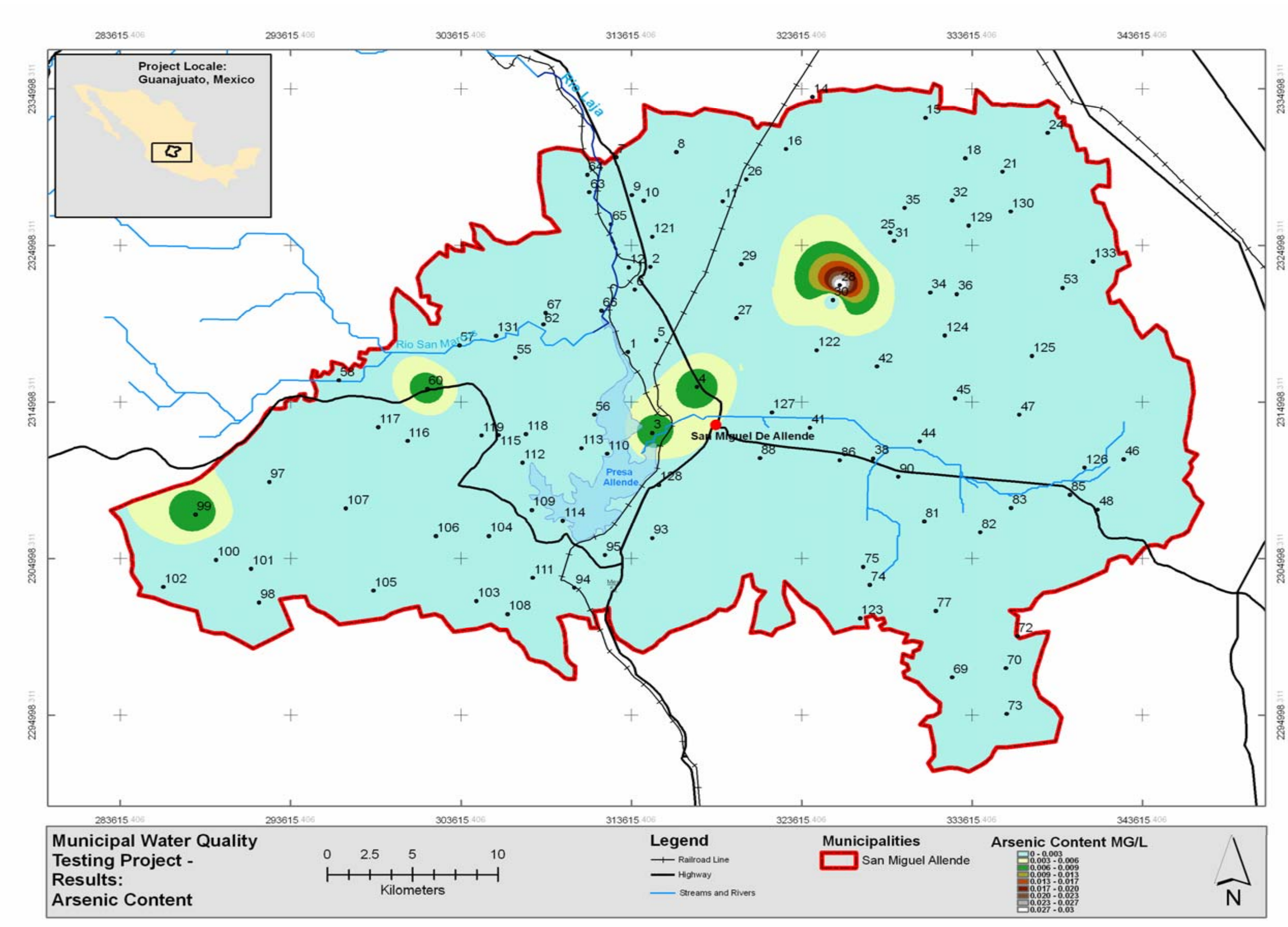

Figure 7. Map of arsenic concentrations interpolated from well water tested in San Miguel de Allende Municipality sampling effort.

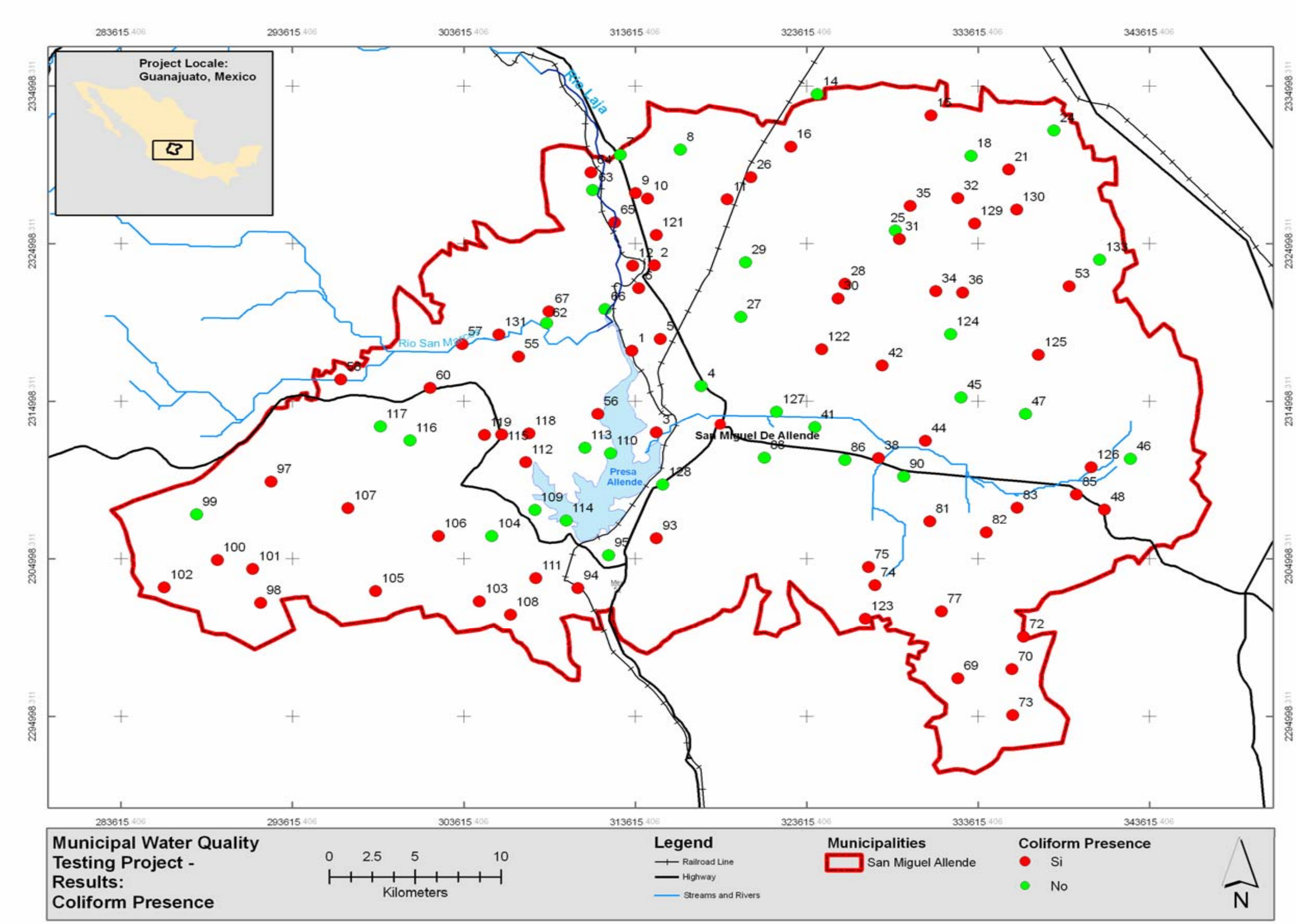

Figure 8. Map showing locations and results of well water testing for total coliform in San Miguel de Allende Municipality sampling effort.

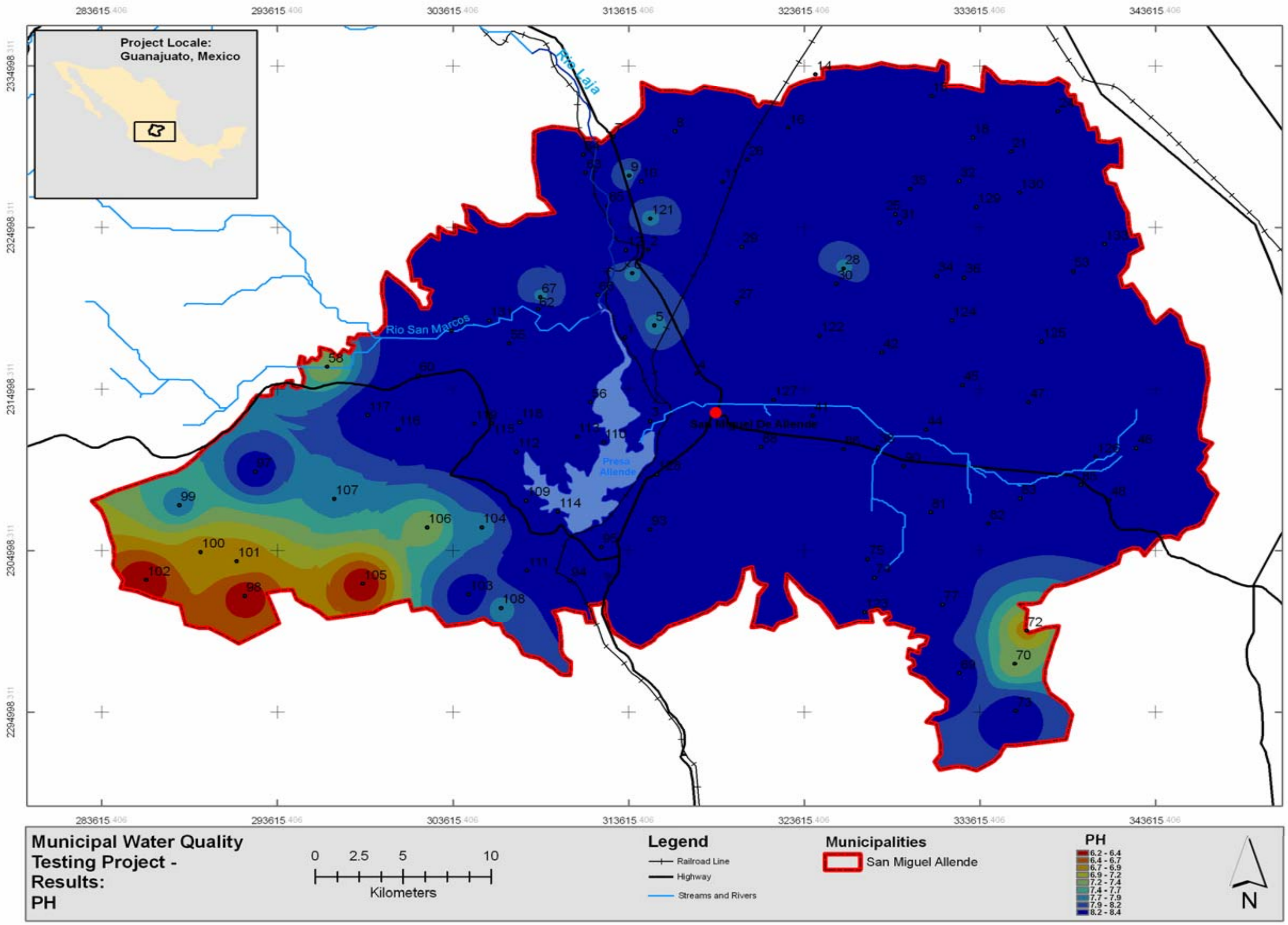

Figure 9. Map of pH values interpolated from well water tested in San Miguel de Allende Municipality sampling effort.

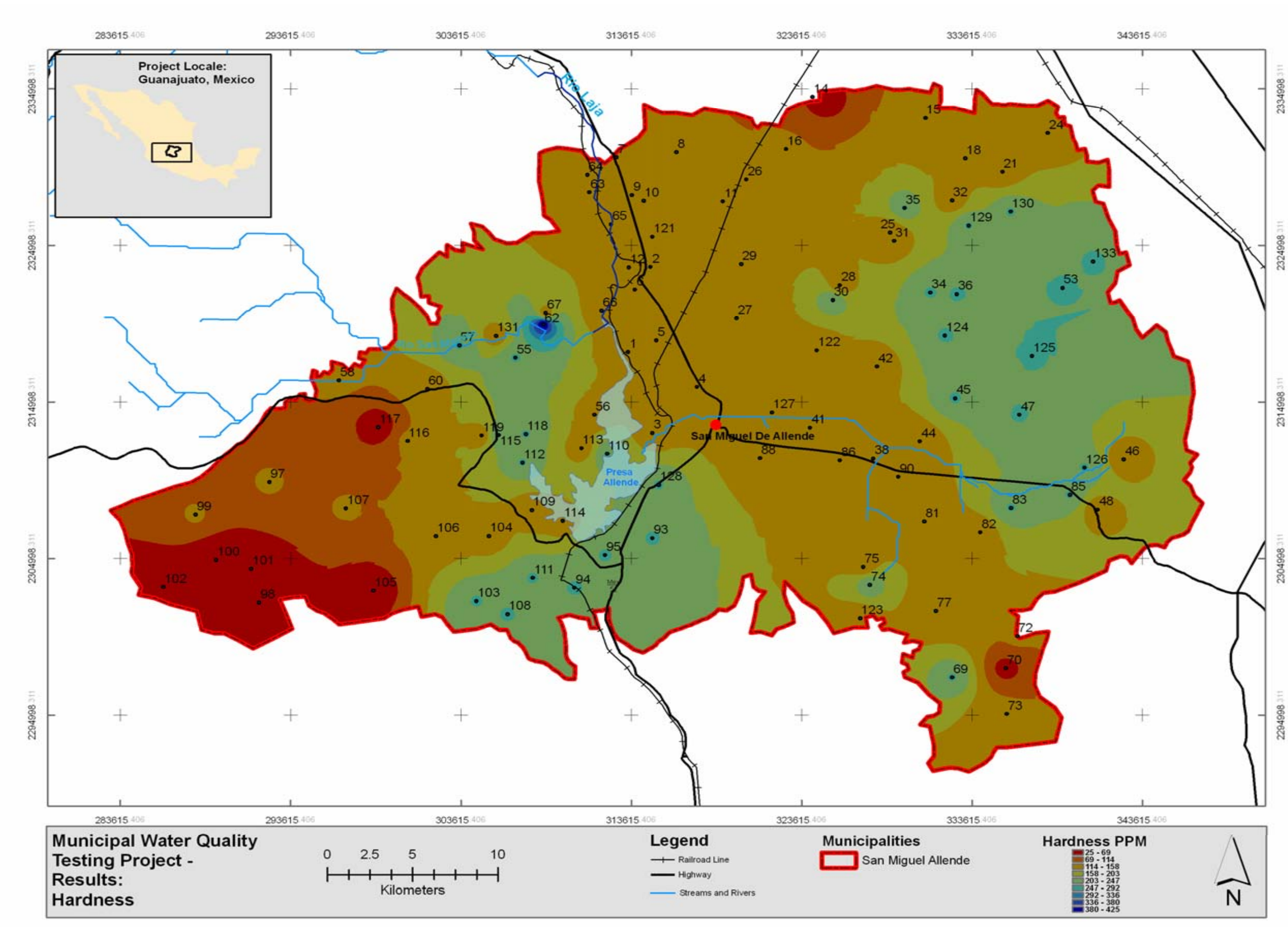

Figure 10. Map of hardness concentrations interpolated from well water tested in San Miguel de Allende Municipality sampling effort.

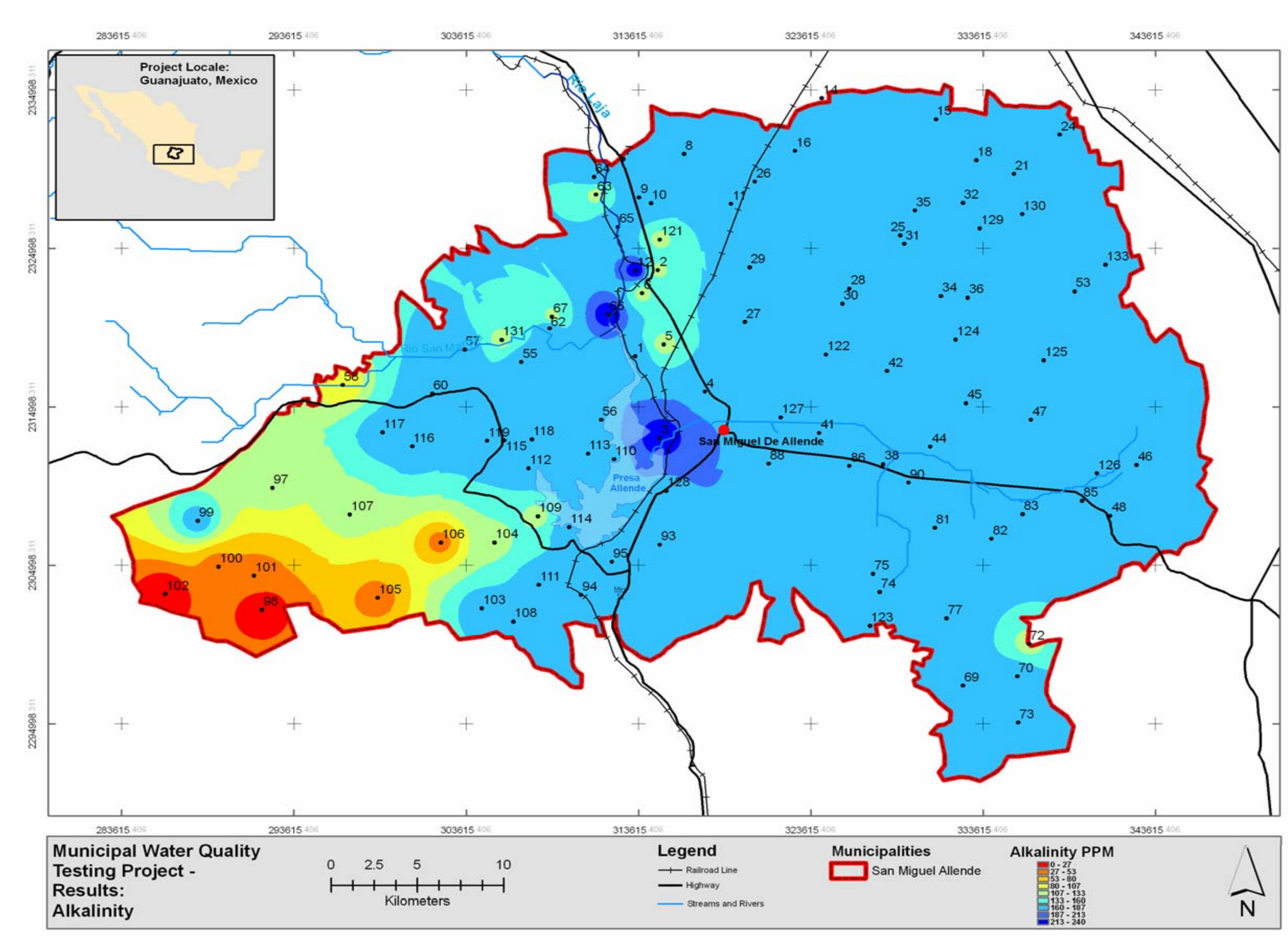

Figure 11. Map of alkalinity concentrations interpolated from well water tested in San Miguel de Allende Municipality sampling effort.

Arsenic
Arsenic concentrations were found to be low throughout the municipality (see Figure 7). The highest arsenic level recorded (0.03 mg/L) was below the Mexican drinking water maximum permissible limit of 0.05 mg/L, and is therefore not identified as an item of further study.

Coliform
Total coliform and fecal coliform were tested for presence/absence to measure the microbiological quality of the drinking water. It is time-consuming, difficult, and expensive to test for specific pathogens, which is why total coliform and fecal coliforms are tested and used as indicator organisms. Sixty-nine of the 101 samples analyzed for coliform tested positive for the presence of coliform bacteria (see Table 4 for a list of these communities and refer to Figure 8). None of the samples tested positive for fecal coliform. Two urban wells of San Miguel de Allende tested positive for total coliforms; it should be noted though, that samples were drawn directly from the well, prior to treatment.

pH (potential of Hydrogen)
The pH results from the water quality samples ranged from 6.2 to 8.4 mg/L. The average pH was approximately 8.3 mg/L, indicating the water is basic or alkaline and has a moderate to high pH. These pH results indicate that the wells sampled are within the normal range for groundwater systems (6-8.5 mg/L) and generally meet the permissible limits for Mexican drinking water standards, which are between 6.5 and 8.5 mg/L. Results are displayed graphically in Figure 9.

Hardness
Water in the sampled well systems generally tested hard, ranging from 25 to 425 mg/L, with an average of 155 mg/L. Several samples indicated very hard water (250 mg/L in the town of La Talega, and 425 mg/L at Cruz del Palmar). These values are all within acceptable limits. Hardness results are displayed graphically in Figure 10.

Alkalinity
In general, alkalinity was within acceptable limits. Of the 101 values recorded for total alkalinity, 180 mg/L is the most frequently recorded value; the mean is 165 mg/L. Two samples have a value of 0.0 mg/L. These results indicate high alkalinity levels, yet within average (20-200 mg/L) alkalinity levels for fresh water (USGS 2006a). Results are displayed geographically in Figure 11.

Discussion

Fluoride Discussion
Results indicate that fluoride levels in approximately 20% of the samples taken exceed the 1995 Mexican drinking water standards established by the National Water Commission. The twenty communities that tested Moderate or High-Risk represent a total population of 6,293 people (SIGOET 2004). This is a cause for concern given the health affects associated with long-term exposure to excessive fluoride concentrations. Since fluoride accumulates in the human body, these levels of fluoride present an especially high risk to children. The intake of contaminated water by children should be limited, and measures should be taken to acquire alternative water sources, even if only for supplemental purposes.

Exposure to excessive amounts of fluoride can cause certain cancers, bone disease, and fluorosis (mottling of teeth). Elevated consumption of fluoride during childhood has also been shown to cause kidney damage and affect intelligence (Connett 2005, JISFR 2006). Fluoride levels above 1.5 mg/L can cause fluorosis and deposits in bones, while levels above 10 mg/L can cause crippling skeletal fluorosis. Recent research suggests that long-term consumption of water with fluoride concentrations even below the Mexican maximum allowable concentration standard of 1.5 mg/L has deleterious health effects (Deogracias 2006). Drinking water is the largest contributor to daily fluoride intake; however, fluoride is also found in vegetables, fruit, tea and other crops.

Table 4. Rural community water sources that tested positive for total coliform, an indicator test, in the San Miguel de Allende Municipality.

ID	Sample Location; Pueblo Name	ID	Sample Location; Pueblo Name
1	La Cieneguita	72	Pinalillo
2	San Francisco	73	Tinaja de los Rodríguez
3	San Miguel Viejo	74	La Campana
5	Fraccionamiento El Nigromante	75	Doña Juana
6	Santa Elena de la Cruz	77	El Membrillo
9	San Martin de la Petaca	81	Bocas
10	Bachoco Pollo No. 34	82	Fajardo de Bocas
11	Tierra Blanca de Arriba	83	Guadalupe de Támbula
12	Santuario de Atotonilco	85	Santas Marías
15	La Medina	93	Don Juan Xidó de Abajo (Cabras de Begoña)
16	La Palmilla	94	La Huerta
21	San Miguelito	97	Cañada de García
26	Las Cañas	98	La Lobera
28	Moral de Puerto de Sosa	100	El Embargo (Nuevo Cimatario)
30	La Talega	101	Las Vegas de Guadalupe
31	El Carmen	102	Rancho Nuevo de la Rosa
32	Peñón de los Baños	103	La Angostura
34	Los Reyes (La Vivienda)	105	San Isidro de la Cañada
35	Los Rodríguez	106	Xotolar
36	Las Cruces	107	Los Toriles
38	Corralejo de Arriba	108	Los Tovares
42	San Agustín del Bordito	111	Los Martínez
44	El Huizachal	112	Tlaxcalilla
48	San José de la Palma	115	Ciénega de Juana Ruiz
53	Cañada de San José	118	Salitre
55	San Isidro Capadero	119	San Antonio de la Joya
56	Guerrero	121	La Palma
57	Juan González	122	San José de Gracia
58	San Damián	123	Elvira
60	Rancho Nuevo Villa de Guadalupe	125	La Calera
64	El Lindero	126	Puerto de Nieto
65	Montecillo de la Milpa (Montecillo)	129	Estancia de San Antonio
67	Los Torres	130	Castaño de Abajo
69	Jalpa	131	Tierra Blanca de Abajo
70	La Joyita		

Fluoride occurs naturally in groundwater and is influenced by the geologic, chemical, and physical characteristics of the aquifer; however, fluoride concentrations increase in the Independence Aquifer as the water levels decrease (Ortega-Guerrero 2004). Fluoride levels are also influenced by industrial processes such as aluminum, steel, and fertilizer manufacturing, coal-burning power plants, and glass and cement production.

Figure 6 shows the pattern of fluoride concentrations, based upon results, and interpolated throughout the municipality. Fluoride concentrations are highest near the Presa Allende, and less concentrated farther away. More research should be designed to investigate this spatial distribution, and how the withdrawal of groundwater via wells can be managed to limit human consumption of high fluoride concentrations. As well, more research should be aimed at discovering the vertical variations in fluoride concentrations throughout the aquifer.

Defluoridation to remove excess fluoride from groundwater is difficult and expensive, though new technologies are being developed such as the Nalgonda technique (uses flocculation to remove fluoride) and adsorption (filtration using activated alumina, charcoal, or ion exchange resins). A sustainable solution to controlling fluoride levels in groundwater is long-term hydrological management to allow recharge and consequently, dilution of the high fluoride concentrations in the groundwater system. Issues regarding the long-term management of groundwater resources cannot be ignored given the expected population increases in this region and the increased water needs.

Results also suggest the focus of future efforts should involve re-testing the water at sites in the moderate to high fluoride risk categories and providing alternative water sources in the form of trucked water and rainwater harvesting systems. Treatment of fluoride levels in groundwater is costly and difficult (ESF 2005, WHO 2006), which is why an alternative water source with lower fluoride levels is recommended above all other treatments. WHO recommends that if there is no other water source that treatment using bone charcoal, the Nalgonda technique, or activated alumina be employed. Precipitation in this region of Mexico should be evaluated with respect to the potential for rainwater harvesting as a viable alternative water source. There are no toxic waste disposal issues associated with capturing rainwater.

Arsenic Discussion

Arsenic concentration was a identified as a parameter worthy of testing (ESF 2005) because high arsenic levels in groundwater have been identified in other studies in areas adjacent to the municipality. Excessive concentrations of arsenic were not discovered in any samples taken in this study. Arsenic concentrations in the Independence Aquifer will likely increase as the aquifer water levels decrease. Although arsenic concentrations are not currently a health threat at the sites that tested, the increased withdrawal of water from the aquifer over time could present a danger to these communities in the future. Because of previous findings of high arsenic concentrations in other parts of the Independence Aquifer, screening for high arsenic concentrations should continue to take place in the San Miguel de Allende Municipality.

Coliform Discussion

Coliform bacteria occur naturally in the environment and are found in soils, plants, and in the intestines of humans, cattle, and other warm-blooded animals. Although not specifically harmful to humans, the presence of these bacteria in drinking water is usually a result of a problem with the well, treatment, and/or distribution system, and indicates that the water may be contaminated with disease-causing bacteria, viruses, and protozoa (Tchobanoglous and Schroeder 1987). Fecal coliform presence indicates that well systems are contaminated with mammal or bird feces. The health effects associated with fecal coliform exposure include diarrhea, cramps, nausea, and headaches.

The Mexican drinking water standard permissible limit for total coliform is 2 (most probable number) per 100mL. For fecal coliform, no detectable amount is permissible per 100ml of water (NOM 1996). Although the project did not investigate coliform concentrations, the presence of fecal coliform does indicate that the water could be contaminated with pathogens. Given that no fecal coliforms were discovered, the immediate health risk to humans is not critical. It is time-consuming, difficult, and expensive to test for specific pathogens, which is why total coliform and fecal coliforms are tested and used as indicator organisms. Most of the water samples taken were not directly from the wells but were delivered through a pipe system, which is likely where the contamination is originating. Many of the communities have water storage facilities where contamination is also possible.

The presence of coliform bacteria in a majority of the samples indicates contamination problems in the groundwater, and/or water distribution systems of rural San Miguel de Allende Municipality. Appropriate water treatment systems should be able to disinfect coliform-infected water, although more research should be undertaken to investigate the cause of contamination. Of the wells that have no purification, 65% tested positive for coliform. Contamination of the shallow groundwater is a problem that should be repaired at the point of contamination, or well water quality will continue to deteriorate, and treatment costs will continue to increase. Of the wells that were treated, 71% were positive for coliform, indicating that contamination is probably occurring in the distribution system after purification. Contamination of the water in the distribution system is less severe, and replacement and maintenance of the distribution system is recommended to solve this contamination issue.

It is interesting to note that numerous communities in rural San Miguel de Allende had equipment for treating water for coliform, yet the equipment was not being used. Of the wells that have purification systems, but are not using them, 75% tested positive for coliform. Reasons for not using the equipment ranged from distaste for chlorine to the unwanted effects of chlorine on clothing to simply that the equipment had fallen into disrepair and was disconnected so as not to disrupt water supply. It is recommended that educational programs be implemented in rural San Miguel de Allende Municipality to inform people of the benefits of water treatment, and to discover a treatment method appropriate to inhabitants.

pH Discussion

The concentration of hydrogen ions in water is the pH and this value determines the solubility (amount of a substance that can be dissolved in the water) and biological availability (amount that can be utilized by aquatic life) of chemical constituents such as nutrients (phosphorus, nitrogen, and carbon) and heavy metals (lead, copper, cadmium, etc.). Levels of pH range from 1 to 14; the 1-7 range is considered acidic, while results in the 7-14 range are basic or alkaline (soapy to the touch): 7 is neutral. In general, water with low pH (< 6.5) is acidic, soft, and corrosive, and could therefore contain metal ions such as iron, manganese, copper, lead, and zinc; metals are more soluble at lower pH levels and more toxic as a result. Elevated levels of toxic metals can cause damage to metal piping, have a metallic taste, stain laundry, and cause health problems.

The results indicate that the well systems tested have a moderate to high pH (high pH is greater than 8.5), which lessens the ability of the water to contain metal ions and therefore does not pose any health risks; however, hard water does form deposits and is difficult to lather. Increased pH levels can also affect the adsorption capability of water; one study showed that as pH increases, the percentage of fluoride adsorbed decreases (Latha et al. 1998).

It is important to monitor pH levels in groundwater systems to determine the normal range so that deviations can be identified. The pH determines many important properties of groundwater, including the suitability of groundwater for domestic and commercial uses and the ability of water to transport potentially harmful chemicals (Fisher 2003). The pH values in groundwater are influenced by bedrock geology, physiographic region, and industrial and agricultural pollutants.

Hardness Discussion

Water hardness is a reflection of the amount of ions (calcium and magnesium) in water; as the amount increases, the hardness increases. Water is considered soft if it contains 0 to 60 mg/L of hardness; moderately hard from 61 to 120 mg/L; hard between 121 and 180 mg/L; and very hard if more than 180 mg/L.

Generally, groundwater hardness is relatively stable and does not change over time (USGS 2006b). Water hardness does not pose any health risks; however, the minerals in very hard water can leave deposits on the inside of pipes, boilers, and tanks, while soft water can corrode metals. Calcium carbonate is derived from dissolved limestone or discharges from mining activity.

Alkalinity Discussion

Alkalinity helps regulate the pH and the metal content of water. It measures the ability of water to resist changes in the pH levels, or the capacity of bases to neutralize acids. Waters with low alkalinity are very susceptible to changes in pH, while high alkalinity waters can resist major changes in alkalinity. Mexican drinking water quality standards do not include permissible limits for alkalinity but do have established limits for pH (see pH discussion). Levels between 100-200 mg/L stabilize pH levels. Levels below 10 mg/L indicate the water is highly susceptible to changes in pH from natural and human-caused sources (USGS 2006b).

Alkalinity is affected by geology and soils; limestone, sedimentary rock, and carbonate-rich soils produce high alkalinity in water while igneous rocks and carbonate-poor soils result in low alkalinity water. Other factors affecting alkalinity are the introduction of wastewater into a water body and changes in pH. Because alkalinity varies greatly due to differences in geology, there aren’t general standards for alkalinity.

Conclusions

Well water quality reflects the water quality of the shallow aquifer, as well as provides information on the quality of water consumed by rural inhabitants. This study is a reconnaissance effort to roughly describe both the condition of the Independence Aquifer, and to screen rural wells for potential drinking water contamination issues. Findings from this study are meant to prioritize future actions, including studies and interventions. Previous research into the Independence Aquifer has demonstrated an increase in various concentrations of dissolved salts and metals (Ortega-Guerrero 2004; Ortega-Guerrero, et al. 2002). The results of this study describe the effect of this trend within the San Miguel de Allende Municipality.

Investigation into fluoride concentrations of well water of the rural San Miguel de Allende Municipality yielded results that indicate more research is needed, future monitoring should be implemented, and alternative water sources should be sought for numerous communities. Investigation into the presence of coliform in well water of rural San Miguel de Allende Municipality yielded results that indicate a need for more research, and that future monitoring should be implemented. All other parameters investigated, arsenic concentration, pH, hardness, and alkalinity, were found to be within acceptable ranges, therefore more research is not necessarily a critical need. If possible, though, future efforts should continue to monitor these parameters, should trends develop.

Education regarding water purification and training in its application is needed throughout the municipality to address the prevalence of coliform in rural drinking water. Such a curriculum combined with a program to establish, repair, and maintain drinking water purification systems in rural areas of San Miguel de Allende Municipality would help to reduce instances of dysentery and other illnesses caused by water-borne organisms. All wells that tested positive for total coliform should continue to be monitored intensively until negative results are achieved. The presence of coliform indicates a potential for contamination from more harmful organisms including fecal coliform. Future monitoring should include testing for coliform densities and not only presence.

Action should be taken immediately to reduce the consumption of fluoride-contaminated water in the High-risk areas identified in this document. Supplementing fluoride contaminated drinking water with non-contaminated water such as that harvested from precipitation would have the greatest positive effect on children. Monitoring of fluoride concentrations should be instituted for all Moderate and High-risk identified wells, as well as for all other wells in the vicinity. Monitoring should be designed to capture temporal variations throughout the year and beyond. Because of the findings of this project as well as trends published elsewhere, the Municipality of San Miguel and other local interests should take steps to support more in-depth research that can elucidate future challenges.

The lack of reasonable treatment techniques for fluoride toxicity is one reason alternative water sources, such as rainwater harvesting, should be pursued. Any supplemental consumption of potable water would help to reduce the effects of fluoride toxicity among inhabitants of Moderate and High-risk communities. Rainwater harvesting systems in communities with water contamination problems not only provides a cleaner alternative water source, but addresses the critical water supply issue in this region. Fluoride concentrations could be stabilized and even reduced at particular locations if less water is withdrawn from the Independence Aquifer. Over time, and if more communities install such systems, rainwater harvesting could contribute to recharging groundwater and diluting salt and metal concentrations. Given the financial and the natural resource constraints in this region, installation of rainwater harvesting systems is the most practical alternative to securing a sustainable water source for the San Miguel de Allende Municipality.

Watershed restoration should be pursued in order to comprehensively address surface and groundwater challenges such as well water toxicity. The restoration of riparian vegetation, stream bank stability, and upland vegetation, for example, has beneficial effects on surface water quality, which in turn affects the shallow aquifer from which drinking water is acquired. Although this project focused on the Municipality of San Miguel de Allende, the problems investigated and the solutions recommended apply to all communities within the Independence Basin. ESF encourages the states of Guanajuato and San Luis Potosi as well as the federal government to cooperate with each other, and with municipalities to further investigate drinking water quality in the region and take steps to manage water resources responsibly.

Study Limitations

This Phase I study is a reconnaissance-level investigation and results should not be interpreted to comprehensively represent well water quality in the San Miguel de Allende Municipality. This is not a reasonable expectation given the temporal, logistical, and fiscal constraints of the study. Such variables as seasonality, precision of testing equipment, and professionalism and experience of staff are important components that deserve refinement for future efforts. Future efforts should strive to capture seasonal (temporal) variations that may exist as well as geographic distributions beyond Municipality boundaries.

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Appendix A. Field and Laboratory Data Forms

DIRECCIÓN DE MEDIO AMBIENTE Y ECOLOGÍA

Ecosystem Sciences Foundation

Ciencias del Ecosistema, A.C.
San Miguel de Allende
Guanajuato, Mexico
www.ecosystemsciences.com

Examen de calidad del agua de los pozos: Forma del Laboratorio:
(para llenar por emlpleados de la Dirección de Medio Ambiente y Ecologia)

Fecha:

Tiempo:

Muestra # (del día)
Nombre de Pueblo (de donde viene la muestra):

Floruro, Metodo de "AccuVac"
mg/L FLORURO

Otras notas:

Arsenico
ppb ARSENICO

"AquaChek 5-in-1" Exámen (Cloro Total, Cloro Libre, Dureza Total, Alcalinidad Total, y pH)
ppm DUREZA TOTAL (3° o almohadilla central)
ppm ALCALINIDAD TOTAL (4°almohadilla)
pH (5° almohadilla)
ppm CLORO TOTAL (1° almohadilla)
ppm CLORO LIBRE (2° almohadilla)

Exámen de Coliforme Presente/Ausente

Resultados despues de 24 horas de incubación:

Resultados despues de 48 horas de incubación:

Resultados cuando se expuso a luz UV; flourescencia?:

Por favor llenar esta forma y imprimirla por el botón debajo. Por el otro botón, inviarla por email a dvarner@ecosystemsciences.com. Si no puede inviarla por email, entonces mandarla por telefax a Ciencias del Ecosistema, A.C. (número 001-208-368-0184) cuando sea lo más pronto posible. Finalmente, por favor archivarla con Don Patterson.

Imprimirla   Inviarla por Email

Imprimirla | Inviarla por Email

DIRECCIÓN DE MEDIO AMBIENTE Y ECOLOGÍA

Ecosystem Sciences Foundation

Ciencias del Ecosistema
San Miguel de Allende
Guanajuato, México
www.ecosystemsciences.com

Procedimientos y Formato para Examinar la Calidad de Agua en el Campo

Fecha: ____________ Tiempo: ____________

Nombre de la persona que lo elaboro: ____________

Código de la zona del sitio de muestra: ________ y código cluster: ________

Muestra # ________ (del día)

El procedimiento del sitio de colecta debe ser el mismo pozo o lo más cercano a este. Preséntate con el Delegado de la comunidad con la carta de introducción o con alguna autoridad y pídele a esta persona que te ayude responder el cuestionario. Considera tomar fotos con el Delegado para documentar la experiencia. Cualquier otra foto que pueda ayudar mejor a describir el lugar.

Nombre de la localidad:____________

Nombre del Delegado:____________

Selecciona el mejor sitio de colecta de la muestra, directamente del pozo o lo más cercano a este. Si estos sitios no están disponibles entonces utiliza una toma de agua pública o la escuela u otro sitio publico.

Nota/describe los sitios de colecta lo más detallado posible:

a) ¿Cual es el nombre del edificio o de la dirección del sitio?

b) ¿Cual es la distancia entre el pozo y el otro sitio de toma?

c) ¿Cuál es el método para llevar el agua de la fuente al sitio?

DIRECCIÓN DE MEDIO AMBIENTE Y ECOLOGÍA

Ecosystem Sciences Foundation

Estando en el sitio de colecta, es importante marcar el punto con el GPS y considera que la señal sea buena. Mantén oprimido el botón "ENTER MARK" y ve la pagina "MARK WAYPOINT".

d) Anota el nombre o numero en la parte arriba de la pagina y registra lo aquí: ______

e) Anota los números de la posición en la parte baja de la pagina:

______

UTM ______

f) Después de registrar esta información, presión el botón "Enter" y entonces apaga el GPS con el botón rojo.

Anota/Describe de forma muy detallada el sitio de colecta:

g) ¿El agua viene de pozo o de otra fuente?

______

h) ¿Cuál es la profundidad del pozo? ______

i) ¿La fuente del agua esta almacenada en algún tipo de depósito como un bordo o tanque (si es, descríbalo)? ______

j) ¿Se utiliza bomba para sacar el agua? ______

k) ¿La muestra de agua viene directamente de pozo o de una llave?

______

l) ¿La fuente de agua esta tratado (para dureza, alcalinidad, o con cloro), si es, descríbalo?

______

m) ¿Anota si la fuente del agua es un pozo, el poza se seca de vez en cuando (anota cuando se seca y por cuanto tiempo)? ______

Anota aquí otras observaciones importantes:

______

Otras notas: ______

Appendix B. Laboratory Procedures (English versions)

Ecosystem Sciences Foundation
San Miguel de Allende
GTO, Mexico
www.ecosystemsciences.com

Well Water Quality Testing Procedures: Laboratory
(to be completed by SMA employee)

Turn on Incubator 2-3 hours (or more) prior to processing of samples. Set temperature to 35°C.

When coolers and samples arrive at office after the sampling effort is complete, remove sample Bottles (not bags) from coolers and allow to warm to room temperature (approximately 1 hour) before processing. The samples should be approximately the same temperature as the distilled water (in glass bottles).

Wash hands and use rubber gloves provided.

Fluoride, AccuVac Method

1. Turn on "Pocket Colorimeter II" by pressing bottom, center button. The arrow should indicate channel 2 (see page 2-4 to change channel, if needed.
2. Fill one 50-mL beaker with at least 40 mL distilled water (from glass bottles provided). Fill other 50-mL beakers (or plastic cups with 40 mL mark) with samples (from glass bottle provided).
3. Remove one SPADNS Fluoride AccuVac Ampuls from blue styrofoam container. Wipe Ampul with soft, dry brown cloth (provided in plastic bag).
4. Holding Ampul in one hand and the beaker with the distilled water in the other hand, turn the Ampul upside down and submerge tip into distilled water. Press the Ampul against the inside of the beaker so that the tip breaks off and distilled water is drawn into Ampul. Withdraw the Ampul and invert several times to mix. Wipe off any liquid or fingerprints with cloth and set aside. Since this Ampul contains distilled water, it is the "Blank."
5. Repeat Steps 3-4 using the beakers (or plastic cups) with the samples (instead of with distilled water). Place Ampul containers in orderly manner near sample Bottles so as not to confuse samples.
6. Wait 1 minute.
7. Place the Blank Ampul container in the cell holder of instrument "Pocket Colorimeter II." Cover the Blank with the instrument cap.
8. Press the left-side, blue button on instrument. The display will show "----" then "0.0." Remove the Blank from the cell holder.
9. Repeat Step 7 using one of the samples instead of the Blank. After covering the sample cell with the instrument cap, press the right-side, green, "check" button. The display will show "----", followed by results in mg/L fluoride.
10. Disposal of Ampul; rinse beakers (and/or cups).

Arsenic

1. Lift the flap on the black cap and *slide* a test strip into the groove so that the reactive pad faces the small opening and completely covers it; secure by pressing the flap back in place.
2. Fill the reaction vessel with sample water to the fill line (50mL).
3. Add the contents of one Reagent #1 powder pillow to the sample and swirl to dissolve.
4. Add the contents of one Reagent #2 powder pillow to the sample and swirl to dissolve (note: solution may be cloudy).
5. Wait at least 3 minutes.
6. Add the contents of one Reagent #3 powder pillow to the sample and swirl to mix (not all of the powder will dissolve).
7. Wait at least 2 minutes and swirl again to mix.
8. Using the plastic scoop, add one level scoop of Reagent #4 to the sample and swirl to mix (most of the powder will dissolve).
9. Add the contents of one Reagent #5 powder pillow to the sample.
10. Immediately attach the black cap, with the test strip inserted, to the reaction vessel. Do not shake or invert! Swirl to mix, but do not allow sample to contact the test strip pad.
11. Allow vessel to react for 30 minutes, but no more than 35 minutes; swirl twice during the reaction period.
12. Remove the test strip and immediately compare the developed color to the chart on the test strip bottle. Do not expose the test strip to direct sunlight.

AquaChek 5-in-1 Test (Total Chlorine, Free Chlorine, Total Hardness, Total Alkalinity, and pH)

After the necessary quantities of water have been removed from the sample Bottles for use in the Arsenic and Fluoride tests, perform the following steps for each sample:

1. Pour approximately 50 mL (or remaining sample) into 50-mL beaker.
2. Open "AquaChek" Water Quality Test Strips (5-in-1) canister and remove one test strip; replace cap to canister.
3. Dip test strip into sample in beaker and then remove. Do not shake excess water from test strip. Hold the test strip level for 30 seconds.
4. Compare TOTAL HARDNESS (3rd or center pad), TOTAL ALKALINITY (4th pad), and pH (5th pad) pads to color chart on canister. Record values for each on data sheet.
5. Dip the strip into sample in beaker again and stir sample for 30 seconds and then remove.
6. Compare TOTAL (1st pad) and FREE CHLORINE (2nd pad) to color chart on canister. Record values for each on data sheet.
7. Discard test strip. Pour remaining sample down drain. Rinse beaker with distilled water for re-use or set to dry.
8. Wash hands if needed.

Rinse Bottles with distilled water and place upside down in dish rack to dry. During the following day, after drying, replace caps on Bottles so that airborne particles do not contaminate bottles.

Coliform Presence/Absence Procedures

1. Collect and organize samples for analysis.
2. Open sample bag and add sample to the 100-mL fill-to line on the P/A Broth Disposable Bottle. Replace cap.
3. Incubate sample at 35°C for 24 hours.
4. Note the reaction after 24 hours of incubation and evaluate based upon the Coliform P/A Interpretation Table below. Record results on appropriate data sheet. If sample is positive, then discontinue incubation and proceed to step 6. If sample is negative, continue incubating for another 24 hours.

Coliform P/A Interpretation Table

Reaction	Comments	Report as:
Color change from reddish purple to yellow or yellow brown.		Positive for total coliform.
No color change after 24 hours.	Incubate for an additional 24 hours and recheck the sample for color change.	
No color change after 48 (+- 3 hours).		Negative for total coliform.
Flourescence under long-wave UV light (if using P/A Broth with MUG).		Positive for E.coli.

5. After 48 (+- 3 hours), recheck sample and reevaluate based upon the Coliform P/A Interpretation Table above.
6. Take samples that test positive to dark room and expose to the long-wave ultraviolet (UV) light. Evaluate based upon the Coliform P/A Interpretation Table above, and record results.
7. Dispose of samples in sewer and destroy sample containers.