

Arsenic Contamination Study of Drinking Water in Nepal

by

Patricia M. Halsey

B.S. Agricultural and Biological Engineering
Cornell University, 1996

SUBMITTED TO THE DEPARTMENT OF CIVIL AND ENVIRONMENTAL
ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

MASTER OF ENGINEERING
IN CIVIL AND ENVIRONMENTAL ENGINEERING
at the
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
June 2000

© 2000 Patricia M. Halsey. All rights reserved.

*The author hereby grants to M.I.T. permission to reproduce and distribute publicly paper and
electronic copies of this thesis document in whole or in part.*

Signature of the Author_____

Patricia M. Halsey
Department of Civil and Environmental Engineering
May 5, 2000

Certified by_____

Susan Murcott
Lecturer
Thesis Supervisor

Accepted by_____

Daniele Veneziano
Chairman, Departmental Committee on Graduate Studies

Arsenic Contamination Study of Drinking Water in Nepal

by

Patricia M. Halsey

Submitted to the Department of Civil and Environmental Engineering on May 5, 2000
In Partial Fulfillment of the Requirements for the Degree of
Master of Engineering in Civil and Environmental Engineering

ABSTRACT

A study of arsenic contamination of drinking water in Nepal was conducted. Samples were collected in Nepal in January 2000 from tube wells, hand dug wells, natural springs, municipal systems and surface water bodies. Samples were analyzed in Nepal using EM Quant® test strips and Affiniti Concentration kits. Samples were also preserved and brought back to the U.S. for analysis using Graphite Furnace Atomic Absorption Spectrometry. Combined results from these tests indicate that no arsenic contamination was found above the World Health Organization (WHO) maximum contaminant level of 10ppb in the Kathmandu Valley. However, 18% of samples taken from the Terai region of Nepal were above the WHO limit. Detectable levels of arsenic were found in tube wells ranging from approximately 30 to 300 feet deep. Forty-eight percent of samples taken from wells aged 9 to 12 years had detectable levels of arsenic. This study concludes that, although not as extensive as in neighboring West Bengal, India and Bangladesh, arsenic contamination does exist in the Terai region of Nepal. A comparison of analytical methods indicates that field kits provide a general indication of high levels of arsenic, but should be used in conjunction with more accurate methods if detailed results are required. Further testing is recommended in the Terai region of Nepal. A detailed study of the geology of the Terai region and potential anthropogenic sources is recommended to further characterize the area.

Thesis Supervisor: Susan Murcott
Title: Lecturer

Acknowledgements

I would like to thank my advisor, Ms. Susan Murcott, for her support throughout this project. Her undying enthusiasm and vision culminated in the amazing experience of this project. I would also like to thank Dr. Eric Adams and the Department of Civil and Environmental Engineering for making this project and the entire school year so rewarding. Thanks to the Nepal Water Project team, including Andy Bittner, Amer Khayyat, Kim Luu, Benoit Maag, Junko Sagara, and Andrea Wolfe, for making the trip to Nepal and execution of this project an unforgettable experience. You all have unique and important gifts to offer the world, and I wish you all the luck in making your mark.

Special thanks go to several members of the Nepal community whose help made our stay most enjoyable. In particular, I would like to thank Mr. Ram Mani Sharma of the DWSS for his help in sample collection and keeping us safe in Parsa District. I would also like to thank Mangala Karanjit for making all of our arrangements, including our stay in Patan, possible.

I would like to thank Professor Harry Hemond for the use of his laboratory and GFAAS unit. This thesis would not have been completed without the guidance of several graduate students at the Ralph M. Parsons Laboratory at MIT. Nicole Keon, Dave Senn and Chris Swartz were a great help in teaching me about arsenic and GFAAS.

Finally, I would like to thank my family and friends for their unrelenting support throughout this year. I would like to dedicate this thesis to my loving parents, Ron and Mary Ann Halsey, whose love and encouragement have made me who I am today. To my siblings, Kathy, Brett and Kristin, thanks for cheering me on and making me laugh. I would like to express a final note of thanks to Jon. Your support and love have made this year amazing and I owe all of this to you. Oh yeah, and thanks for the fruit.

Table of Contents

CHAPTER 1 - INTRODUCTION.....	10
1.1 Nepal Water Project	10
1.1.1 Project Motivation.....	10
1.1.2 Project Purpose.....	11
1.2 Arsenic Contamination Study	12
1.2.1 Study Motivation.....	13
1.2.2 Study Purpose.....	13
CHAPTER 2 - BACKGROUND	15
2.1 Arsenic in the Environment.....	15
2.1.1 General Chemistry	15
2.1.2 Common Sources.....	17
2.2 Arsenic Contamination in Other Countries	19
2.2.1 Crisis in Bangladesh	20
2.2.2 Crisis in India.....	23
2.2.3 Contamination in the United States.....	24
2.3 Overview of Hydrology and Geology of Nepal	25
2.3.1 Geography and Geology	25
2.3.2 Typical Water Sources.....	27
CHAPTER 3 - HEALTH EFFECTS	32
3.1 Toxicology of Arsenic Compounds	32
3.1.1 Arsine.....	32
3.1.2 Inorganic Arsenic	33
3.2 Exposure Limits and Health Guidelines.....	34
3.3 Symptoms of Arsenic Poisoning	35
3.3.1 Acute Health Effects	35
3.3.2 Chronic Health Effects	35
3.4 Health Problems in Nepal.....	36

CHAPTER 4 - ANALYTICAL METHODS	38
4.1 Possible Test Methods.....	38
4.2 EM Quant® Test Strips.....	46
4.2.1 Theoretical Principles	46
4.2.2 Description of Procedure Used.....	47
4.3 Affiniti Concentration Kits.....	50
4.3.1 Theoretical Principles	50
4.3.2 Description of Procedure Used.....	52
4.4 Graphite Furnace Atomic Absorption Spectrometry.....	54
4.4.1 Theoretical Principles	54
4.4.2 Description of Procedure Used.....	55
4.5 NIPSOM Field Test Kits	57
4.5.1 Theoretical Principles	57
4.5.2 Description of Procedure Used.....	58
CHAPTER 5 - RESULTS	59
5.1 Analytical Results Obtained by the Author.....	60
5.1.1 EM Quant® Test Kit Results.....	60
5.1.2 Affiniti Concentration Kit Results	61
5.1.3 Graphite Furnace Atomic Absorption Spectrometry Results	63
5.2 Analytical Results Obtained by DWSS.....	64
5.3 Discussion of Results	66
5.4 Comparison of Analytical Methods	69
CHAPTER 6 - CONCLUSIONS AND RECOMMENDATIONS.....	71
6.1 Study Conclusions.....	71
6.2 Recommendations	72
REFERENCES.....	73
APPENDIX A - TRIP REPORT	77
APPENDIX B – DATA TABLES AND CALIBRATION CURVES	80

APPENDIX C - LIST OF ACRONYMS	123
--	------------

List of Tables

Table 3-1: Incidence Rates for Male Adults in Various Countries.....	37
Table 4-1: Possible Analytical Methods for Measurement of Arsenic in Potable Water.....	40
Table 4-2: Possible Chemical Interferences for EM Quant® Test Kits	44
Table 4-3: Procedure for using EM Quant® Test Strips	49
Table 4-4: Procedure for Using Stage II Affiniti Concentration Kits.....	52
Table 4-5: Procedure for Regeneration of Used Affiniti Concentration Kits.....	54
Table 4-6: Procedure for GFAAS Testing.....	56
Table 5-1: EM Quant® Test Kit Results	60
Table 5-2: Affiniti Concentration Kit Results	62
Table 5-3: Graphite Furnace Atomic Absorption Results	63
Table 5-4: Summary of Results of DWSS Arsenic Sampling Program	65
Table B-1: Sample Descriptions	81
Table B-2: Test Results for EM Quant® Test Strips and Affiniti Concentration Kits.....	94
Table B-3: GFAAS Results	98

List of Figures

Figure 2-1: Eh – pH Diagram for Arsenic at 25°C and One Atmosphere	16
Figure 2-2: Predominance Charts for Arsenite and Arsenate at Varying pH	17
Figure 2-3: Chemical Forms of Arsenic and Their Transformations in Soils.	18
Figure 2-4: A Simplified, Comprehensive Cycle Transfer of Arsenic	19
Figure 2-5: Map of Bangladesh	21
Figure 2-6: Map of Arsenic Contamination in Bangladesh.....	22
Figure 2-7: Arsenic Contamination in West Bengal.....	24
Figure 2-8: Map of Nepal	26
Figure 2-9: Typical Hand Pump Tube Well	28
Figure 2-10: Typical Hand Dug Well	29
Figure 2-11: Traditional Public Water Spout in Patan Durbar Square	30
Figure 2-12: Traditional Natural Spring Water Source	31
Figure 3-1: Conversion of Arsenite to Water Soluble DMAA	33
Figure 4-1: Experimental Set-up for EM Quant® Test Strips.....	48
Figure 4-2: Picture of EM Quant® Test Strip Kit	49
Figure 4-3: Picture of Affiniti Concentration Kit Resins.....	51
Figure 4-4: Experimental Set-up for Affiniti Concentration Kits.....	53
Figure 5-1: Locations of Sampling Areas.....	59
Figure 5-2: Em Quant® Test Strip Results.....	61
Figure 5-3: Affiniti Concentration Kit Results	62
Figure 5-4: GFAAS Results.....	64
Figure 5-5: NIPSOM Test Results Obtained by DWSS	65
Figure 5-6: Sampling Locations in the Kathmandu Valley	67
Figure 5-7: Sample Frequency by Well Depth	68
Figure 5-8: Sample Frequency by Well Age	69
Figure B-1: Calibration Curve for Sample Group 1	104
Figure B-2: Calibration Curve for Sample Group 2	105
Figure B-3: Calibration Curve for Sample Group 3	106
Figure B-4: Calibration Curve for Sample Group 4	107

Figure B-5: Calibration Curve for Sample Group 5	108
Figure B-6: Calibration Curve for Sample Group 6	109
Figure B-7: Calibration Curve for Sample Group 7	110
Figure B-8: Calibration Curve for Sample Group 8	111
Figure B-9: Calibration Curve for Sample Group 9	112
Figure B-10: Calibration Curve for Sample Group 10	113
Figure B-11: Calibration Curve for Sample Group 11	114
Figure B-12: Calibration Curve for Sample Group 12	115
Figure B-13: Calibration Curve for Sample Group 13	116
Figure B-14: Calibration Curve for Sample Group 14	117
Figure B-15: Calibration Curve for Sample Group 15	118
Figure B-16: Calibration Curve for Sample Group 16	119
Figure B-17: Calibration Curve for Sample Group 17	120
Figure B-19: Calibration Curve for Sample Group 19	122

Chapter 1 - Introduction

1.1 Nepal Water Project

The Nepal Water Project is a collective effort by seven Master of Engineering students at the Massachusetts Institute of Technology (MIT) to document and analyze several water quality and household water treatment issues in the country of Nepal. The study has been completed as part of the degree requirements for the Master of Engineering program, and each student has completed an individual thesis and collaborated to produce a group report. The advisor for the project is Susan Murcott, and Nepalese hosts and partners in this effort include the Royal Government of Nepal Department of Water Supply and Sewerage (DWSS), the Business and Professional Women's Federation of Nepal, the Nepal Water Supply Corporation (NWSC) and the local chapter of the United Nations Children's Fund (UNICEF-Nepal).

The project advisor, Susan Murcott, initiated the Nepal Water Project. Ms. Murcott was involved in a Women and Water Conference held in Kathmandu, Nepal in 1998. During this conference, the water quality issues plaguing the country became evident and real to her. This sparked the beginning of the Master of Engineering program project in Nepal. The project involved a myriad of research topics all relating to water quality issues, and included a three-week field trip to the country. This thesis is one of the products of the study efforts, and is submitted as a portion of the overall goal of the project.

1.1.1 Project Motivation

Nepal is a developing country bordered by India to the south, east and west and China to the north. More than half of the Nepalese population lives below the international poverty line, making it the seventh poorest nation in the world. The average yearly income for a Nepalese person is only \$210, and many rural communities live within a subsistence economy.¹ Like many other countries with limited economic means, serious health and sanitation concerns in Nepal stem from over-population of areas with limited available natural resources.

¹ U.S. Agency for International Development, 2000.

Of the many health issues that plague the country, none is more important than the prevalence of waterborne illness. Seventy percent of the population does not have access to clean, safe drinking water.² According to UNICEF, one in ten children die before the age of five³ and many of these deaths are associated with water-borne illnesses. Of those children who do survive, 67% have stunted growth due to the loss of essential nutrients during illnesses.⁴

The serious health problems associated with poor drinking water quality have provided the motivation to undertake this study. Information documenting drinking water quality and both municipal and household treatment techniques in Nepal was relatively unknown to team members prior to initiation of this project. This study was initiated because of the seriousness of health problems in Nepal and the lack of true scientific data about them.

1.1.2 Project Purpose

The Nepal Water Project has two main objectives. First, is to quantify water quality issues with specific data and analysis and add to the minimal body of water quality data available. Second, is to make recommendations about acceptable point-of-use treatment systems for implementation in Nepalese households, based on effectiveness and cultural acceptance. These two initiatives are discussed in more detail below.

The water quality analysis portion of the project is divided into three specific studies. The first of these is a microbiological and turbidity study. The purpose of this study is to measure the levels of microbial pathogens and turbidity from a wide range of Nepalese drinking water samples. This study also includes an analysis of the water quality in the Bagmati River, a central water body that flows through the heart of Kathmandu, the nation's capital. A second study involves an analysis of nitrate and ammonia contamination in drinking water. Contamination with high levels of nitrate can result in serious adverse health effects in infants, and is usually the result of agricultural run-off and leaking septic systems. Although there is no standard for safe drinking water levels of ammonia concentration, this parameter is an indicator for microbial

² Water Resources Institute, 2000.

³ United Nations Childrens Fund, 2000.

⁴ Murcott, Susan, 1999.

pathogens. The third water quality study, which provides the basis for this thesis, is an analysis of arsenic contamination in Nepalese drinking water. As discussed in later chapters of this document, arsenic contamination is a severe issue in the neighboring countries of India and Bangladesh. Exposure to arsenic can cause various health effects including acute disorders of the skin and chronic diseases such as cancer.

The point-of-use treatment portion of the project can also be divided into four specific studies. The first of these involved an analysis of the use of coagulation and settling techniques for removal of microbial pathogens and turbidity. This study also made recommendations for this treatment option based on efficacy and acceptability at the household level. The second study focused on filtration. It involved the analysis of several filters, made both locally and in foreign countries, for ability to remove microbial pathogens and turbidity. The study made recommendations based on an analysis of the acceptability of filtration as a treatment option based on interviews with local communities and villagers. A third study analyzed three disinfection options: solar, chlorination and ultraviolet. This study made recommendations based on efficiency of removal of microbial pathogens and acceptability by local villagers. A final study involved an economics and logistics study on the distribution and availability of various filters. This was undertaken in conjunction with the filtration study described above.

1.2 Arsenic Contamination Study

The arsenic contamination study of the Nepal Water Project is the focal point of this thesis. By prior arrangement during the fall of 1999, this MIT thesis study has become a small portion of a larger initiative in the country of Nepal. In 1999, the DWSS, in conjunction with UNICEF-Nepal, commenced a lengthy sampling program that will be used to assess the existence and extent of arsenic contamination in Nepalese drinking water. Other international agencies have also implemented sampling programs to test wells in Nepal for arsenic. These sampling programs have mainly focused on testing in the Terai, or southern, region of Nepal.

All of these organizations have been helpful in formulating and executing the sampling program for the purpose of this study. All have been more than generous in sharing their information with

the Nepal Water Project team, and the information presented in this document will be provided to them in an ongoing effort to collaborate on this important water quality issue.

1.2.1 Study Motivation

Arsenic contamination in drinking water has caused a recent health crisis in West Bengal, India and Bangladesh. The installation of tube wells in an effort to provide drinking water free of microbial pathogens has resulted in widespread arsenic poisoning of people living in these areas. The arsenic contamination in these countries is considered to be of natural origin. Naturally occurring arsenic bound to solid substrates in the subsurface is believed to have been deposited through natural processes in the region. Because of the proximity of Nepal to these affected areas, and the similarity in hydrology and geology of the region, the possibility of arsenic contamination in Nepalese drinking water seemed quite possible. Prior to initiation of this study, little was known about arsenic contamination in Nepal. Even the DWSS sampling program began only after this study was proposed. Because of the potential for arsenic contamination in Nepal and the lack of sufficient data on the subject, this study was initiated as part of the Nepal Water Project.

1.2.2 Study Purpose

There are three goals associated with this study. The first and most important goal for this study is to assess the level of arsenic contamination in Nepalese drinking water. Because the amount of time for sampling in Nepal was limited, the study focused on collecting and testing samples from two districts in the Terai and several sources in the Kathmandu Valley. This study also provides an analysis of several samples collected by an international agency from a third district in the Terai. Data from the DWSS sampling effort is also presented to provide the most complete picture of the state of arsenic contamination as it is known at this time.

A second goal for this study is to provide an analysis of analytical testing methods. Three methods were used for this study, and the data of a fourth method has also been provided. This study performs a comparison of the relative accuracy of each method used and discusses the advantages and disadvantages associated with them. Whenever data was crosschecked between

the methods used in this and other studies, those results are provided to give better information on the accuracy of the tests used.

A final goal of this study is to present recommendations for future testing and monitoring in Nepal. Based on the data collected and analyzed by this author, and on that received from other organizations, suggestions are made as to which areas require further testing, and which areas should be monitored continually for contamination.

Chapter 2 - Background

This chapter provides the background necessary to understand the purpose and motivation for the study. It provides basic information about arsenic in the environment, including its chemistry, an overview of arsenic contamination around the world, a description of the hydrology and geology of Nepal, and finally a description of typical water sources found in Nepal.

2.1 Arsenic in the Environment

Arsenic occurs in the environment in several forms, and possesses a unique chemistry. A thorough discussion of the complex chemistry associated with this element is beyond the scope of this paper. However, basic information about the element and its forms that are of most concern in aqueous environments is presented. A discussion of its common sources in the environment, both natural and anthropogenic, is also provided.

2.1.1 General Chemistry

Arsenic is a highly toxic metalloid that is brittle, crystalline, odorless and tasteless in its elemental form.⁵ Arsenic is commonly used in glass making and termite control, as a pesticide and herbicide, and in timber preservation, fertilization, wallpaper and ceramics.⁶ As a heavy metal, it is stable in the -III, 0, +III, and +V oxidation states.⁷ It forms several inorganic and organic compounds, and is commonly found in the environment.

The most common species of arsenic found in aqueous environments are arsenite (H_3AsO_3), arsenate (H_3AsO_4), monomethylarsonic acid (MMAA), and dimethylarsonic acid (DMAA). The most important species with relevance to toxicity in humans are arsenite and arsenate. These two species, therefore, are of most concern to this study. The analytical methods discussed in later chapters are based on measurement of these two species in water samples to determine total arsenic present. Information collected did not focus on speciation because this study is only concerned with determining the presence and extent of total arsenic in Nepalese drinking water.

⁵ WebElements, 1999.

⁶ Total Environment Centre, 1999.

Factors such as pH and oxidation/reduction environments can drastically affect the state of arsenic in the subsurface. Figure 2-1 shows a plot of the complicated chemistry behind arsenic speciation in different environments. The Eh-pH diagram is for arsenic at 25°C and one atmosphere with total arsenic 10^{-5} mol/L and total sulfur 10^{-3} mol/L. From the plot, it can be seen that several different species of arsenic can be present in a sample based on environmental conditions and other chemicals present. Figure 2-1 also shows that arsenic can exist in both solid and aqueous states, depending on the conditions.

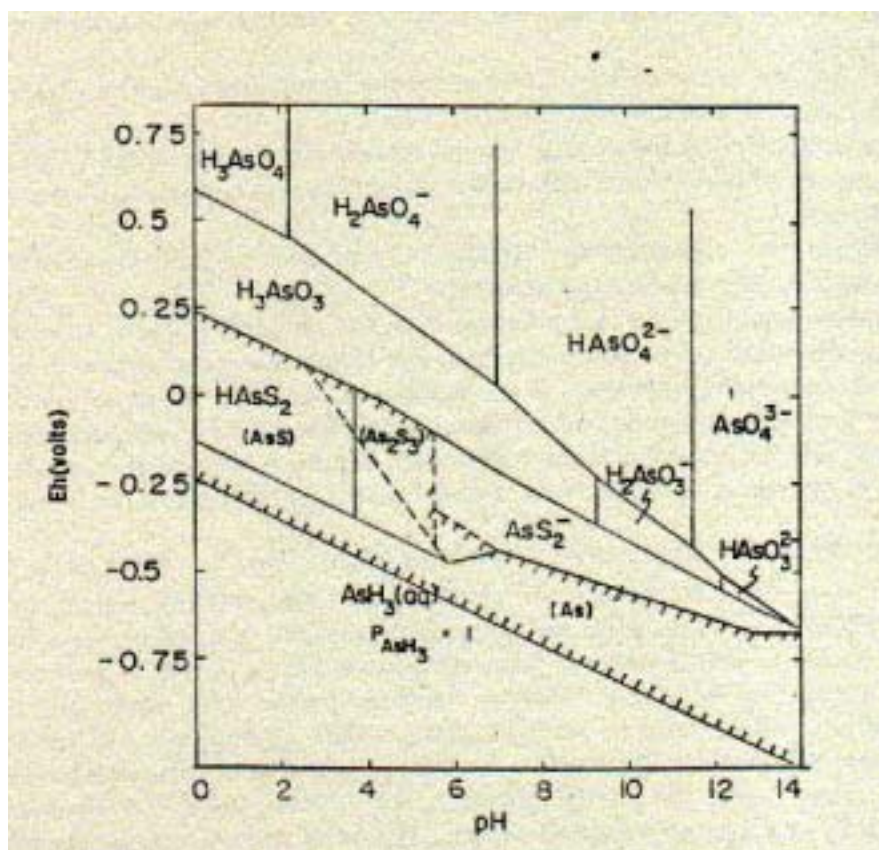


Figure 2-1: Eh – pH Diagram for Arsenic at 25°C and One Atmosphere
[With total arsenic 10^{-5} mol/L and total sulfur 10^{-3} mol/L. Solid species are enclosed in parenthesis in crosshatched area, which indicates solubility less than $10^{-5.3}$ mol/L.]⁸

Figure 2-2 shows the predominance plot for arsenate. This plot shows the variety of species that can be present depending on environmental conditions. It can be noted from the graph that at a

⁷ Stanley, Rachel, 1998.

⁸ Ferguson, John F., and Jerome Gavis, 1972.

pH of 4, for example, arsenate is negatively charged. However, at that same pH, arsenite, is not charged. This demonstrates that depending on the pH, different species will have different charges. This fact becomes the underlying principle for many separation techniques used to determine speciation. This is important for both analytical testing methods that attempt to separate species and remediation techniques that use ion exchange for separation and treatment. This is also important in assessing subsurface chemistry, because the charge on a species may cause different interactions in the subsurface. Arsenate, for example, is relatively immobile in the subsurface because it tends to sorb onto positively charged particles, such as iron hydroxides. Changes in redox conditions, such as reduction of metal oxides, may enhance the mobility of arsenic. However, in a more reducing sulfidic environment, arsenite may precipitate as arsenic sulfide minerals.

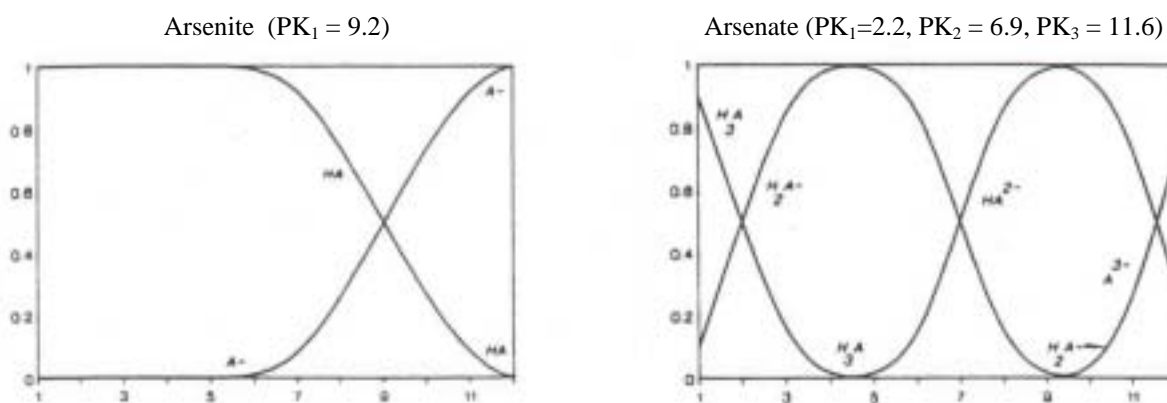


Figure 2-2: Predominance Charts for Arsenite and Arsenate at Varying pH⁹

2.1.2 Common Sources

In soils, arsenic occurs both naturally and as a result of human influences. Arsenic can be naturally derived from several parent materials in soil, including magmatic sulfides and iron ores. The most important arsenic ores are the arsenopyrites, which are often present in sulfide ores. Human influences that can result in a build-up of arsenic include the use of arsenical

⁹ Korte, N.E. and Q. Fernando, 1991.

pesticides, the application of certain fertilizers, irrigation, dust from the burning of fossil fuels, and disposal of industrial and animal wastes.¹⁰

Species of arsenic can also be found naturally in aquatic environments. Both in surface waters and groundwater, species of arsenic such as arsenite, arsenate, MMAA and DMAA are most commonly found. Chemical forms of arsenic in both aqueous and soil environments can cycle through the two mediums depending on the surrounding conditions. Figure 2-3¹⁰ shows a diagram representing the various chemical forms of arsenic in aquatic environments and their transformations in soils.

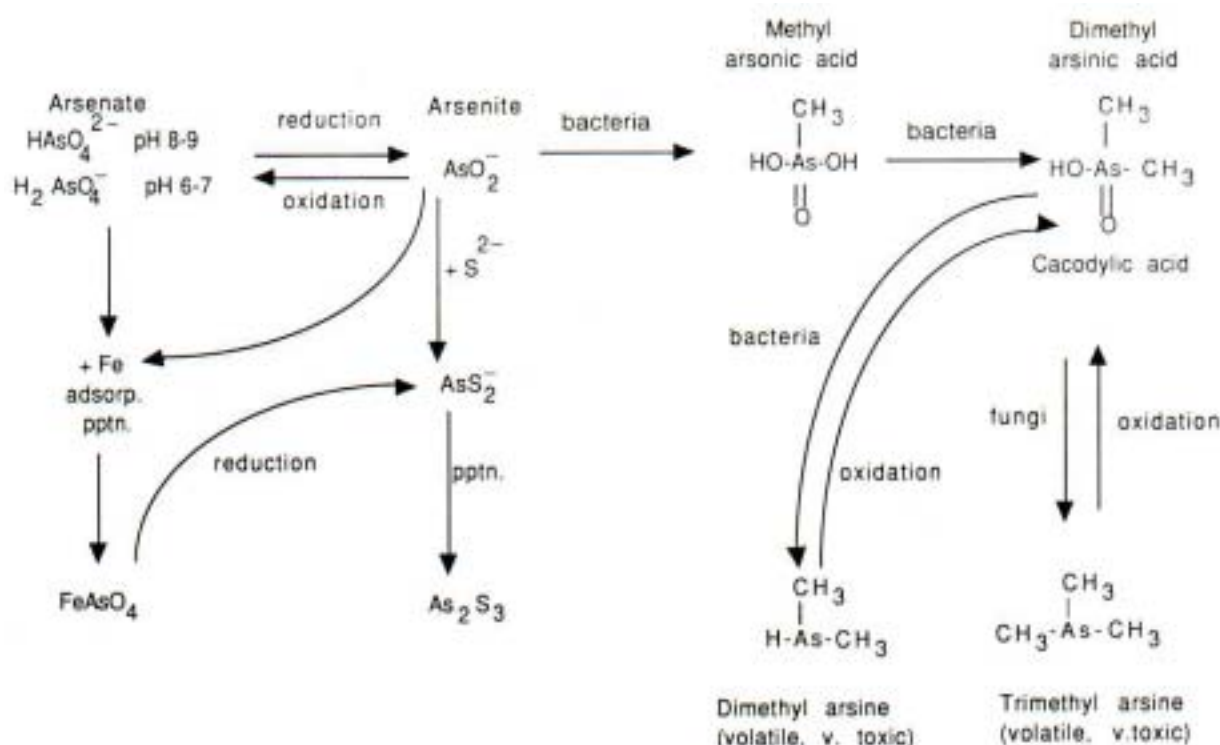


Figure 2-3: Chemical Forms of Arsenic and Their Transformations in Soils.

The cycle of arsenic through the environment is quite intricate because of the various forms of arsenic occurrence in different media. However, a simplified cycle that is useful in depicting the typical pathways of arsenic in the environment is presented in Figure 2-4¹⁰. This figure shows multiple potentials for human exposure from different environmental pathways. According to the figure, humans can be exposed through direct contact with water, soil, pesticides, and the

¹⁰ Blumba, D.K. and R.F. Keefer, 1994.

atmosphere. Although this may seem obvious, it is important to note that all of these pathways present serious dangers based on the toxicity of arsenic. The toxic nature of arsenic is discussed at greater length in the next chapter.

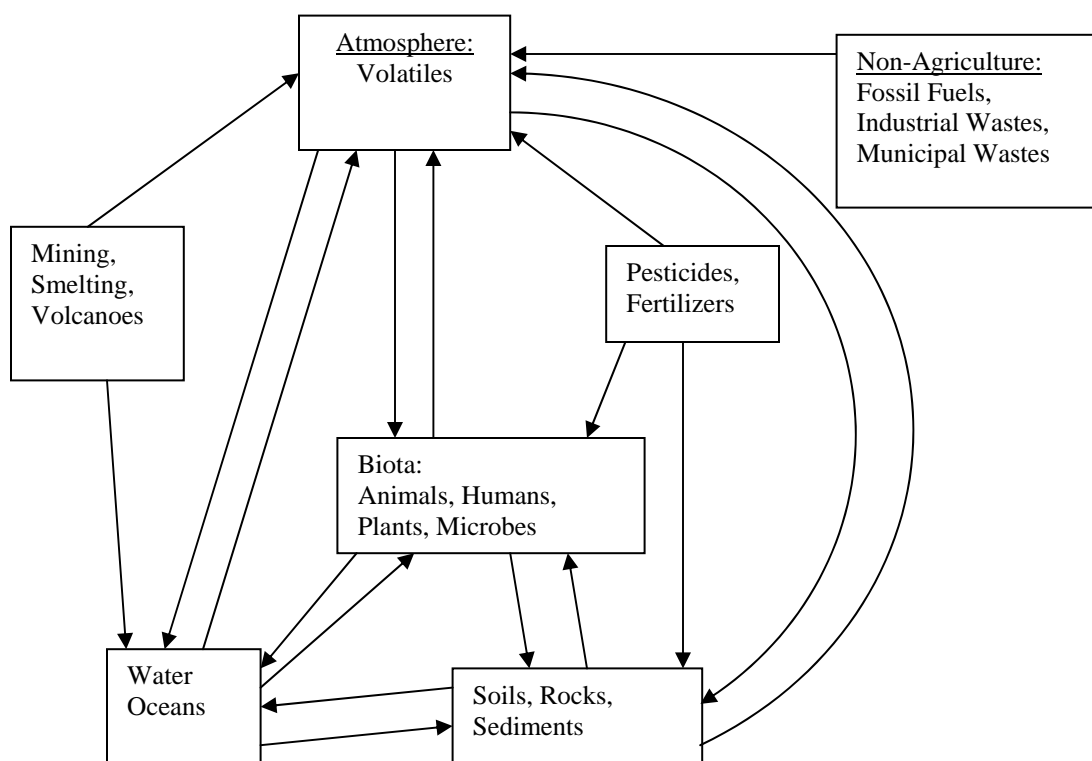


Figure 2-4: A Simplified, Comprehensive Cycle Transfer of Arsenic

2.2 Arsenic Contamination in Other Countries

The impetus for this study stems from ongoing crises in other countries. Two of the largest and most widespread cases of arsenic contamination occur in neighboring countries to Nepal. Both Bangladesh and India have experienced extensive arsenic contamination in their drinking water and subsequent adverse health effects. Details of each of these cases are provided in the following sections. Also included in this section is a discussion of arsenic contamination in the U.S. Several states in the U.S. are home to some of the highest levels of arsenic in the world,

and although this contamination has not led to adverse health effects because of detection, treatment and/or provision of alternate water supply, they are worth noting for adequate representation of known arsenic contamination around the world.

2.2.1 Crisis in Bangladesh

The concern over arsenic contamination in Nepalese drinking water was initiated by the recent crisis in neighboring Bangladesh. After the installation of over 4 million tube wells in Bangladesh, a widespread occurrence of arsenic poisoning has plagued the country. According to the United Nations Development Programme, approximately 20 million people are thought to be exposed to arsenic poisoning, and another 50 million are considered to be at risk.¹¹ Measurements performed by several scientists indicate that the amount of arsenic in the wells varies greatly, and that levels higher than 50 ppb are common.¹² Levels as high as 2,000 ppb have been reported. Many wells exceed the World Health Organization (WHO) drinking water standard of 10 ppb.¹³

According to the West Bengal & Bangladesh Arsenic Crisis Information Centre, the geology of Bangladesh consists mainly of thick alluvial and deltaic sediments.¹⁴ These sediments consist of sandy and silty materials, characterized by a high hydraulic conductivity. The areas of alluvial deposition can be further divided into two main distinctions. The terrace area includes geologic materials that are estimated to be as much as one million years old. The floodplain areas, which lie mainly in the Ganges, Brahmaputra, Tista and Meghna river basins, consist of, on a geological time scale, much younger deposits. Arsenic sampling and testing in Bangladesh has revealed that much of the arsenic has been found in these floodplain areas. Figure 2-5 provides a map of the area, and the location of the river systems in Bangladesh.

¹¹ United Nations Development Programme, 1999.

¹² Harvard University, "Arsenic Project." 1999.

¹³ World Health Organization, "Arsenic in Drinking Water." 2000.

¹⁴ West Bengal & Bangladesh Arsenic Crisis Information Centre, 1999.

Figure 2-5: Map of Bangladesh¹⁵

Figure 2-6 shows the extent of arsenic contamination in Bangladesh. From the map, it can be seen that the majority of the contamination is located along the Ganges and Brahmaputra River floodplains. Maximum concentrations in the floodplains range from 1000 to 2000 ppb. This area is characterized as widespread alluvial deposits of high hydraulic conductivity. The arsenic below the surface is believed to be of natural origin, and at least two schools of thought exist about the probable sources of the contaminant. One theory is that a large-scale geologic event resulted in mass deposition of the arsenic thousands of years ago. It is believed that fine-grained clays and iron oxides coagulated when the rivers that were carrying them came in contact with

¹⁵ Harvard University, "Bangladesh." 2000.



Figure 2-6: Map of Arsenic Contamination in Bangladesh¹⁶

the saline waters of the Bay of Bengal. This is thought to have resulted in the mass deposition of fine-grained sediment suspected of being the source of arsenic. The arsenic is believed to have been deposited in the floodplains after transport through the river systems from a naturally occurring source in hard rock outcrops further upstream. A second school of thought is based on the hydrology and topography of the area. The upstream Himalayas of Nepal could be the cause of massive groundwater discharge in the lowlands of Bangladesh. Because of this, water passes through surface sediments and accumulates arsenic concentrations. The highly fluctuating water table caused by monsoonal rains characteristic of the area provides the dynamic subsurface environment that would be needed to have arsenic concentrations build up. Both schools of

¹⁶ Dainichi Consultant, 2000.

thought accept the hypothesis that the arsenic is of natural origin. Based on either of these theories, it seemed plausible that arsenic contamination could exist in groundwater drinking sources in Nepal.

The situation in Bangladesh is dire, and numerous non-governmental, academic and governmental organizations are working to find solutions to the problem. Some have suggested returning to the highly polluted surface water sources. This, however, would cause another increase in mortality due to microbial pathogen intake. Other options include implementing various treatment techniques, such as carbon adsorption, or installing deeper tube wells to extract water that is out of the arsenic contaminated zone. All of these options, however, require further analysis, and for the time being, wells that have been tested and are known to be of high arsenic concentration have been painted red and the villagers have been told not to drink them. Unfortunately, some villagers are still drinking from red-painted wells, simply because there is no other convenient water supply.

2.2.2 Crisis in India

Similar to the situation in Bangladesh, severe arsenic contamination has been discovered in India. Particularly, groundwater in areas of West Bengal has been discovered to contain some of the highest levels of arsenic in the world. According to the World Health Organization, six eastern districts in West Bengal, India are contaminated with arsenic levels ranging from 60 ppb to 1,860 ppb.¹⁷ The arsenic is believed to be of the same general origin as that found in Bangladesh. The location of West Bengal relative to Bangladesh and Nepal and the contaminated regions within it are shown in Figure 2-7. This area's hydrology is dominated by the Ganges and Brahmaputra Rivers. The large alluvial deposits of West Bengal contain arsenic. The many river systems of the Himalayas, some of which flow through Nepal, are intricately involved in the transport of arsenic in the area, and for these reasons, the hypothesis that there could be arsenic contamination in Nepal seemed justifiable.

¹⁷ World Health Organization, "Arsenic in Drinking Water and Resulting Arsenic Toxicity in India and Bangladesh: Recommendations for Action." 2000.

Figure 2-7: Arsenic Contamination in West Bengal¹⁸

2.2.3 Contamination in the United States

Arsenic concentrations above the safe drinking water limit imposed by the U.S. Environmental Protection Agency (USEPA) have been found within the United States. Several states, including Nevada, Arizona, California, Wisconsin, Michigan, Utah, New Hampshire and Maine, have been reported to have concentrations as high as 180 ppb. The source of much of the contamination is

¹⁸ Dipankar Chakraborti, 2000.

believed to be of natural origin and not of anthropogenic origin.¹⁹ The sources are either currently being treated or have been abandoned for arsenic-free options. The arsenic contamination in the U.S. has fortunately not resulted in poisoning of the population as in Bangladesh and West Bengal. It is interesting to note, though, that arsenic has been found around the world in the subsurface, and consequently is a potential problem for many countries around the globe.

2.3 Overview of Hydrology and Geology of Nepal

2.3.1 Geography and Geology

The geology of Nepal is a complex system centered around the great elevation change from the top of the Himalayas to the flatlands of the Terai. The upper Himalayas form a massive mountain terrain that stretches the northern length of the country bordering China. The mountains in this area are famous, home to the highest peak in the world, Mount Everest (elevation 8,848 m²⁰), and the greatest number of high peaks in any mountain range.²¹ This range of mountains dramatically dictates the climate and hydrology of Nepal. Figure 2-8 shows the topography and some of the surface hydrology in Nepal. Extensive systems of rivers flow down all sides of the mountains. Some flow through Nepal and into India and Bangladesh, whereas others flow through China. Of note are two major rivers that originate in the mountains. The Kosi River drains out through eastern Nepal and feeds into the vast Ganges River in India before it flows into the Bay of Bengal. Waters of the Kosi originate in the Himalayas and join to form the Kosi River system in eastern Nepal. This is the biggest river, according to C.K. Sharma²¹, with affluent catchment areas totaling approximately 62,000 square kilometers and annual sediments of 118 million cubic meters. Another major river originating in this mountain system in China is the Bhramaputra, which flows through China and the West Bengal portion of India into Bangladesh. Both of these rivers, along with the multitude of minor rivers that originate in the mountains, have massive deposition associated with their flow patterns. The high velocities achieved while the rivers flow down the steep mountains allow for massive transport of sediments along the way. When the river velocities decrease as they reach lower

¹⁹ Peters, Stephen C., et al., 1999.

²⁰ Central Intelligence Agency. 2000.

elevations, suspended sediments in the water are deposited in massive quantities. These river systems, therefore, dictate a good deal of the geology in the lower lands of the country.



Figure 2-8: Map of Nepal²²

The foothills of the mountains give rise to highly industrialized areas in the middle latitudes of Nepal. This region is home to the Kathmandu Valley, which is one of the most densely populated regions of the country. The relatively industrialized cities of Patan, Kathmandu and Bhaktapur in the Kathmandu Valley contain many industries, businesses and personal residences. The hydrology in this region is mainly dominated by the Bagmati River, which flows through the heart of the valley. The drainage area of this river is 2,720 square kilometers, and it has an average discharge of $161.6 \text{ m}^3/\text{s}$.²¹ This valley region was once a lake, and sediments of the nearby hills and plant material were deposited as it dried up. Soils in the valley today consist of highly fertile black clay. Outside the valley in the foothills, soils tend to be sandy and less fertile.

The low plains area to the south of Nepal is called the Terai region. It extends from west to east along the southern border with India. The region is characterized as flat plains and farmland. Also, heavy agricultural use occurs in the area. It is densely populated, mainly with agricultural communities and scattered industrial complexes. The climate in the area is tropical, with high temperatures and humidity throughout the year. During the monsoon season, this region, along

²¹ Sharma, Chandra K., 1977.

²² Travel-Nepal.com, 2000.

with the foothills, receives extensive amounts of rainfall (average annual precipitation in Kathmandu is 90 inches²³). Many of the river systems that originate in the mountains and foothills to the north flow through these flatlands and into India. The geology of the region is characterized in general as alluvial deposits. The subsurface consists of a layer approximately 5,000 feet thick of alluvium.²¹ The soils of the Terai contain a large amount of iron oxides, which result in iron contamination in the groundwater.²¹

2.3.2 Typical Water Sources

Water samples were taken from a wide range of sources. Descriptions of the sources are provided below, along with an explanation of where these sources are typically used for drinking water:

- **Tube Wells:** Tube wells are hollow pipes, typically of steel or polyvinyl chloride, which are driven into the ground. Typical depths of tube wells sampled in this study ranged from 30-300 feet below the surface. Tube wells extract groundwater from the subsurface by the use of a pump. In the Terai regions of Nepal, hand pumps are commonly used to extract the water. Figure 2-9 shows a typical hand pump tube well located in the Terai region. The majority of the samples taken from the Terai region were from tube wells similar to the one shown.

²³ Nepal.com, 2000.



Figure 2-9: Typical Hand Pump Tube Well

- **Hand Dug Wells:** Hand dug wells are those that are literally dug by hand. These are typically much shallower than tube wells, and are larger in diameter. Water is usually extracted from the wells by lowering a bucket into the well. Figure 2-10 shows a hand dug well in Nepal. Only a small number of the samples taken in Nepal were from hand dug wells.



Figure 2-10: Typical Hand Dug Well

- **Municipally Supplied Water:** In many areas of the Kathmandu Valley, municipally supplied water systems are prevalent, providing approximately 58% of the water in Kathmandu.²⁴ These systems may be simple collection and re-distribution systems, or may include one, if not more, stages of water treatment. Some of the treatment facilities found in the Kathmandu Valley have collection, aeration, coagulation, filtration, chlorination and distribution components. In most cases, the treated water is distributed to public taps that are turned on twice a day for collection. Often several households and commercial establishments use these taps as their sole water source. A portion of the samples taken from the Kathmandu

²⁴ United Nations Development Programme, 1998.

Valley for the purposes of this study were from various points in these distribution/treatment systems.



Figure 2-11: Traditional Public Water Spout in Patan Durbar Square

- **Natural Springs:** In large urban centers, natural spring water is often pumped to traditional public water spouts (also known as traditional stone taps) which are used for bathing, washing and occasionally drinking. Figure 2-11 shows a typical public water spout in the heart of the Kathmandu Valley. Natural spring sources are also used as traditional water sources in rural areas of Nepal. These are often hand dug springs that contain natural groundwater. Figure 2-12 shows a woman retrieving water from such a source. It is interesting to note that this woman, when asked why she did not drink the municipally supplied, treated water located a few feet from this spring, stated that she preferred this source because her family has been drinking it for generations and because she did not trust the treated water. This is true of many people who prefer traditional water sources in Nepal.
- **Surface Water:** Less frequently, surface water is used as a direct source of water for rural communities. In general, surface water in Nepal is highly polluted, particularly in urban centers of the Kathmandu Valley. The Bagmati River is the main surface water source that

runs through the Kathmandu Valley. This river is used as a sewer, a garbage repository, and a bathing area. No surface water samples were tested for the purpose of this arsenic study²⁵, but it should be noted that surface water does serve as a source for drinking water.



Figure 2-12: Traditional Natural Spring Water Source

²⁵ Wolfe, Andrea N.C., 2000.

Chapter 3 - Health Effects

Arsenic has long been known as a poison, and its effects on health even at small doses can be quite devastating. The recent crises in India and Bangladesh give frightening testament to the far-reaching, chronic effects of arsenic poisoning. This chapter provides an outline of the health effects of arsenic poisoning, both acute and chronic, and provides background information on the current state of regulations concerning tolerable thresholds and safe drinking water limits in the environment. An epidemiological analysis of current health problems in Nepal is also provided.

3.1 Toxicology of Arsenic Compounds

Arsenic can enter the body through the three main pathways to exposure: inhalation, ingestion, and absorption. Arsenic can also be passed from a pregnant woman to her unborn child. In various different forms, the chemical can be toxic to humans. This section provides a brief overview of the toxicological principles behind arsenic chemistry in the body. Information is provided on arsine gas (AsH_3), a common inhalation hazard, and inorganic arsenic compounds that are normally ingested in food and contaminated water.

3.1.1 Arsine

Arsine gas (AsH_3) is classified as an extremely toxic chemical. It is a Class A, flammable poison with a threshold limit value of 50ppb.²⁶ Because it is a gas, arsine poses an inhalation hazard. When arsine enters the lungs from the outside environment, it travels directly to the alveoli in the lungs where it freely diffuses into the bloodstream and finally into the red blood cells. Once in these cells, water hydrolyzes the arsine to form arsenous acid ($\text{As}(\text{OH})_3$). This compound is extremely nucleophilic, and reacts with the thiol groups of hemoglobin, DNA and cell membrane enzymes. These reactions cause the cell to erupt and die. An individual receiving large doses of arsine gas will become dizzy, experience central nervous system malfunction, abdominal pain, and liver and kidney dysfunction. Ultimately, heart failure and/or renal dysfunction cause death.

²⁶ Massachusetts Institute of Technology, 2000.

3.1.2 Inorganic Arsenic

Inorganic arsenic is also extremely toxic. Various forms of inorganic arsenic can enter the body when contaminated food and water are ingested. When, for example, arsenite enters the body from the outside environment, it is converted by the enzyme arsenic methyl transferase to a water soluble form that can be excreted in the urine. The arsenite ion, however, has a high affinity for thiol groups. If the toxin is in the body for a long enough time or a high enough dosage, the arsenite can bind to thiol groups before it has a chance to be converted by the transferase enzyme to a safe form. Arsenite particularly binds to the many thiol groups found on common enzymes. The arsenite blocks the active sites of these enzymes, thereby disabling them. This process can result in eventual death if enough enzymes are affected.

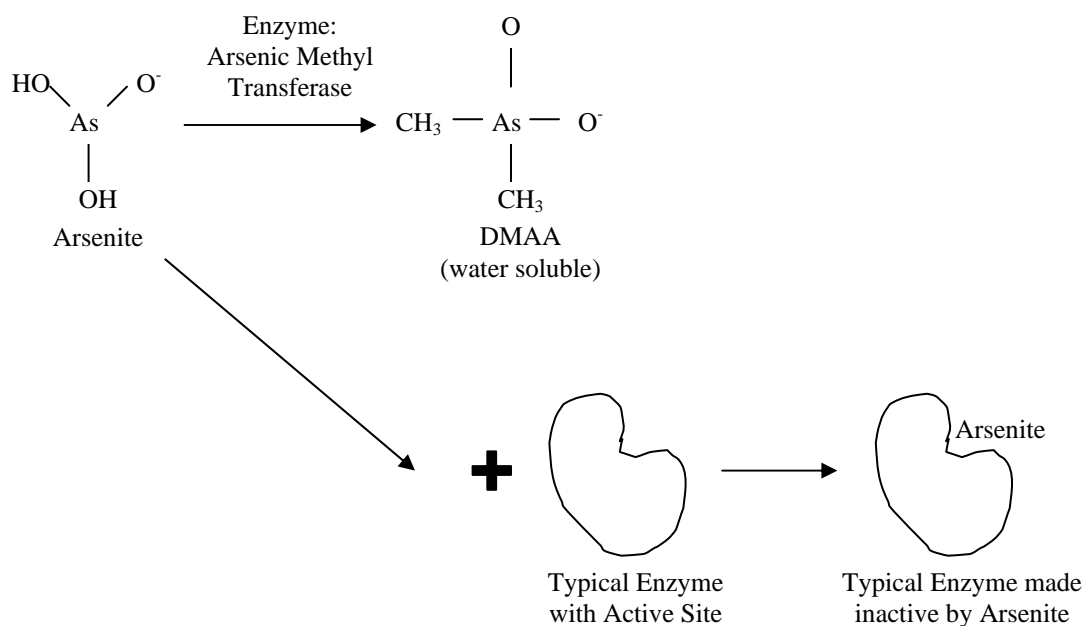


Figure 3-1: Conversion of Arsenite to Water Soluble DMAA

An example of the chemical interactions of arsenite in the body is shown in the molecular diagrams provided in Figure 3-1. Arsenite is converted by arsenic methyl transferase to water soluble DMAA. Figure 3-1 also shows that if arsenite is in the body so that significant time must pass before all of the toxin is converted, arsenite becomes bound to the active site of a typical enzyme and therefore shuts down the function of the enzyme. If enough arsenite is introduced

into the body, toxic effects result. This is just one example of the many deleterious outcomes of arsenic exposure to humans.

3.2 Exposure Limits and Health Guidelines

Several limits have been placed on human exposure to arsenic based on the believed toxicity of arsenic. For example, arsine gas is extremely toxic to humans, and an exposure of 20 to 50 ppm for 30 minutes is reported to be lethal.²⁷ The Reference Concentration for arsine gas is 0.00005 mg/m³.²⁷ The USEPA has established a Reference Dose of 0.0003 mg/kg/d for inorganic arsenic.²⁷ Because of the use of this compound in industrial applications, the Occupational Safety and Health Administration has established standards designed to protect workers from occupational exposure to inorganic arsenic.²⁸

For aqueous arsenic species (mainly arsenite and arsenate), the standards have been set based on what is believed to be an allowable level of arsenic intake over time. The WHO has set the international drinking water guideline for arsenic at 10 ppb. This is a strict standard due to the high toxicity associated with this chemical.

On a country by country basis, drinking water guidelines vary based on different regulations and governments. According to the Code of Federal Regulations, the maximum contaminant level for arsenic in the U.S. is currently 50 ppb.²⁹ This less stringent standard is due to the fact that some of the highest levels of arsenic in the world have been found in U.S. groundwater and it is expensive to treat or provide alternate water supplies. The USEPA, however, is currently reviewing the drinking water standard for arsenic. A final ruling on the drinking water standard for arsenic is scheduled to be released by the USEPA on January 1, 2001.³⁰ Similarly, countries currently plagued with arsenic contamination, including India and Bangladesh, have adopted standards of 50ppb in conjunction with several international organization standards. Although this is a higher allowable concentration than the WHO limit, it is considerably less than the levels of arsenic that are being found in those countries. There are currently no drinking water

²⁷ U.S. Environmental Protection Agency, "Arsenic and Compounds." 2000.

²⁸ Occupational Safety & Health Administration, 2000.

²⁹ 40 CFR 141.11

standards for any water quality parameters in Nepal, including arsenic. However, in 1996, Roshana Shakya and Suman Prasad Sharma of WHO/SEARO proposed a water quality goal in Nepal of 50 ppb for arsenic.³¹

3.3 Symptoms of Arsenic Poisoning

Symptoms of arsenic poisoning can be described in two categories: acute and chronic. Acute symptoms are those that occur directly after brief exposure at high concentrations. Chronic effects occur gradually over time, and tend to develop after long term exposure to low levels of arsenic. Symptoms associated with both of these types of health effects are described in detail below.

3.3.1 Acute Health Effects

There are several symptoms characteristic of arsenic poisoning that manifest immediately if the dose is large enough. Signs of acute poisoning typically occur within 30 minutes of entry into the body. Initial symptoms can include muscle pain, and weakness, followed by severe nausea, abdominal pain and diarrhea. Other symptoms include numbness in hands and feet, red rashes on the skin, intense thirst, decreased urine output, drowsiness and confusion, paranoid delusions, hallucinations, and delirium. Ultimately, seizures, coma and death occur.³²

In general, acute health effects are seen when arsenic levels of about 300 to 3,000 ppb enter the body.³³ Approximately 60,000 ppb of arsenic can be fatal in adult humans.³³

3.3.2 Chronic Health Effects

Chronic health effects are the more common in India and Bangladesh. Although the levels of arsenic in the drinking water for these countries is quite high, the gradual ingestion of the arsenic has, over time, led to widespread chronic health effects. When arsenic is introduced in the body,

³⁰ U.S. Environmental Protection Agency, "Drinking Water Priority Rulemaking: Arsenic." 2000.

³¹ Shakya, Roshana, and Suman Prasad Sharma. 1996.

³² Saha, J.C., et al., 1999.

³³ ECO-USA, 2000.

unless it is at a level that produces acute effects, it will accumulate until an injurious state is reached. The metal will accumulate in the tissues, organs, hair and nails of the individual who is exposed, and will gradually build up to toxic levels. At that point, the arsenic begins to cause skin disorders. They begin as dark spots, particularly on the hands and feet, and gradually spreading to the neck and chest. The skin problems can become worse, leading to open sores on the body. Severe disorders, such as gangrene and melanoma, can also result if the level of toxin builds up enough over time. Other symptoms, such as a black tongue, nausea, vomiting, stomach pain, diarrhea, partial paralysis and blindness can also occur.

Aside from the skin disorders caused by arsenic poisoning, the chemical is also believed to cause several types of cancer of the internal organs. The USEPA has classified inorganic arsenic as a Group A human carcinogen, with a 1/ED10 value of 140 per (mg/kg)/dd.²⁷ Prolonged exposure to arsenic is believed to cause tumors in the bladder, kidney, liver and lungs. These chronic effects often do not manifest in the exposed individual until after several years of exposure.

3.4 Health Problems in Nepal

Current statistics concerning health problems in Nepal provide no direct links to arsenic poisoning in the country. However, information is available about some of the various symptoms associated with the toxin. From the data available, some general epidemiological conclusions can be drawn about the possibility of arsenic contamination in Nepalese drinking water.

The World Health Organization's International Agency for Research on Cancer has developed a 1990 worldwide cancer incidence and mortality index called GLOBOCAN 1.³⁴ According to this index, incidence rates for common cancers have been determined for Nepal. The data for cancer in males that are typical of arsenic exposure are provided in Table 3-1. Rates for Nepal, Bangladesh, India and the world are provided for comparison.

³⁴ World Health Organization, "GLOBOCAN1." 2000.

Table 3-1: Incidence Rates for Male Adults in Various Countries
(Incidence Rates represent an age-standardized rate expressed per 10,000 people)³⁴

Cancer Type	Nepal	Bangladesh	India	World
Liver Cancer	2.79	1.35	2.63	14.67
Lung Cancer	11.95	23.27	9.64	37.46
Melanoma of Skin	0.38	0.35	0.28	2.25
Bladder Cancer	4.39	1.31	3.74	9.89
Kidney Cancer	1.40	0.63	1.33	4.34

The data presented in Table 3-1 provides a survey of some common chronic health effects of arsenic poisoning. In countries such as India and Bangladesh, where known arsenic poisoning has occurred, incidence rates for liver cancer, melanoma of the skin, bladder and kidney cancer are actually less than those for Nepal. Of course there are several causes of these cancers, and a direct relationship between arsenic contamination and cancer incidence cannot be drawn. However, this data does not decrease the possibility of arsenic contamination in Nepalese drinking water.

Because of the common symptoms associated with arsenic poisoning, it is possible that exposure could be misdiagnosed as various other diseases. For instance, the skin disorders associated with arsenic poisoning can be mistaken for leprosy. Similarly, various types of cancers can be caused by several factors, including natural causes, and diseases like cancer are not commonly diagnosed in third world countries. Because of this, it is possible that arsenic poisoning may exist in Nepal without the symptoms being linked to arsenic.

Chapter 4 - Analytical Methods

Three analytical methods were used to determine arsenic concentrations in samples collected in Nepal in January 2000. There were several choices of methods, and the first portion of this chapter explains the available options and the reasoning behind the decisions that were made. Next, detailed descriptions of each of the three methods used are provided, along with the specific procedures that were performed.

4.1 Possible Test Methods

There are several test methods available that can be effectively used to measure arsenic concentrations in water samples. Each of these methods has significant advantages and disadvantages. Because of the unique nature of this project, each viable method was evaluated with respect to certain criteria important to this particular study. These criteria included the following:

- **Detection limit:** The detection limit for any given method is important. Because of the uncertainty of the concentrations of arsenic expected to be found in Nepal, a wide range of detection limits was preferred. The ability to accurately determine arsenic concentrations at the WHO guideline of 10 ppb was desirable.
- **Field applicability:** The method's applicability for use in the field was also another important consideration. For the purpose of this study, any instruments used had to be portable and rugged. The instruments also needed to be suitable for use in the climate of Nepal.
- **Electricity/refrigeration requirements:** The requirements of electricity and refrigeration are also important to this study. Resources available were not fully understood until the author arrived in Nepal. Because of this, methods not requiring electricity or refrigeration were desirable.
- **Other chemical interferences:** The interference of other chemicals with each method is also important for the study. Little is known about other chemical levels in Nepalese drinking water. Therefore, a method with few interactions with other chemicals was preferred.

- **Safety issues:** Another important factor concerning the determination of the appropriate analytical method was safety. Because arsenic is highly toxic, it was important that persons conducting tests be kept at low risk of adverse health effects when performing analytical procedures.
- **Cost:** The final factor affecting the analytical method decision was cost. Because of the limited resources available to this project, it was important that the method used be relatively inexpensive.

These criteria were used to evaluate several testing methods prior to choosing the most appropriate one(s). Each of the methods that were evaluated for potential use during this study are described below. Table 4-1 shows a matrix of the testing method selection process, and is a general summary of the information presented here.

- **Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES):**

This is a USEPA approved method for measuring arsenic in drinking water.³⁵ An ICP-AES instrument utilizes optical spectrometry to measure the characteristic atomic emission spectra of the analyte in question.³⁶ ICP-AES uses a modified version of atomic emission spectroscopy (AES). In AES, analyte atoms are aspirated into a region where they are desolvated, vaporized and atomized by a flame, discharge or plasma.³⁷ The excited atoms radiate, and at a characteristic wavelength, the intensity is directly proportional to the concentration of the analyte. With ICP-AES, the same concept is used, but a much higher temperature flame eliminates common interference and error sources.³⁸ The detection limit for this method ranges from 5-8 ppb.³⁵ This instrument is not applicable for use in the field because of its large size and sensitivity to transportation, and would not be practical for use in Nepal. It requires electricity, but no refrigeration. ICP-AES can have several chemical interferences. When analyzing for arsenic, these include: aluminum, antimony, cerium, chromium, cobalt, iron, molybdenum, nickel, and vanadium. There are several safety issues associated with this method. First, the

³⁵ U.S. Environmental Protection Agency, "Arsenic in Drinking Water: Analytical Methods." 1999.

³⁶ U.S. Environmental Protection Agency, Region 9 Laboratory, 2000.

³⁷ McMaster University, Faculty of Science, "Atomic Emission Spectroscopy." 1999.

³⁸ McMaster University, Faculty of Science, "Inductively-Coupled Plasma Atomic Emission Spectroscopy." 1999.

Table 4-1: Possible Analytical Methods for Measurement of Arsenic in Potable Water

Test Name	Method	Detection Limit (ppb)	Applicable in field?	Electricity required?	Refrigeration required?	Other Chemical Interferences	Safety Issues	Cost
ICP-AES	USEPA recommended method using optical spectrometry to measure atomic emission	5-8	No	Yes	No	Al, Sb, Ce, Cr, Co, Fe, Mo, Ni, V	UV radiation, high voltage, toxic reagents	High initial cost, \$15-25/test
ICP-MS	USEPA recommended method using mass spectroscopy	0.2	No	Yes	No	ArCl	UV radiation, high voltage, toxic reagents	High initial cost, \$10-15/test
GFAAS	USEPA recommended method using principles of light absorption by free atoms	1-5	No	Yes	No	Yes	magnetic field, high temps, toxic chemicals	No initial cost, \$15-50/test
STP-GFAAS	USEPA recommended method using principles of GFAA with a background corrector	0.5	No	Yes	No	Yes	magnetic field, high temps, toxic chemicals	High initial cost, \$15-50/test
GHAA	USEPA recommended method using atomic absorption of hydrides	0.5	No	Yes	No	Yes	magnetic field, high temps, toxic chemicals	High initial cost, \$15-50/test
ASV	Uses principles of electro-chemistry to separate metal ions in solution	0.5	Yes	Yes	No	Cu, Hg, Zn, Bi	high voltages, toxic reagents	\$6,000 to purchase unit
EM Quant® Test Strips	Utilizes a simple chemical reaction that produces a color stain on an indicator paper	100	Yes	No	No	See Table 4-2	arsine gas production, toxic reagents	\$75/100 tests
Affiniti Concentration Kit	Uses resins to concentrate As in a sample. Used in conjunction with EM Quant® Test Strips	10	Yes	No	No	See Table 4-2	arsine gas production, toxic reagents, explosive	\$100/20 resins
Arsenator 510	Uses photodiode to measure production of arsine gas above sample	0.5	Yes	Yes	No	See Table 4-2	arsine gas production, toxic reagents	\$3,000 to purchase unit

toxicity of the reagents used is not fully understood, and all mixing and acidification should be performed under a fume hood. Second, radio-frequency and UV radiation is emitted when the instrument is in use. Finally, high voltages are present while the unit is in operation.³⁶ The exact cost of this instrument varies, but can generally be classified as beyond the resources of this study. The cost to run each test, after initial purchase of the instrument, is reported as \$15-\$25.³⁵

- **Inductively Coupled Plasma Mass Spectroscopy (ICP-MS):**

This is also a USEPA approved method for measuring arsenic in drinking water.³⁵ This method combines the theory of mass spectroscopy (MS) and inductively coupled plasmas to determine analyte concentrations. MS uses differences in mass to charge ratios to separate ionized atoms from each other.³⁹ The detection limit for this method is 0.2 ppb.⁴⁰ This instrument is not applicable for use in the field because of its large size and sensitivity to transportation, and would not be practical for use in Nepal. ICP-MS requires electricity, but no refrigeration. This method can have other analytical interferences, including high levels of chloride (which form complexes with the argon carrier gas) which can be mistaken for arsenic because of its proximity in mass. There are safety issues associated with this method similar to those listed for ICP-AES. The exact cost of this instrument varies, but can generally be classified as beyond the resources of this study. The cost to run each test, after initial purchase of the instrument, is reported as \$10-\$15.³⁵

- **Graphite Furnace Atomic Absorption Spectrometry (GFAAS):**

This is also a USEPA approved method for measuring arsenic in drinking water.³⁵ GFAAS is a method that uses the principle that atoms will absorb light at characteristic wavelengths. The amount of light absorbed by an element at a certain wavelength can be linearly correlated to the concentration of the element.⁴¹ The GFAAS unit uses a graphite tube to linearly heat a sample to atomization and vaporization. The detection limit for this method is from 1-5 ppb.³⁵ This instrument is not applicable for use in the field because of its large size and sensitivity to transportation, and would not be practical for use in Nepal. GFAAS

³⁹ McMaster University, Faculty of Science, "Mass Spectrometry." 1999.

⁴⁰ West Coast Analytical Service, 1999.

⁴¹ Umeå University Research Group For Atomic Spectrometry, 1999.

requires electricity, but no refrigeration. This method can have other chemical interferences, which is partially remedied by the use of matrix modifiers. Safety issues associated with this method include exposure to intense magnetic fields and emissions. Handling standards necessary to calibrate the instrument is also a potential hazard. Although the initial cost of the instrument is well outside the resources of this study, a GFAAS unit is available for use in the Ralph M. Parsons Laboratory at MIT. The cost to run each test, after initial purchase of the instrument, is reported as \$15-\$50.³⁵

- **Stabilized Temperature Platform Graphite Furnace Atomic Absorption Spectrometry (STP-GFAAS):**

This is also a USEPA approved method for measuring arsenic in drinking water.³⁵ STP-GFAAS uses the same principles as described above for GFAAS. It, however, uses a transversely heated graphite atomizer as a background corrector.⁴² The detection limit for this method is 0.5 ppb.³⁵ This instrument is not applicable for use in the field because of its large size and sensitivity to transportation, and would not be practical for use in Nepal. STP-GFAAS requires electricity, but no refrigeration. Other chemical interactions associated with this method are similar to those for GFAAS, although use of a stabilized temperature platform and matrix modifiers help to eliminate these interferences. The safety issues associated with this method are similar to those listed for GFAAS. The exact cost of this instrument varies, but can generally be classified as beyond the resources of this study. The cost to run each test, after initial purchase of the instrument, is reported as \$15-\$50.³⁵

- **Gaseous Hydride Atomic Absorption (GHAA):**

This is also a USEPA approved method for measuring arsenic in drinking water.³⁵ GHAA uses the principles of atomic absorption to measure gaseous hydrides. Under certain conditions, arsenic forms a hydride that can be measured based on a characteristic wavelength. The detection limit for this method is 0.5 ppb.³⁵ This instrument is not applicable for use in the field because of its large size and sensitivity to transportation, and would not be practical for use in Nepal. GHAA requires electricity, but no refrigeration. This method has similar chemical interactions and safety issues to GFAAS. The exact cost of this

⁴² Subramanian, K. S., et al., 1997.

instrument varies, but can generally be classified as beyond the resources of this study. The cost to run each test, after initial purchase of the instrument, is reported as \$15-\$50.³⁵

- **Anodic Stripping Voltammetry (ASV):**

This is not a USEPA approved method for measuring arsenic in drinking water.³⁵ ASV uses principles of electrochemistry to separate metal ions in solution. A mercury electrode at a negative potential reduces metal ions in solution and the ions migrate to the electrode. The ions that have collected on the electrode are then reoxidized using a ramped potential, and a current signal is generated. This signal can then be used to calculate the concentration of the metal ions. The detection limit for this method is 0.5 ppb if a deposition time of 80s is used.⁴³ Traditional ASV instruments are not applicable for use in the field because of their large size and sensitivity to transportation, and these would not be practical instruments for use in Nepal. There is, however, a field deployable unit developed by Huiliang Huang and Purnendu K. Dasgupta of Texas Tech University. According to Huang and Dasgupta⁴³, the instrument is a relatively small, self-containing unit that requires a desktop computer for data recording. Both the traditional units and the field deployable instrument require electricity, although that required for the field instrument is less. Neither of the units requires refrigeration. ASV can have other chemical interactions with the following: copper, mercury, zinc and bismuth. Safety issues associated with this method include the use of high voltages and toxic metals. The exact cost of traditional ASV units vary, but can generally be classified as beyond the resources of this study. The field deployable instrument costs approximately \$6,000.⁴⁴

- **EM Quant® Test Strips:**

This is not a USEPA approved method for measuring arsenic in drinking water.³⁵ This method uses a simple reaction, called the Gutzeit reaction, to volatilize all aqueous arsenic in a sample to arsine gas. The arsine gas then leaves forms a complex which produces a stain on an indicator strip that can be interpreted as a concentration using a color chart. The detection limits for this instrument are 100 ppb. Concentrations below this limit are difficult

⁴³ Huang, Huiliang, and, Purnendu K. Dasgupta.

⁴⁴ Dasgupta, Purnendu K., 1999.

to read, and cannot be reported as anything but a range between 0 and 100 ppb. This method is extremely field applicable. It is light weight and easily transportable, and requires no electricity. The kit is required to be kept between 0°C and 25°C. Based on the average temperatures in Nepal during the month of January, this range of temperatures is possible to achieve without refrigeration. The EM Quant® test strips do have several other chemical interactions. EM Science reports in their product literature that interference of both anions and cations above certain levels are possible.⁴⁵ A summary of these interferences are listed in Table 4-2.

Table 4-2: Possible Chemical Interferences for EM Quant® Test Kits
(Interferences occur above the levels listed)⁴⁵

Anions:	Limit Value
Acetate, citrate, tartrate, ascorbic acid, oxalic acid, CO_3^{2-} , SO_4^{2-} , CN^- , I^- , Br^- , $\text{S}_2\text{O}_8^{2-}$, ClO_4^- , $\text{Cr}_2\text{O}_7^{2-}$, CrO_4^{2-} , OCN^- , EDTA	1000 mg/L
F^- , MnO_4^- , BrO_3^- , IO_3^-	500 mg/L
PO_4^{3-} , NO_2^- , NO_3^-	100 mg/L
SO_3^{2-} , ClO_3^-	25 mg/L
SCN^- , S^{2-} , $\text{S}_2\text{O}_3^{2-}$	1 mg/L
Cations:	
Be^{2+} , Pb^{2+} , B^{3+} , Cd^{2+} , Ca^{2+} , Cr^{3+} , Fe^{2+} , Fe^{3+} , K^+ , Li^+ , Mg^{2+} , Mn^{2+} , Mo^{6+} , Sr^{2+} , Ti^{4+} , U^{6+} , V^{5+} , W^{6+} , Zn^{2+} , Zr^{4+} , Na^+	1000 mg/L
Ba^{2+} , Rb^+ , Tl^+	500 mg/L
Al^{3+} , Ce^{3+} , Ga^{3+} , Th^{4+} , Sn^{2+}	100 mg/L
Ni^{2+}	25 mg/L
Co^{2+} , Hg^+ , Hg^{2+} , Bi^{3+}	5 mg/L
Sb^{3+} , Se^{4+}	1 mg/L
Pd^{6+} , Cu^{2+}	0.5 mg/L

There are significant safety issues associated with the use of these kits. The arsine gas that is produced during the Gutzeit reaction is itself a toxin, as discussed in Chapter 3. Hussam et al. determined that levels as high as 35 times the threshold limit value for arsine gas are generated in the work space around the reaction vessel from a single experiment with 100 ppb total arsenic in solution.⁴⁶ This is a significant disadvantage of this testing method. Safety issues also arise from the handling of the toxic reagents associated with the test strips,

⁴⁵ EM Science, 2000.

⁴⁶ Hussam, A., et al., 1999.

including concentrated hydrochloric acid. Each kit includes 100 tests and costs approximately \$75.

- **Affiniti Concentration Kits:**

This is not a USEPA approved method for measuring arsenic in drinking water.³⁵ This method is used in conjunction with EM Quant® test strips. These kits are resin tubes that use a reverse dilution method to achieve lower detection limits. These kits are applicable for use in the field, and their detection limit is 10 ppb. There is no electricity or refrigeration required for this process. Chemical interferences associated with this method are the same as for the EM Quant® test strips (see Table 4-2). Aside from the safety issues associated with the EM Quant® test strips described above, an additional explosive safety hazard exists with the use of the Affiniti resins upon contact with strong oxidizers. Cost for these resins is \$100 for a box of 20.

- **Arsenator 510:**

This is not a USEPA approved method for measuring arsenic in drinking water.³⁵ The Arsenator 510 is a field deployable instrument that uses the same Gutzeit method used by the EM Quant® test strips. The intensity of the stain produced by the reaction, however, is analyzed by a photodiode to achieve a more accurate measure of concentration.⁴⁷ The minimum detection limit for this instrument is 0.5 ppb for a 50 mL sample.⁴⁸ This is a field deployable instrument that would be practical for use in Nepal. It is easily transportable, and small in size. It performs within the ambient temperature ranges characteristic to Nepal in January. The unit operates on a rechargeable battery, so only electricity to recharge the battery is required.⁴² No refrigeration is required for this unit. The chemical interactions that may affect the accuracy of this method include those also found to adversely affect the EM Quant® test strips. The same safety issues of arsine gas generation and toxicity of reagents associated with the EM Quant® test strips also apply to the Arsenator. Cost for this unit is approximately \$3,000.⁴⁹

⁴⁷ Kosmos, Walter, 2000.

⁴⁸ Arsenator, 1999.

⁴⁹ “‘Arsenator’ can detect arsenic more efficiently, cheaply.” 1998.

From the data presented above and in Table 4-1, EM Quant® test kits, Affiniti Concentration kits and GFAAS were chosen for this study. Both the EM Quant® and Affiniti kits provided a cheap and easy field method for analyzing arsenic concentrations during the January 2000 field trip. The safety issues associated with these units were overcome by modifying the experimental setup and using safe handling practices. The fact that neither of the kits required electricity or refrigeration was also a big advantage. Analysis on GFAAS was performed on preserved samples that were brought back to the U.S. GFAAS was chosen because it was available for use in the Parsons Laboratory at MIT. The lower detection limit of this method was desired to achieve more precise results. The safety issues associated with this method were overcome by using safe laboratory practices. The principles and procedures associated with the three methods used are described in further detail in the next sections.

4.2 EM Quant® Test Strips

The primary testing method used on site in Nepal was EM Quant® test strips. Three kits, each capable of analyzing 100 samples, were transported to Nepal and used on site. Below is a detailed description of the theory behind the test method and of the exact procedure used in Nepal.

4.2.1 Theoretical Principles

EM Quant® test strips utilize simple chemical reactions to determine ranges of arsenic concentrations. The sample is mixed with two reagents, 32% hydrochloric acid and zinc powder, which subsequently react with arsenic in the sample to produce arsine gas (AsH_3). Both arsenite and arsenate are converted in the reaction vessel to arsine gas. The gas rises above the sample and passes over a paper impregnated with mercuric bromide held in the cap of the vessel. The arsine gas then reacts with the mercuric bromide to produce a yellow to brown colored stain based on the following reaction:



The intensity of the stain is an indicator of concentration, and can be read based on a color chart provided in the kit.

4.2.2 Description of Procedure Used

EM Quant® test strips were used for analysis of raw water samples in Nepal. On average, samples were analyzed no more than 12 hours after collection. Samples were collected in 250 or 500 mL high density polyethylene sample bottles with caps and were transported from the field site to a laboratory for analysis. The first step in the analysis was to insert the test strip in the slit in the cap of the reaction vessel, or Gutzeit tube. The strip was inserted with the impregnated mercuric bromide pad end facing down approximately midway on the strip. The clean Gutzeit tube was filled with 5 mL of raw water sample. The unfiltered sample was delivered using a pipettor. The Gutzeit tube was placed in a 100 mL beaker, which acted as a holder for the tube. For the case of the experiments performed in Nepal, time was a crucial factor. Therefore, more tubes than those supplied in the three kits were brought to Nepal. This allowed for multiple reactions to occur at one time. Special caps that fit these tubes were also brought, and slits were made in them using a knife so that the strips could be held above the sample in the reaction vessel. A diagram of the Gutzeit tube, cap and strip set-up is shown in Figure 4-1.

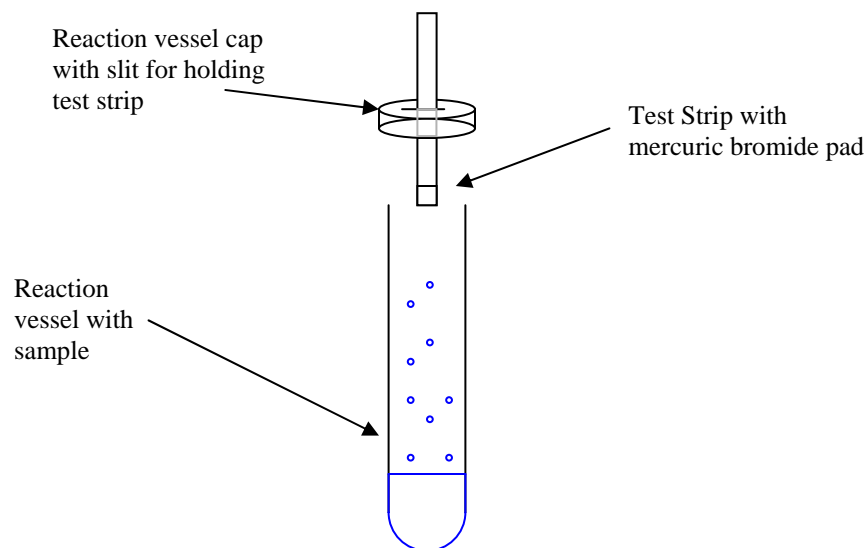


Figure 4-1: Experimental Set-up for EM Quant® Test Strips

Once the sample was delivered to the tube, the two reagents were added. First, a scoop-full of the zinc powder, or Reagent 1, was added to the sample. (The appropriate sized scoop was provided in the test kit package.) The sample was then swirled within the tube so that all powder on the sides of the tube was dissolved in the sample. Next, 32% hydrochloric acid (Reagent 2) was added to the sample. Instructions for the kit state that 5 drops, or 0.5mL, of the acid should be added. For ease, a pipettor was used to deliver the acid instead of the dropper provided. Immediately after adding the acid, the cap holding the test strip was placed on the tube, and the contents of the tube were gently swirled. Care was taken to make sure that the strip did not get wet. The reaction vessel was then set by an open window in front of a small fan blowing out. This was a safety measure used to guard against exposure of the researcher to arsine gas vapors. A digital clock was used to record the 30 minute reaction time. Once complete, the strip was removed from the cap and placed against the color chart provided in the kit. The result was recorded as a range of values in a laboratory notebook. These steps are summarized in Table 4-3. A picture of the EM Quant® field test kit is shown in Figure 4-2.

Table 4-3: Procedure for using EM Quant® Test Strips

1. Insert EM Quant® test strip with pad facing down into Gutzeit tube.
2. Place cap midway on strip.
3. Fill Gutzeit tube with 5mL raw water sample with pipettor.
4. Place Gutzeit tube upright in support stand.
5. Add one scoop of zinc powder to raw water in tube and mix well, covering all surfaces of the tube.
6. Add 0.5mL of acid to tube with pipettor.
7. Immediately place cap on tube.
8. Gently swirl mixture (do not get test strip wet).
9. Let react for 30 minutes. Place in well ventilated area, using a small fan when needed.
10. Record results.
11. Clean tube immediately with distilled water and dry.



Figure 4-2: Picture of EM Quant® Test Strip Kit

4.3 Affiniti Concentration Kits

Affiniti Concentration kits were used in most cases along with EM Quant® field test kits. The primary reason for this was the high detection limits and degree of uncertainty surrounding the EM Quant® test kits. The Affiniti kits, however, required a large amount of time and sample volume, so certain samples were not tested using these kits due to these constraints.

4.3.1 Theoretical Principles

Affiniti Concentration kits use a simple method of concentration in order to achieve lower detection limits. The sample is pushed through a resin in order to achieve a concentrated measure of arsenic levels. There are two types of Affiniti Concentration resins, as described below.

Stage I: These resins are shown to the right in Figure 4-3. They can be used to measure both arsenic species through subtraction. The resin in the tube binds any arsenate in the sample. The resin is a patented Per-fix material that is used to retain all arsenate as the sample is passed through it. The bound arsenate is removed by passing sodium chloride through the resin. This displaces the bound arsenate and the effluent can be collected for analysis using some other method. When measuring with EM Quant® test strips, the amount of arsenate will be 10 times that of the original sample if 50 mL are passed through the resin. This results in a detection limit of 10 ppb. Because the Stage I columns bind only arsenate, any arsenite in the sample will not be removed. The effluent from the Stage I columns can be analyzed to determine the amount of arsenite in the solution, and the total of the two species can be added to determine total arsenic in solution. This study did not focus on speciation, so Stage I resins were not used because of the greater reaction time required to determine total arsenic.

Stage II: These resins are shown to the left in Figure 4-3. They contain two media that are used to bind both arsenite and arsenate in the sample. The upper, dark-brown resin oxidizes arsenite to arsenate. The lower, tan resin is the same arsenate binding resin as in the Stage I columns. When a sample is passed through these columns, any arsenite

present is converted to arsenate in the first section. Then, all arsenate is bound to the second section. This results in both species of arsenic being removed from the sample as it is passed through the column. The arsenic species can then be displaced using sodium chloride and collected for analysis. When measuring with EM Quant® test strips, the amount of arsenate will be 10 times that of the original sample if 50 mL are passed through the resin. Again, this results in a detection limit of 10 ppb, as opposed to the 100 ppb limit for the EM Quant® test kits alone. Stage II columns were used in this study because of their efficient analysis of total arsenic concentrations.

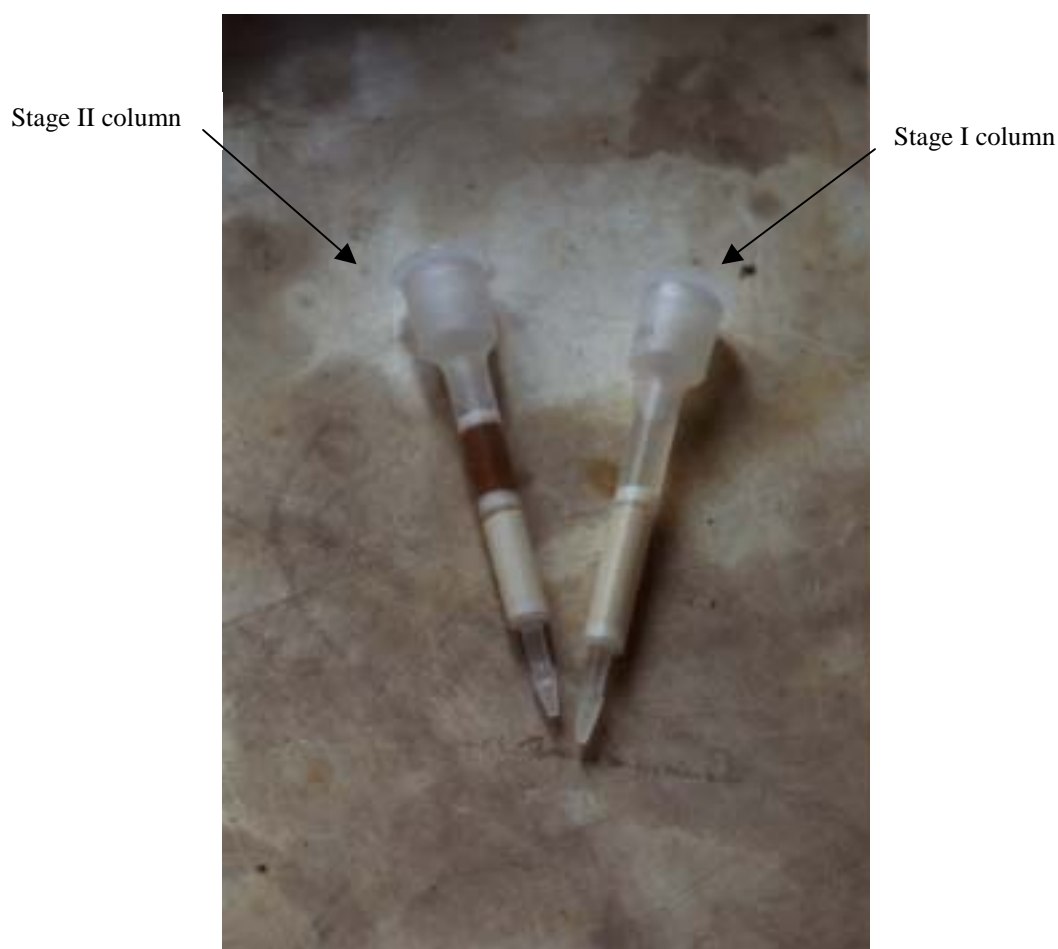


Figure 4-3: Picture of Affiniti Concentration Kit Resins

Both of the resins described above are reasonable for use in the field. The plastic columns are easily transported and give lower detection limits than the EM Quant® kits alone. Use of these resins, however, is time consuming, as can be seen in the following procedural discussion.

4.3.2 Description of Procedure Used

After analysis using EM Quant® test strips, a portion of sample was passed through a Stage II resin. The steps described below are also summarized in Table 4-4.

The first step in the process was to remove the cap from the sealed resin column and to cut and discard the bottom tip. Next, distilled water in the resin column was allowed to drain. The process was accelerated by using a 10 mL plastic syringe to deliver air through the column. The rate of fluid flow was no more than 3 drops per second, and the column was never allowed to run completely dry. The effluent was collected in a waste container and discarded. 50 mL of raw, unfiltered sample was then measured into a 100 mL plastic beaker. A 10 mL syringe was used to deliver the 50 mL sample through the column in five increments of 10 mL. The flow rate in the column was no more than 3 drops per second. The effluent was collected in a waste container and discarded.

Table 4-4: Procedure for Using Stage II Affiniti Concentration Kits

1. Remove the cap from the top of the concentrator mini-column.
2. Cut and remove the bottom tip portion of the column and discard.
3. Let distilled water drain into waste container. Accelerate process by pushing about 1mL of air through the column using a 10 mL syringe.
4. Measure 50 mL of raw water sample in a beaker.
5. Use a 10 mL syringe to deliver the sample in 5 increments of 10 mL at no more than 3 drops per second. Allow effluent to collect in waste container and discard.
6. Place Gutzeit tube under the column, and deliver 5 mL of 1M NaCl through the column at a rate of no more than 3 drops per second.
7. Run sample through EM Quant® test steps in Table 4-3.
8. Record amount by dividing what is found on the color chart by 10.

Once all 50 mL of raw sample were delivered through the column, the waste container below was removed. A clean Gutzeit tube was placed underneath the resin column. Another 10 mL syringe was used to deliver 5 mL of 1M sodium chloride through the column. The effluent was collected in the Gutzeit tube. The sample in the Gutzeit tube was then analyzed using the EM Quant® test strip procedure outlined in Table 4-3. A diagram of the Affiniti Concentration kit experimental set-up is provided in Figure 4-4.

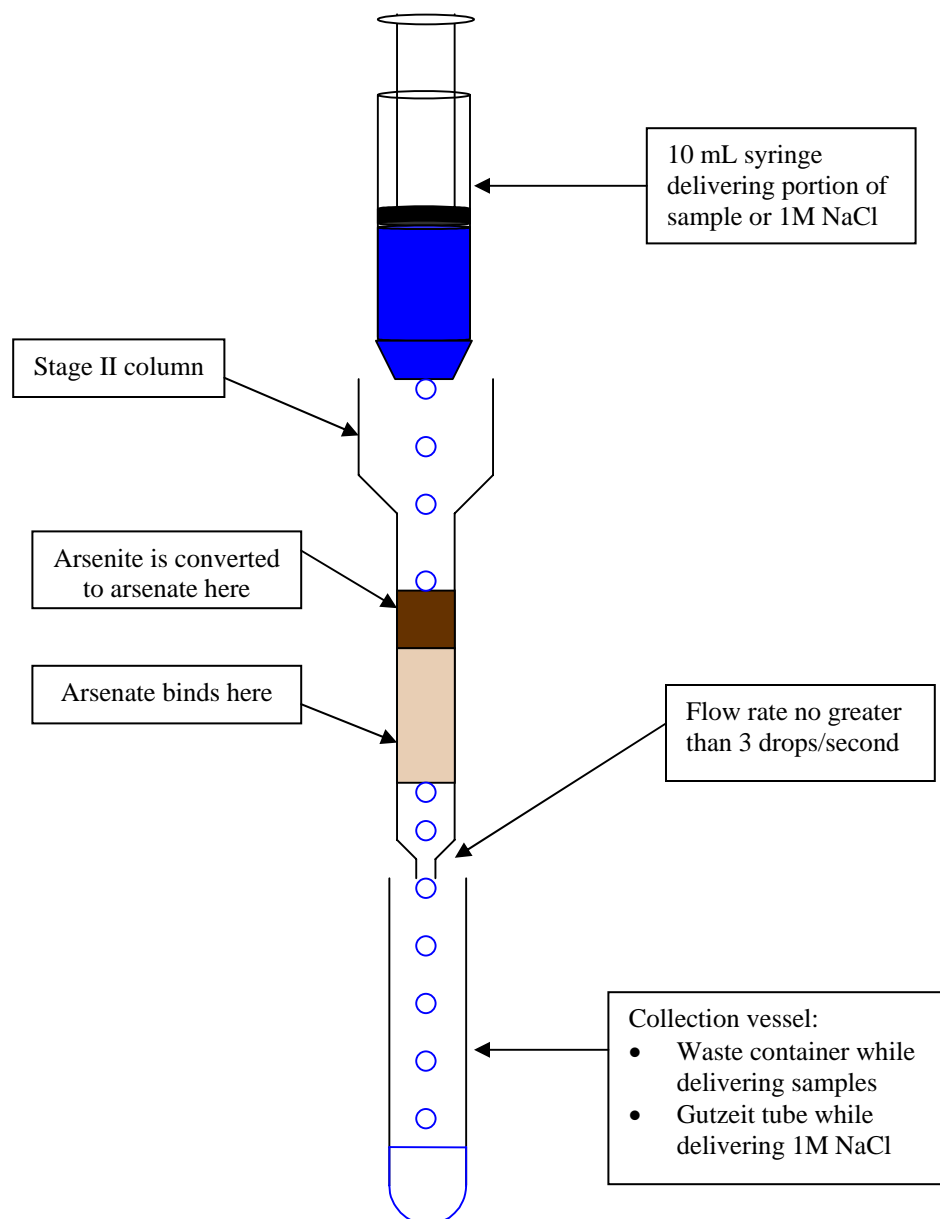


Figure 4-4: Experimental Set-up for Affiniti Concentration Kits

Upon completion of running one sample through the concentration kits, the resins were regenerated using a series of simple rinsing steps. These steps are outlined in Table 4-5. First, two bed volumes (approximately 6 mL) of distilled water were run through the columns at a rate of no more than 3 drops per second. Then, one bed volume (approximately 3 mL) of 1M sodium chloride was delivered through the column, followed by another bed volume of distilled water. Next, 2 bed volumes of white vinegar (purchased in a Nepalese grocery store) were delivered.

Finally, one bed volume of distilled water was run through the column and the space above the resin in the column was filled to the top with distilled water. The cap was placed back on the column, which was stored upright until the next use. In general, the resins were used approximately ten times before discarding. Indication of overuse was appearance of dark colors in the resins.

Table 4-5: Procedure for Regeneration of Used Affiniti Concentration Kits

- | |
|---|
| <ol style="list-style-type: none">1. Deliver two bed volumes of distilled water.2. Deliver one bed volume of 1M NaCl.3. Deliver one bed volume of distilled water.4. Deliver 2 bed volumes of white vinegar (white apple cider/acetic acid).5. Deliver one bed volume of distilled water.6. Run next test. |
|---|

4.4 Graphite Furnace Atomic Absorption Spectrometry

GFAAS was used to evaluate arsenic concentrations in samples that were brought back to the U.S. for analysis at MIT. This method was used because of its low detection limits and availability for use in the Parsons Laboratory at MIT. The procedure used was based on the existing practices of several researchers at the Parsons lab.

4.4.1 Theoretical Principles

The theory behind the GFAAS test method is more complicated than either of the field kits that were used. The GFAAS unit works by heating a small amount of sample at different time steps until the right temperature is reached to volatilize arsenic atoms in the sample. The concentration of the atoms is then determined based on their absorption at a wavelength characteristic to the element. For arsenic, this wavelength is 193.7 nm.

After the atoms are excited, an optical beam is passed through the head space above the sample and the absorption is analyzed. The instrument reports the absorption as a peak focused around the wavelength in question. The maximum peak area is recorded, and this is used to determine concentration. Because of the variances associated with the instrument, a standard calibration curve was developed for every ten samples analyzed to maintain accurate readings. The

calibration curves were then used to determine sample concentrations, as described further in Chapter 5.

4.4.2 Description of Procedure Used

Prior to any analysis using the GFAAS unit, samples in Nepal were preserved for transportation back to the U.S. This was needed to avoid any precipitation of iron hydroxides in the sample that might scavenge dissolved arsenic. Concentrated nitric acid (69% HNO_3) was brought to Nepal and used to preserve the samples. Small 10 mL sample tubes with caps were used for transportation. The samples were preserved to 1% acidification, resulting in the following amounts being added in the sample tubes:

Total Preserved Sample Size = 10 mL at 1% HNO_3 requires:

$$\text{Total acid} + \text{Total raw sample} = 10 \text{ mL} \quad (4.2)$$

$$69\% * \text{Total acid} = 1\% * 10\text{mL} \quad (4.3)$$

Therefore, total raw sample added = 9.855mL and total HNO_3 added = 0.145mL

The amounts outlined above were added to the tubes using pipettors. The tubes were capped, labeled and transported back to the U.S. at the end of the trip.

The preserved samples were analyzed in the Parsons lab using GFAAS. The steps discussed below are outlined in Table 4-6. First, the argon gas supply was turned on, along with the computer, printer and GFAAS unit. The software was set up for analysis using the correct program file and element parameters. The wavelength was set at 193.7 nm and the energy was approximately 52. If a new graphite furnace tube had been placed in the unit, it was properly lined up for correct insertion of samples into the tube.

Table 4-6: Procedure for GFAAS Testing

<ol style="list-style-type: none"> 1. Turn on Argon gas supply. 2. Turn on computer and printer. 3. Turn on GFAAS unit. 4. On computer, click on icon for GFAAS program. 5. After the software and machine have warmed up (two icons on screen become colored), click on the 'AUTO' icon. 6. Click on Element File. 7. Chose the file NK_AS_MM.GEL. 8. Check that all element parameters, including wavelength and energy, are correct. 9. Check that sampler is lined up correctly for insertion of sample directly into tube. 10. Give the data file a name so that the data will be saved as well as printed. 11. Place the two matrix modifiers in the following positions and enter ID information in ID/Weight Parameter Window: Position #74: MgNO₃ Position #75: Pd 12. Place standards in the following positions and enter ID information in ID/Weight Parameter Window: Position #41: Blank – 5% HNO₃ Position #42: 5 ppb As Position #43: 10 ppb As Position #44: 25 ppb As Position #45: 50 ppb As Position #46: 75 ppb As Position #47: 100 ppb As Position #48: 150 ppb As 13. Place samples in desired positions, excluding 1-10, and enter ID information in ID/Weight Parameter Window. 14. Analyze samples according to the following sequence: 1 set of standards 5 samples 1 10 ppb standard 5 samples Repeat 15. Change graphite tube when high background is observed (after approximately 300 analyses). 16. After analysis, shutdown equipment in reverse order as listed above.

Small sample vials were filled appropriately and placed on the automatic sampler. Two matrix modifiers were used in order to avoid interferences and to make appropriate background corrections. The two modifiers used, MgNO₃ and Pd, were placed in sample positions #74 and #75, respectively. A blank solution of 5% HNO₃ was placed in position #41. A series of

standards were placed in #42-48. The standard solutions had arsenic concentrations of 5 ppb, 10 ppb, 25 ppb, 50 ppb, 75 ppb, 100 ppb and 150 ppb. Finally, actual field samples from Nepal were placed in the remaining sample slots (excluding #1-10 because these are reserved as auto-calibration positions, which were not used in this analysis). Each position was labeled with an appropriate identification name so that the sample numbers assigned in Nepal were printed in the data output.

The sample sequence involved running a calibration curve with each standard, five samples, a 10ppb standard, and five more samples. This process was repeated for every ten samples, and 170 samples that were collected in Nepal were analyzed. The results were printed out and saved to a data file.

4.5 NIPSOM Field Test Kits

Although the author of this paper did not use NIPSOM field test kits, it is important to provide a brief overview of the procedure involved with them. Mr. Ram Mani Sharma of the DWSS used these test kits in several sampling programs in the Terai region of Nepal. The data he obtained prior to the MIT Nepal Water Project is presented as part of the results of this study. It is therefore important that the reader be aware of the experimental method used by Mr. Sharma in performing these tests. Mr. Thakur Pandit of the DWSS, who performed arsenic sampling and analysis along with MIT NEPAL Water Project members in Lumbini District, also used these kits.

4.5.1 Theoretical Principles

NIPSOM field test kits utilize the same theoretical principles as the EM Quant® field test strips. Four reagents are used in the following quantities:

0.1g potassium iodide

0.1g stannous chloride

0.5g zinc powder

4mL of 1:1 hydrochloric acid

Reagents are allowed to react with 15 mL of sample, and this results in the production of arsine gas. Total reaction time is 5 minutes. The arsine gas is allowed to react with an indicator paper impregnated with mercuric bromide. This produces a color stain whose intensity is a measure of concentration. The stain is compared with a color chart provided with the kit. The detectable concentration range for the NIPSOM field kit is reported as 0.02 - 0.7 mg/L, or 20 – 700 ppb.⁵⁰

4.5.2 Description of Procedure Used

NIPSOM field kit procedures are quite similar to those employed with the EM Quant® test kits. The sample is poured into the reaction vessel to a previously marked height (total sample size of 15 mL). A piece of impregnated paper is placed in the cap of the reaction vessel. Four reagents are added to the sample, and the vessel is sealed with the cap. After approximately 5 minutes, the paper is removed from the cap and any stain on the paper is compared with a color chart. Because the sample size is larger, the reaction takes less time to produce a color change than for the EM Quant® test strips. One main difference, however, is that the indicator paper is placed perpendicular to the flow of gas, where as it is parallel in the EM Quant® test strips.

⁵⁰ Sharma, Ram Mani, 2000.

Chapter 5 - Results

A large amount of data was obtained on the field trip to Nepal in January 2000. Specific details of the trip, including a listing of daily project activities, can be found in the Trip Report provided as Appendix A. This chapter presents the findings of this study, including data collected in Nepal or found in other literature. It also provides a detailed discussion of the results and a comparison of the performance of the analytical methods that were used.

The January 2000 field trip to Nepal was spent collecting samples and analyzing them both immediately and upon return to the U.S. Samples were typically collected in the morning, and analysis was performed in the afternoon and/or evening. The four main locations from which samples were collected included the Parsa, Bara and Lumbini Districts in the Terai, and the Kathmandu Valley. Each of these locations are starred on the map in Figure 5-1. Samples from the Bara District were obtained by an outside organization and were provided to the author for analysis in collaboration with their own testing efforts. The samples collected in the Kathmandu Valley by the author were analyzed in the NWSC Central Laboratory. Samples from the Parsa and Lumbini Districts were analyzed in those locations. A figure showing the approximate locations of sampling sites in the Kathmandu Valley is provided in Section 5.3. Exact sampling site locations were not available for the samples from the Parsa, Bara and Lumbini Districts.

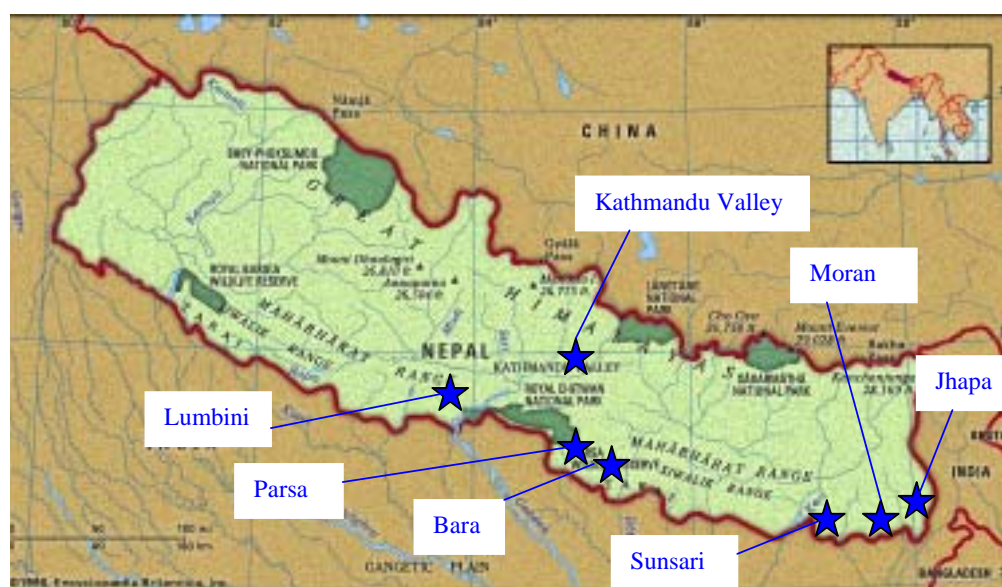


Figure 5-1: Locations of Sampling Areas⁵¹

⁵¹ Encyclopedia Britannica, Inc., 2000.

5.1 Analytical Results Obtained by the Author

The analytical results presented in this section are those that were obtained directly by the author during the January 2000 field trip. The next section provides data that was obtained by the DWSS in Nepal. This data is presented to provide further information as to the extent of arsenic contamination in Nepal. The data that was collected by this author is presented in three subsections corresponding to the three test methods that were used. Detailed tables of all of the data collected in Nepal, along with descriptions of each sample source, are provided in Appendix B.

5.1.1 EM Quant® Test Kit Results

All of the samples available during the field trip to Nepal were analyzed using EM Quant® test kits. The results of each of these tests were recorded as concentration ranges based on the color chart provided in the kit. The data is summarized in Table 5-1.

Table 5-1: EM Quant® Test Kit Results

Location	Total Number of Samples Analyzed	Number of Non-Detect samples	Number of Samples 0-100 ppb As
Parsa District	22	20	2
Bara District	83	83	0
Lumbini District	36	36	0
Kathmandu Valley	31	31	0

The results in Table 5-1 show that only 2 of the 172 samples (1%) analyzed with EM Quant® test kits had detectable levels of arsenic. Both of these samples were taken from tube wells. Sample number 14/01, taken at Inaruwa in the urban periphery of the city of Birganj, Parsa District, Ward 19, was estimated by villagers to be 250 feet deep and 4 years old. The well was a hand pump with a concrete pad that had a drainage ditch running immediately adjacent to it. 35 households were served by this well. The arsenic concentration, according to the EM Quant® test kit, was in the range of 0-100 ppb. Sample number 15/03, taken in the rural agricultural village of Bagahi outside of Birganj, Parsa District, Ward 6, was estimated by villagers to be 65 feet deep and 10 years old. This was also a hand pump well that served 7 households. The arsenic concentration in this well was also in the range of 0-100ppb. The remaining samples

analyzed in the field were all non-detect according to the EM Quant® test kits. Figure 5-2 shows the results of the EM Quant® test strips as a percentage of the total samples analyzed using this method.

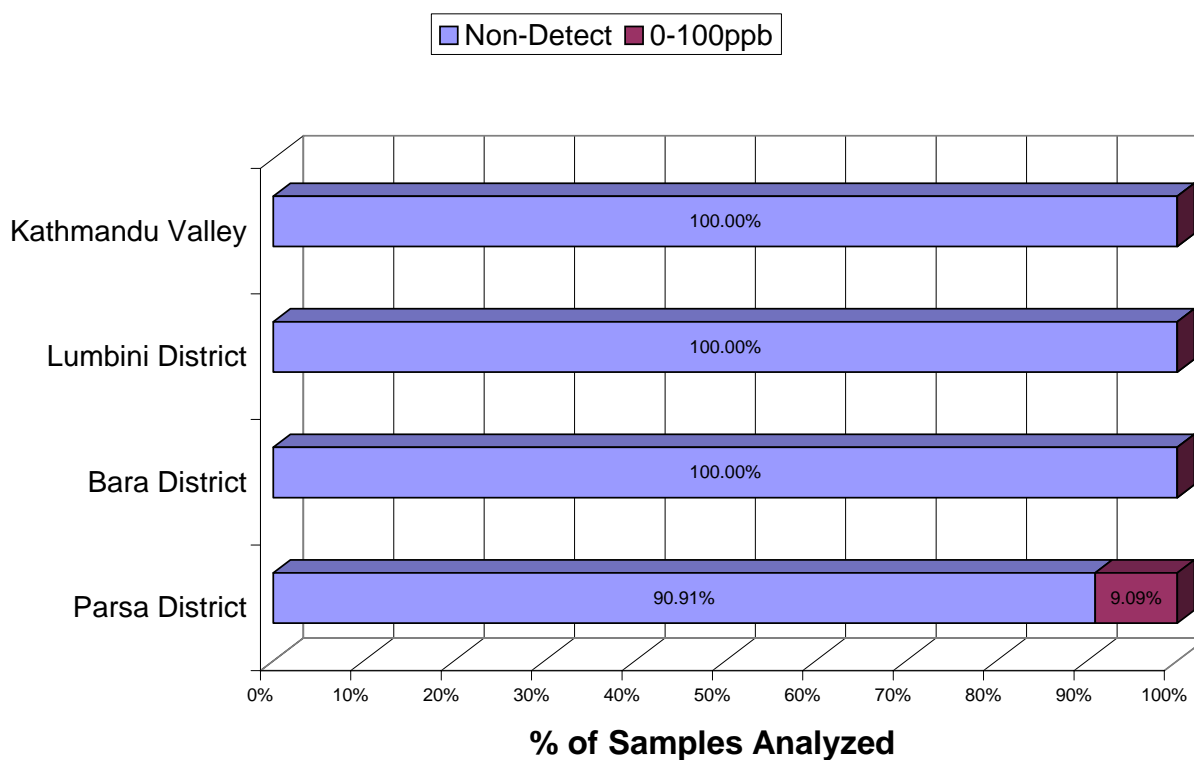


Figure 5-2: Em Quant® Test Strip Results

5.1.2 Affiniti Concentration Kit Results

A number of the samples collected were analyzed using Affiniti Concentration kit resins. Because of time constraints, all of the samples retrieved from Bara District and some of the Kathmandu Valley samples were not analyzed using the resins. Table 5-2 summarizes the results for those samples that were analyzed with the resins.

Table 5-2: Affiniti Concentration Kit Results

Location	Total Number of Samples Analyzed	Number of Non-Detect Samples	Number of Samples ND-10 ppb As	Number of Samples 10-50 ppb As	Number of Samples 50-100 ppb As
Parsa District	22	12	8	1	1
Lumbini District	36	34	2	0	0
Kathmandu Valley	25	16	9	0	0

The results in Table 5-2 show that 2 of the 83 samples (2%) analyzed using the Affiniti Concentration kits were shown to have levels above the WHO limit. This is in agreement with the EM Quant® test strip results shown in Table 5-1. The two samples found to have high values with the Affiniti Concentration kits were numbers 14/01 and 15/03, the same as for the EM Quant® test kit results. However, it should be noted that the number of non-detect samples decreased considerably after use of the concentration resins. This is a reflection of the lower detection limits achievable through use of these kits. Thirty-six percent of Kathmandu Valley samples, 5.5% of Lumbini District samples and 45.5% of Parsa District samples showed detectable concentrations of arsenic. The results obtained using the Affiniti Concentration kits in conjunction with EM Quant® test strips are shown in Figure 5-3.

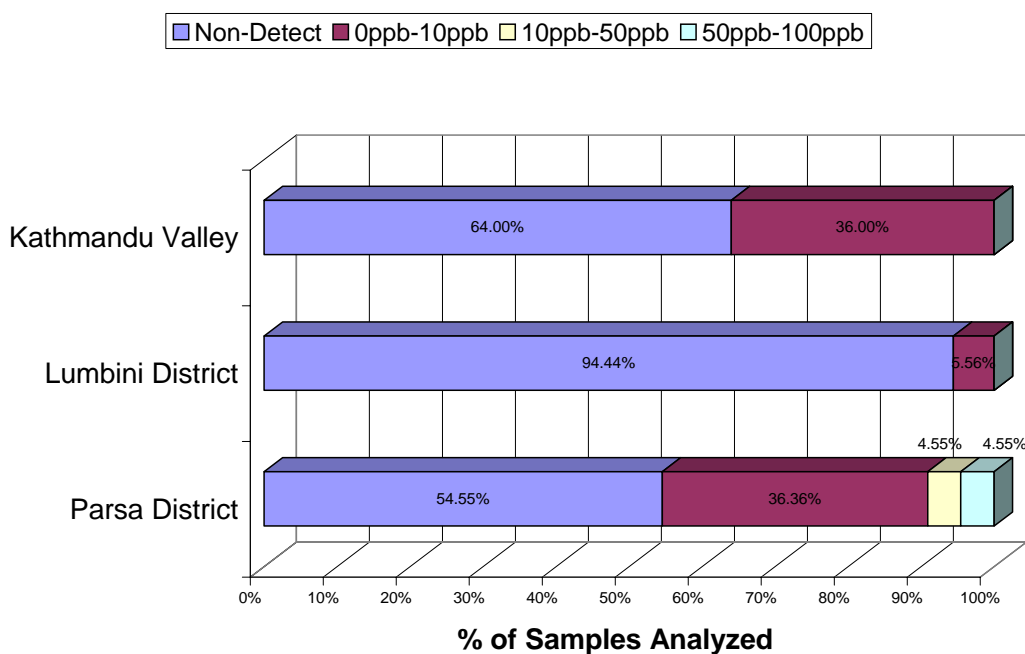


Figure 5-3: Affiniti Concentration Kit Results

5.1.3 Graphite Furnace Atomic Absorption Spectrometry Results

Almost all of the samples collected in Nepal were brought back for analysis using GFAAS. As described in Chapter 4, the samples were preserved using concentrated nitric acid. All of the samples were analyzed in the GFAAS unit located in the Parsons Laboratory at MIT. Table 5-3 summarizes the results for the samples analyzed using GFAAS.

Table 5-3: Graphite Furnace Atomic Absorption Results

Location	Total Samples Analyzed	No. of ND Samples	No. of Samples ND-10 ppb	No. of Samples 10-20 ppb	No. of Samples 20-50 ppb	No. of Samples 50-100 ppb	No. of Samples 100-150 ppb
Parsa District	22	13	2	4	1	1	1
Bara District	83	66	2	5	9	1	0
Lumbini District	34	31	0	3	0	0	0
Kathmandu Valley	31	30	1	0	0	0	0

The results presented in Table 5-3 were calculated based on calibration curves of standard solutions. Generally, a calibration curve was developed for every ten samples that were analyzed. The standards used were 5% HNO₃ (a blank), 5 ppb, 10 ppb, 25 ppb, 50 ppb, 75 ppb, 100 ppb, and 150 ppb. The peak absorption areas determined by the GFAAS unit were used to create a calibration curve. A linear regression was performed on each of the curves and the concentrations for each of the 10 samples were determined from this line. Calibration curves and GFAAS data are provided in Appendix B.

The results obtained using the GFAAS unit were quite different than those for the other methods used. 25 of the 139 samples (18%) from the Terai region were determined to have concentrations greater than the WHO limit. 13 of the 139 samples (9%) from the Terai region were determined to have concentrations greater than the US, Bangladesh, and India standards of 50 ppb. None of the 31 samples taken from the Kathmandu Valley had concentrations above the WHO limit. Figure 5-4 depicts the results for the GFAAS analysis.

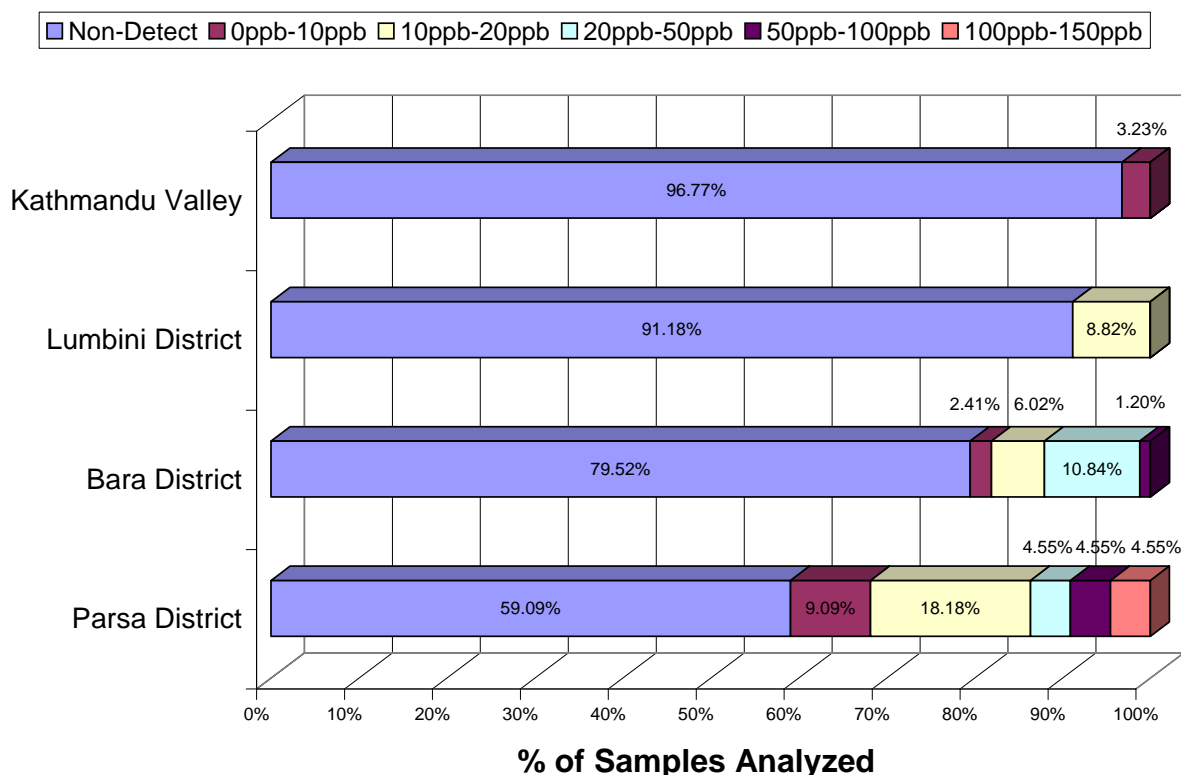


Figure 5-4: GFAAS Results

5.2 Analytical Results Obtained by DWSS

Prior to the January 2000 MIT Nepal Water Project field trip, arrangements were made with UNICEF-Nepal and DWSS to work in partnership to advance the collective knowledge and understanding of the issue of potential arsenic contamination of groundwater supplies in Nepal. Upon arrival, the MIT Nepal Water Project team met with members of UNICEF-Nepal and DWSS. During this meeting, more detailed information was learned about the initiative by both agencies to perform a survey of arsenic concentrations in several districts of the Terai region of Nepal. Mr. Ram Mani Sharma headed the sampling program initiated in September 1999 by DWSS. Over a period of three months, 268 samples were taken from the Terai Districts of Jhapa, Morang and Sunsari.⁵² (See Figure 5-1 for locations of these districts.) The samples were analyzed using NIPSOM field test kits. Table 5-4⁵² shows a summary of the findings of this program, as provided in a report written by Mr. Sharma.

⁵² Sharma, Ram Mani, 1999.

Table 5-4: Summary of Results of DWSS Arsenic Sampling Program

Location	Total No. of Samples Analyzed	Number of Samples in the range of non-detect to < 5ppb As	Number of Samples in the range of 5 ppb to 10 ppb As	Number of Samples in the range of 10 ppb to 50 ppb As	Number of Samples >50 ppb As
Jhapa	92	86	3	3	0
Morang	90	79	2	9	0
Sunsari	86	70	4	10	2

The results presented in Table 5-4 show that 24 of the 268 samples (9%) analyzed were determined to be above the WHO limit of 10ppb. Similarly, 2 of the 268 samples (1%) analyzed were above the Bangladesh, India and U.S. standard. Figure 5-5 depicts the results of the NIPSOM tests as a percentage of all the samples analyzed during the DWSS sampling program.

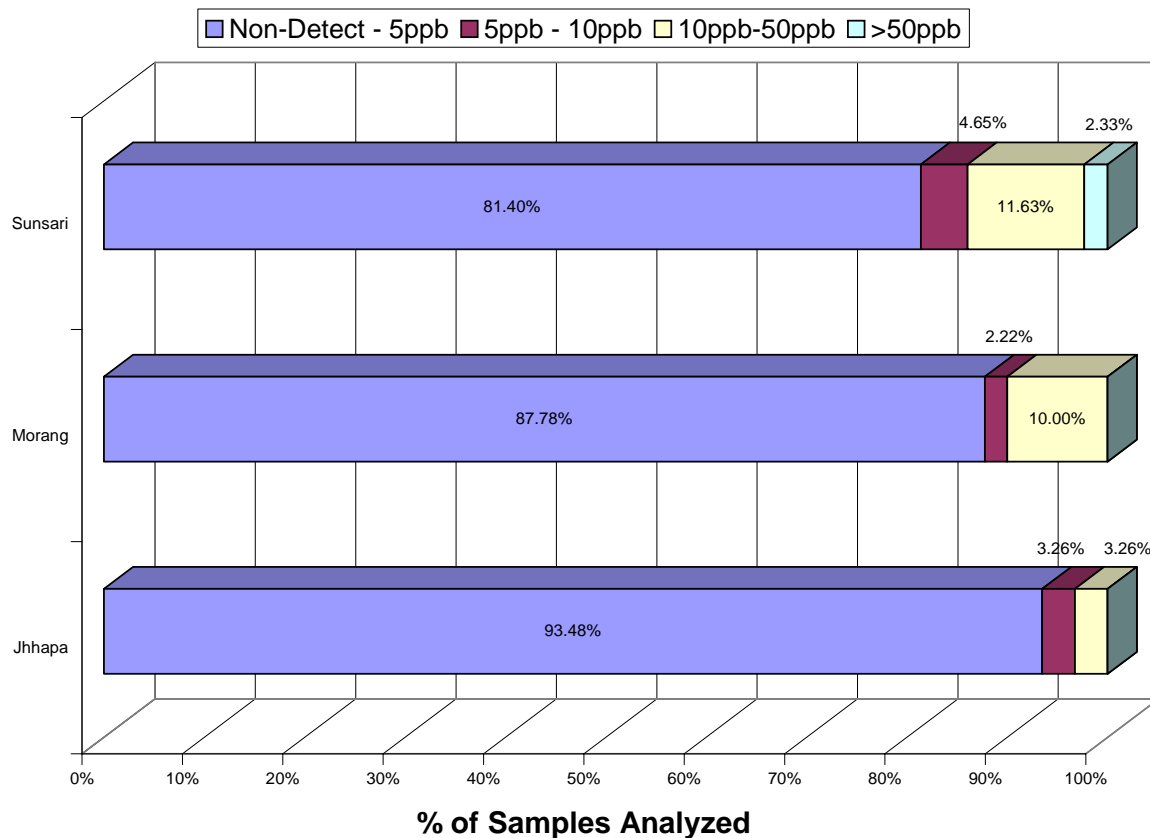


Figure 5-5: NIPSOM Test Results Obtained by DWSS

5.3 Discussion of Results

The results presented in Sections 5.1 and 5.2 help to draw preliminary conclusions about the state of arsenic contamination in Nepalese drinking water. It is obvious by the data collected, both by this author and other researchers, that arsenic contamination is present in select areas of Nepal. The contamination does not appear to be nearly as widespread in Nepal as in Bangladesh and India. Nevertheless, there is an issue of arsenic contamination in drinking water in some Terai Districts. A discussion of areas where it was found and reasons as to its existence is provided in this section.

Figures 5-2 to 5-5 indicate that arsenic contamination does exist in the Terai region. Combining the data provided by the author (using the GFAAS method because it is the most accurate) and the DWSS shows that approximately 12% of samples from the Terai region were above the WHO limit and 4% were above the Bangladesh, India, and U.S. standards. This data provides a limited picture of the extent of contamination in the Terai. Therefore, it is recommended that more sampling be completed in these and other districts of the Terai to further characterize the region.

Figure 5-6 shows the sampling locations in the Kathmandu Valley. Because global positioning instruments were not available, it is difficult to pinpoint the exact locations where sampling occurred, but the picture does provide a general idea of where the samples were collected. All of the samples in the figure had arsenic concentrations below the WHO limit. From this figure, it is clear that no arsenic contamination exists in the Kathmandu Valley.



Figure 5-6: Sampling Locations in the Kathmandu Valley

Figure 5-7 shows the sample frequency of detectable arsenic levels with respect to well depth for those samples collected by the author. Because not all source depths were known, only the data for which depth information was available is presented. The arsenic data that is presented was taken from the GFAAS results. Figure 5-7 shows a correlation with well depth and arsenic contamination. In general, of the wells tested, those found to contain arsenic were less than 300 feet deep. This is in accordance with the well depths associated with arsenic contamination in Bangladesh and India. As stated in Chapter 2, the geology of the Terai is such that a thick layer of alluvial deposits exists in the upper subsurface. Some of these alluvial deposits are from the same rivers that flow through the contaminated areas in Bangladesh and India. The deposits, therefore, could be from the same arsenic rich source as in these countries. Little specific information is available about the geology of Nepal. Further study on the geology in contaminated areas would help to better determine the source of the contamination.

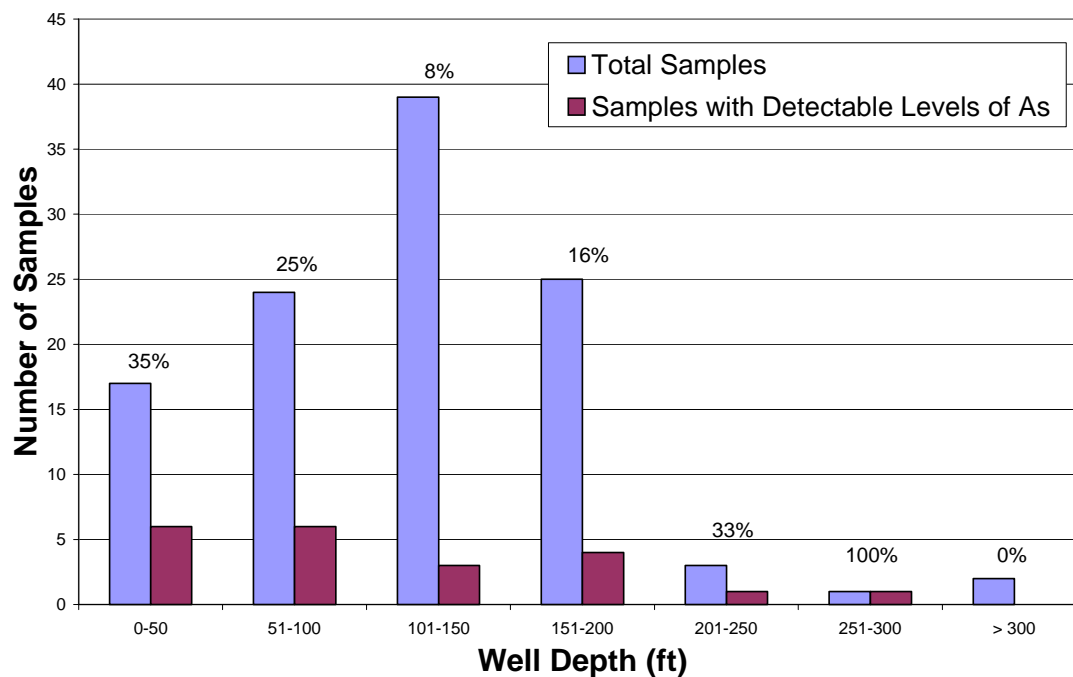


Figure 5-7: Sample Frequency by Well Depth

During the field trip to Nepal, information about well age was also collected when known and available. Figure 5-8 shows sample frequency with detectable levels of arsenic for different well ages. The plot indicates that no real trend about well age and contamination can be determined. It is interesting to note, however, that 48% of samples taken from wells aged 9 to 12 years had detectable levels of arsenic. An explanation for this may be that different well depths are associated with a given time period of well installation. Another explanation might be that changes in subsurface chemistry associated with drawdown of the water table due to long term well operation is causing arsenic in the soil to mobilize and subsequently enter the groundwater. Again, investigations into the geology of the region and the specific well installation procedures, along with a correlation between well depth and age, would help to further substantiate these theories.

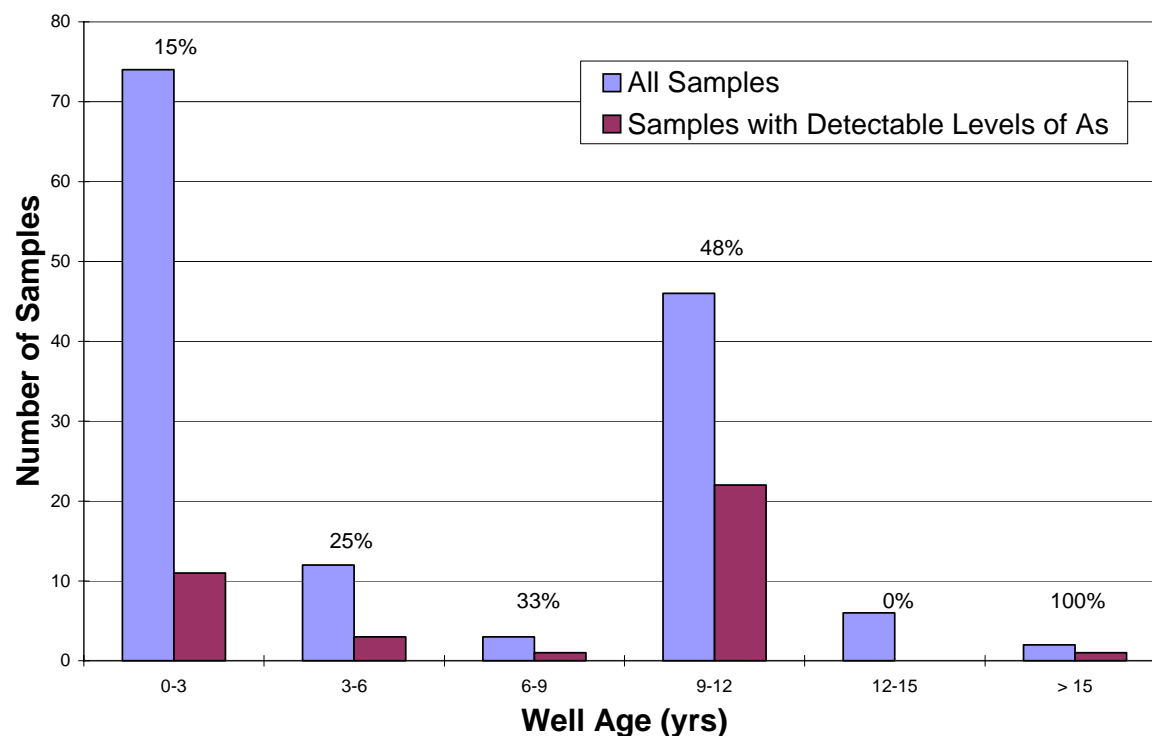


Figure 5-8: Sample Frequency by Well Age

Early investigations indicate that the arsenic contamination in the Terai region of Nepal is of natural origin. However, no formal analysis of possible anthropogenic sources has been made. Future study into the natural geology of the region, as well as human influences (such as use of pesticides and industrial practices) will provide the background information necessary to make a more accurate determination of the source of the contamination.

5.4 Comparison of Analytical Methods

The analytical methods that were used in this study have a wide range of advantages and disadvantages, as discussed in Chapter 4. Based on the analyses performed for this study, several practical recommendations can be made for the use of the three techniques.

EM Quant® test strips were easily used in the field. They were easy to transport, relatively inexpensive, and if enough reaction vessels were available, could be completed in a relatively short time. The results obtained by these kits, however, were relatively inaccurate. For example,

Figure 5-2 indicates that 100% of the samples taken from the Bara District were non-detect. This is in contrast to the 79.52% of these same samples found to be non-detect using GFAAS. The kits did show detectable readings for the two most highly contaminated samples in the Parsa District, however. EM Quant® test strips on their own provide an indication of only the most contaminated samples, and therefore should be used when the samples are expected to be highly contaminated, or when low level contamination results are not required.

Any program that requires more accurate measurements in the field should use EM Quant® test strips in conjunction with Affiniti Concentration kits. The Affiniti kits were relatively easy to use in the field, but added a significant amount of time to the analysis. They were easily transportable and followed a simple procedure. Use of the Affiniti kits showed more accurate results than when the EM Quant® strips were used on their own. Figure 5-3 indicates that more specific results were obtained in the Kathmandu Valley, Lumbini District and Parsa District when the Affiniti kits were used. Although the kits still give up some accuracy because of the detection limits of the EM Quant® kits, the overall combination of the two provided a fairly reliable indication of major contamination in a relatively cheap and easy field method.

The GFAAS unit was obviously the most accurate method. It was also, however, the most expensive and logistically difficult method. Samples had to be transported back to the U.S., and expensive equipment had to be purchased to analyze the samples. The analysis itself was not excessively time consuming, requiring approximately 25 hours of analysis time for 170 samples. The results shown in Figure 5-4, however, indicate a more accurate and detailed picture of contamination than do Figures 5-2 and 5-3. It is therefore ideal to use a method such as this when detailed and accurate results are desired and when the resources are available.

Chapter 6 - Conclusions and Recommendations

6.1 Study Conclusions

The results of this study indicate that no arsenic contamination of drinking water exists in the Kathmandu Valley. However, some contamination does exist in the Terai region of Nepal. Results from analysis by the author indicate that 18% of the samples taken from the Terai region were above the WHO limit of 10 ppb, and that 9% of the samples were above the Bangladesh, India, and U.S. limits of 50 ppb. When these results are combined with the DWSS results, 12% of samples were above the WHO guideline, and 4% were above the Bangladesh, India and U.S. standards.

An analysis of the samples for which well depth was available indicates that detectable levels of arsenic were found in wells up to 300 feet deep. The soils associated with these depths are generally classified as alluvial deposits in the Terai region. These deposits are similar in composition to the vast alluvial deposits that make up the subsurface in Bangladesh and West Bengal. The river systems that flow through this region generally originate in the Himalayan Mountain range, flow through Nepal and Bangladesh, and empty into the Bay of Bengal. The similar depths of contamination, geology of the subsurface, and hydrology of Nepal and Bangladesh suggest that the arsenic may be coming from the same natural source.

An analysis of the samples for which well age was available indicates that no real trend of contamination and well age exists. However, 48% of the samples taken from wells aged 9-12 years had detectable levels of arsenic. This may indicate that time related drawdown is changing the subsurface chemistry, which in turn is promoting conversion to mobile arsenic species.

A comparison of the analytical methods used indicates that the field kits provide a general indication of areas with high concentrations. For low level arsenic contamination, however, more accurate methods are required for a reliable determination of concentrations. If a field kit is required, use of EM Quant® test strips in conjunction with Affiniti Concentration kits will provide an easy, adequate picture of the general trend in arsenic contamination. These kits,

however, should be used in conjunction with a more accurate laboratory method when detailed analysis is desired.

6.2 Recommendations

Based on this study, several recommendations can be made for future testing in Nepal. Because of the limited amount of arsenic data in the Terai region, it is recommended that more extensive sampling and analysis of this region be performed in order to further characterize the area. Similarly, because limited information about the geology of the region exists, further study to characterize the subsurface in areas with detectable levels of arsenic will help to determine the source. Also, a study of possible anthropogenic sources of arsenic, such as industry and farming practices, will help to determine if any arsenic is present as a result of human influences.

Should a sampling program be initiated in Nepal, or any other location, field kit measurements should only be regarded as general indications of areas of mass contamination. Specific results should also be obtained using more accurate methods if a detailed delineation of contamination is to be made.

References

40 CFR 141.11

Arsenator. "Arsenator 510." Internet. November 11, 1999. Available:
www.arsenator.com/ars510_data.htm.

"'Arsenator' can detect arsenic more efficiently, cheaply." The Daily Star December 21, 1998.

Blumba, D.K. and R.F. Keefer. "Arsenic Mobilization and Bioavailability in Soils." Ed. J.O. Nriagu, Arsenic in the Environment. Part I: Cycling and Characterization. New York: John Wiley & Sons, Inc. 26 (1994).

Central Intelligence Agency. "The World Factbook 1999 – Nepal." Internet. Available:
www.odci.gov/cia/publications/factbook/np.html.

Dainichi Consultant. April 2000. Japan.

Dasgupta, Purnendu K. Personal Communication. November 13, 1999.

Dipankar Chakraborti. "Arsenic Orphans." Internet. March 8, 2000. Available:
education.vsnl.com/soesjucal/asorphan.html.

Eco-USA. "Arsenic." Internet. March 10, 2000. Available: www.eco-usa.net/toxics/arsenic.html.

EM Science. "10026 EM Quant® Arsenic Test." Internet. March 16, 2000. Available:
www.emscience.com/literature/index.asp.

Encyclopedia Britannica, Inc. "Nepal." Internet. April 25, 2000. Available:
www.britannica.com/bcom/eb/article/0/0,5716,115625+1+108755,00.html.

Ferguson, John F., and Jerome Gavis. "A Review of the Arsenic Cycle in Natural Waters." Water Research 6 (1972): 1259-1274.

Harvard University. "Arsenic Project." Internet. November 17, 1999. Available:
www.phys4.harvard.edu/~wilson/arsenic_frames.html.

Harvard University. "Bangladesh." Internet. April 23, 2000. Available:
phys4.harvard.edu/~wilson/bangladesh_map12.gif.

Huang, Huiliang, and, Purnendu K. Dasgupta. "A Field-Deployable Instrument for the Measurement and Speciation of Arsenic in Potable Water."

Hussam, A., et al. "Evaluation of Arsine Generation in Arsenic Field Kit." Environmental Science & Technology 33 (1999): 3686-3688.

- Korte, N.E. and Q. Fernando. "A Review of Arsenic (III) in Groundwater." Critical Reviews in Environmental Control. 21 (1991): 1-39.
- Kosmos, Walter. "The evaluation of the arsenator." Internet. April 23, 2000. Available: www.bicn.com/acic/infobank/dch98-12conf/paper2-3.htm.
- Massachusetts Institute of Technology. "Chemical Safety Data." Internet. March 8, 2000. Available: www-mtl.mit.edu/CAFÉ/sop/chemical-notes.html.
- McMaster University, Faculty of Science. "Atomic Emission Spectroscopy." Internet. November 13, 1999. Available: www.science.mcmaster.ca/Biology/4S03/c_tBii.htm.
- McMaster University, Faculty of Science. "Inductively-Coupled Plasma Atomic Emission Spectroscopy." Internet. November 13, 1999. Available: www.science.mcmaster.ca/Biology/4S03/c_tBvi.htm.
- McMaster University, Faculty of Science. "Mass Spectrometry." Internet. November 13, 1999. Available: www.science.mcmaster.ca/Biology/4S03/c_tBvii.htm.
- Murcott, Susan. "Women and Water." Peacework. March, 1999.
- Nepal.com. "Facts: Land and Climate." Internet. April 28, 2000. Available: www.nepal.com/facts/land.html.
- Occupational Safety & Health Administration. "Inorganic Arsenic." Internet. March 8, 2000. Available: www.osha-slc.gov/OshStd_data/1910_1018.html.
- Peters, Stephen C., et al. "Arsenic Occurrence in New Hampshire Drinking Water." Environmental Science & Technology 33 (1999): 1328-1333.
- Saha, J.C., et al. "A Review of Arsenic Poisoning and Its Effects on Human Health." Critical Reviews in Environmental Science and Technology 29 (1999): 281-313.
- Shakya, Roshana, and Suman Prasad Sharma. "Drinking Water Quality Surveillance Program in Nepal." WHO/SEARO Regional Consultation on Planning and Developing Drinking Water Quality Surveillance Program. September 1996.
- Sharma, Chandra K. Geology of Nepal. Delhi: Educational Enterprises Ltd., 1977.
- Sharma, Ram Mani. Personal Communication. April 17, 2000.
- Sharma, Ram Mani. "Research Study on Possible Contamination of Groundwater with Arsenic in Jhapa, Morang, and Sunsari Districts of Eastern Terai of Nepal Draft Report." December 1999.

- Stanley, Rachel. "Chemical Reactions of Inorganic Arsenic in Soil, Sediments, and Water." Massachusetts Institute of Technology. April 8, 1998.
- Subramanian, K. S., et al. "Antimony in Drinking Water, Red Blood Cells, and Serum: Development of Analytical Methodology Using Transversely Heated Graphite Furnace Atomization-Atomic Absorption Spectrometry." Environmental Contamination and Technology 32 (1997): 431-436.
- Travel-Nepal.com. "Nepal Map." Internet. April 28, 2000. Available: www.travel-nepal.com/images/maps/map-nepal.gif
- Total Environment Centre. "Toxins in Your Environment." Internet. November 17, 1999. Available: nccnsw.org.au/member/tec/projects/tyce/tox/Arsenic.html.
- Umeå University Research Group For Atomic Spectrometry. "Graphite Furnace Atomic Absorption Spectrometry." Internet. November 13, 1999. Available: 130.239.34.200/aas/Gfaas.htm.
- United Nations Childrens Fund. "Nepal." Internet. April 27, 2000. Available: www.unicef.org/statis/Country_1Page123.html.
- United Nations Development Programme. "Nepal Human Development Report." Internet. March 3, 2000. Available: www.undp.org.np/keydoc/nhdr98/summary.html.
- United Nations Development Programme. "United Nations Development Programme tests water in 500 Bangladeshi villages for arsenic." Internet. November 3, 1999. Available: www.undp.org/dpa/frontpagearchive/june99/9june99/secondpage.htm.
- U.S. Agency for International Development. "USAID Assistance for Nepal." Internet. April 21, 2000. Available: www.info.usaid.gov/country/ANE/nepal.html.
- U.S. Environmental Protection Agency. "Arsenic and Compounds." Internet. March 8, 2000. Available: www.epa.gov/ttnuatw1/hlthef/arsenic.html.
- U.S. Environmental Protection Agency. "Arsenic in Drinking Water: Analytical Methods." Internet. November 9, 1999. Available: www.epa.gov/OGWDW/ars/ars7.html.
- U.S. Environmental Protection Agency. "Drinking Water Priority Rulemaking: Arsenic." Internet. April 23, 2000. Available: www.epa.gov/OGWDW/ars/arsenic.html.
- U.S. Environmental Protection Agency, Region 9 Laboratory. "Standard Operating Procedure 505." Internet. April 23, 2000. Available: www.epa.gov/region09/lab/sop/505.pdf.
- Water Resources Institute. "Nepal at a Glance." Internet. April 21, 2000. Available: www.wri.org/facts/cs-pdf/nepal.pdf.

- WebElements. "The Periodic Table on the WWW." Internet. November 17, 1999. Available: www.webelements.com/webelements/elements/text/key/As.html.
- West Bengal & Bangladesh Arsenic Crisis Information Centre. "Arsenic Special Issue, BCAS Newsletter." Internet. December 2, 1999. Available: www.bicn.com/acic/infobank/asi_bcas.htm.
- West Coast Analytical Service. "Arsenic Analysis and Speciation." Internet. November 11, 1999. Available: www.wcaslab.com/tech/arsenic.htm.
- Wolfe, Andrea N. C.. "Microbial Contamination of the Kathmandu Valley Drinking Water Supply and Bagmati River." MIT Master of Engineering Thesis. May 5, 2000.
- World Health Organization. "Arsenic In Drinking Water." Internet. March 7, 2000. Available: www.who.int/inf-fs/en/fact210.html.
- World Health Organization. "Arsenic in Drinking Water and Resulting Arsenic Toxicity in India and Bangladesh: Recommendations for Action." Internet. March 8, 2000. Available: bicn.com/acic/infobank/whoarec.htm.
- World Health Organization. "GLOBOCAN1." Internet. March 7, 2000. Available: WWW-DEP.IARC.FR/dataava/globocan/globoJava.htm.

Appendix A - Trip Report

Project: Nepal Water Project, Arsenic Contamination Study

Traveler: Patricia Halsey

Trip Dates: 1/5/00 – 1/30/00

Destination: Nepal

Itinerary:

1/5/00 – Left Boston for Kathmandu, Nepal.

1/8/00 – 1/12/00– Arrive in Kathmandu. Gather lab equipment and purchase supplies. Sightsee.

1/11/00 – Myself and five other students met with members of the Nepal Department of Water Supply Sanitation and Sewerage (DWSS), the Melamchi Water Supply Project, and UNICEF-Nepal. Below is a list of attendees:

<u>Name</u>	<u>Organization</u>
Mr. Hans Sprujit	UNICEF-Nepal
Mr. Ram Mani Sharma	DWSS
Mr. Namaste	UNICEF-Nepal
Ms. Magala Karanjit	Melamchi Water Supply Project
Mr. Amer Khayyat	MIT
Ms. Junko Sagara	MIT
Ms. Kim Luu	MIT
Mr. Andrew Bittner	MIT
Ms. Andrea Wolfe	MIT
Ms. Patricia Halsey	MIT

The purpose of the meeting was to introduce the student group from MIT to our host organizations and to discuss our intended work with them. During the meeting, each student provided an overview of their project and their intended work in Nepal. Mr. Sprujit explained the role of UNICEF-Nepal in the project, and offered advice on student work. During the meeting, the logistics of several events were planned, including a trip to a rural village in Kavre, a trip to the Parsa District for water quality sampling, and a trip to Nargarkot for a training workshop. Mr. Sharma provided an overview of the arsenic testing that he had overseen for the previous three months in three Terai districts.

In the evening of January 11, Andrew, Andrea and myself met with Mr. Sharma to further develop our work plan for the trip to Parsa district. Each of the students outlined to Mr. Sharma exactly what parameters they would be testing, what analytical methods were to be used, and what type of samples were to be targeted. The logistics of sample location were decided, and a plan to focus on three different sampling areas was developed. Samples were to be taken from an urban area, a rural agricultural area, and a rural industrial area.

1/13/00 – Mr. Sharma, Andrew, Andrea and myself traveled to Parsa district by car. Most of the morning was spent traveling, and we arrived in the city of Birganj in mid-afternoon. We

immediately stopped at the local DWSS office to obtain some information on water quality issues in the area and potential sampling sites. We were able to obtain a map of the Parsa district, and made arrangements to travel with a member of the local DWSS office while we were sampling. We then checked into our hotel and settled in for the night.

1/14/00 – We spent the morning taking samples around the urban periphery of the city of Birganj. We returned to the hotel for lunch, and then continued sampling until mid-afternoon. A total of 12 samples were taken that day. We returned to our hotel room and analyzed the samples we had collected. I conducted tests using both Merck field test kits and Affiniti Concentration kits. Because these kits take some time, the rest of the evening was spent analyzing the samples. A small amount of each sample was also preserved and placed in containers to be transported back to the U.S. for analysis at MIT.

1/15/00 – We spent the morning taking samples from some rural agricultural areas outside of the city of Birganj. In the afternoon, we traveled to some rural areas located near industrial sites. After sampling was complete, we traveled back to the hotel and completed analysis of the samples in our hotel rooms that night.

1/16/00 – We returned to the Kathmandu valley by car. The trip took approximately 10 hours, with stops for traffic jams and livestock traffic. Upon returning to the valley, we checked into the Royal Nepal Administrative Staff College in Patan.

1/17/00 – After a morning meeting with the student group, Andrew and myself traveled to various locations to obtain information and generate a sampling plan for the rest of our time in Nepal. We purchased maps of the area and made preparations to sample for the remaining two weeks. We meet with a representative from UNICEF-Nepal to get suggestions on sampling locations in the Kathmandu Valley. We also made arrangements with Mr. Sharma to collect samples in Bhaktapur the following day.

1/18/00 – Mr. Sharma, Andrew and myself hired a taxi to take us to various sampling locations outside of Bhaktapur. Some samples were taken from a water collection, settling and distribution system. Others were taken from a different water collection system. A total of four samples were taken. The afternoon was spent analyzing the samples at the Nepal Water Supply Corporation's (NWSC) central lab.

1/19/00 – Andrew and myself traveled to Thimi, a small town outside of Kathmandu. We retrieved several drinking water samples, including some from a gas station, two restaurants, a household and a health center. A total of 5 samples were taken in Thimi. In the afternoon, the samples were analyzed at the NWSC central lab. We also analyzed the central lab's tap water, making the total number of samples 6 for that day.

1/20/00 – Andrew and myself sampled from various water spouts in Patan and Kathmandu upon the recommendations of UNICEF-Nepal. The samples were taken from traditional water spouts and from a restaurant and hotel. The samples were analyzed at the NWSC central lab later that afternoon.

1/21/00 – The student group from MIT traveled to Nargarkot with Mr. Hans Sprujit of UNICEF-Nepal for a training workshop. During the workshop, I gave a 30 minute talk on the testing methods that I was using and the preliminary results of my tests. I explained the process used for the Merck field test kits and gave a demonstration on their use. The other students gave similar presentations on their respective studies. The workshop went through the afternoon, and the evening was spent at a cultural event organized by some of our hosts.

1/22/00 – In the morning, most of the group traveled to see the sunrise in Nargarkot. We then met with the workshop attendees and toured the training facility's new lab. During the meeting Andrew and I made arrangements with Mr. Thakur of the DWSS to do some sampling with him the following day. Our student group then traveled back to Patan.

1/23/00 – Mr. Thakur, Andrew and myself traveled to Naikap and Sitapaila in the Kathmandu valley. We sampled from various points along a water treatment system and at a stream surface water source. A total of 7 samples were taken. The samples were then returned to the central lab and analyzed that afternoon.

1/24/00 – Andrew and myself traveled to various sampling points in Kathmandu upon the suggestion of UNICEF-Nepal. Samples were taken from a restaurant near the Royal Palace, from the public water spout at Sundhara, and from a restaurant near Sundhara. The three samples were then returned to the central lab and analyzed that afternoon.

1/25/00 – Andrew and myself traveled to various sampling points in Kathmandu upon the suggestion of UNICEF-Nepal. Samples were taken from some traditional water sources in the Kathmandu Durbar Square area. The three samples were returned to the central lab and analyzed that afternoon. Three samples obtained from a treatment plant by Andrea Wolfe were also analyzed using the Merck field test kits.

1/26/00 – Andrew and myself spent the morning collecting samples from Mitrapark in the Kathmandu Valley. I did not analyze these samples, but I helped Andrew collect them. In the afternoon I met with Mr. Sakae Yamada from the Japanese Red Cross and representatives from ENPHO. I analyzed 84 samples that the Red Cross had taken from the Terai region, along with one standard. The analysis was performed at the ENPHO lab in Kathmandu.

1/27/00 – In the morning, several members of our group met with the director of the Nepal Water Supply Corporation. We presented him with our preliminary results and thanked him for the use of his lab. Then the group received a briefing on the Melamchi Water Supply Project. The afternoon was spent packing up supplies at the central lab. We cleaned up the space we had been using and packed up for the trip home.

1/28/00 – Our final day in Nepal was spent sight seeing and taking care of last minute details.

1/29/00 – We left Kathmandu.

1/30/00 – Arrived back in Boston.

Appendix B – Data Tables and Calibration Curves

Table B-1: Sample Descriptions

Sample Number:	Date:	Time of Sample:	Location of Well/Water Source:	Water Source / Well Type:	Depth of Well (ft):	Age of Well (yrs):	Number of Households Served:	Comments:
14/01	Jan. 14, 2000	8:40 AM	Inaruwa, Ward 19, Birganj Periphery	STW	250	4	35	Drainage ditch flows under well; Cows, chickens, goats grazing nearby
14/02	Jan. 14, 2000	9:15 AM	Naguwa, Ward 19, Birganj Periphery	STW	200	10	10	Pond across from street used for washing clothes; Sonde results of pond water: Temp. 17.4 C, NO ₃ ⁻ 0.44 mg/L, NH ₄ ⁺ 1.06 mg/L, Turb. 2.2 NTU, DO 5.68 mg/L
14/03	Jan. 14, 2000	9:45 AM	Bisuwwa, Ward 18, Birganj Periphery	STW	135	1	5-6	No well pad - just bricks; Possibly leaky
14/04	Jan. 14, 2000	10:00 AM	Badeihi, Ward 18, Birganj Periphery	STW	160	3	16	
14/05	Jan. 14, 2000	10:35 AM	Elachhmania, Ward 18, Birganj Periphery	HD	24	>50	15	Not used for drinking except during emergencies; 5-6 foot diameter, STWs in area are shallow (20-30 ft) - water comes from same aquifer as this HD well
14/06	Jan. 14, 2000	10:35 AM	Elachhmania, Ward 18, Birganj Periphery	STW	60	15	1	Private Well; Older man with skin problems typical of Arsenicosis - dark black spots on hands and legs
14/07	Jan. 14, 2000	11:05 AM	Pipara, Ward 17, Birganj Periphery	STW	160	1	5	
14/08	Jan. 14, 2000	11:25 AM	Bahuari, Ward 17, Birganj Periphery	STW	140	5	15	Not a good seal for tube - possibly leaky
14/09	Jan. 14, 2000	1:45 PM	Bazaar Zhapakaiya, Ward 1, Birganj Periphery	STW	260	>10	26	Possible adverse health effects typical of Arsenicosis found on two men; Flooded well pad with stagnant water
14/10	Jan. 14, 2000	2:30 PM	Near India Customs, Ward 2, Birganj Periphery	STW	160	1	>20	Near large stagnant pond
14/11	Jan. 14, 2000	2:45 PM	Ghadi Arwa, Ward 12, Birganj City Center	STW	160	10	20	
14/12	Jan. 14, 2000	3:10 PM	Resan Kothi, Ward 7, Birganj City Center	STW	200	10	20	

Sample Number:	Date:	Time of Sample:	Location of Well/Water Source:	Water Source / Well Type:	Depth of Well (ft):	Age of Well (yrs):	Number of Households Served:	Comments:
15/01	Jan. 15, 2000	9:15 AM	Bagahi Village, Ward 2, Village outside Birganj	STW	250	5	Public well near school; used mostly by children	Rural site; Bagahi Village is agricultural; Population is 3,000 - 4,000, 9 or 10 wells total
15/02	Jan. 15, 2000	9:35 AM	Bagahi Village, Ward 2, Village outside Birganj	STW	60	3	15	Rural site; Bagahi Village is agricultural; Population is 3,000 - 4,000, 9 or 10 wells total
15/03	Jan. 15, 2000	9:50 AM	Bagahi Village, Ward 6, Village outside Birganj	STW	65	10	7	Rural site; Bagahi Village is agricultural; Population is 3,000 - 4,000, 9 or 10 wells total
15/04	Jan. 15, 2000	10:20 AM	Lalpasa Village, Ward 2, Village outside Birganj	STW	60	7	7	Rural site; Lalpasa Village is agricultural; Population is 3,000 - 4,000, 9 or 10 wells total; There are two aquifers one at about 60 ft. and the other at about 110 feet; The shallow aquifer is contaminated with iron (2.5 - 10 mg/L) which creates aesthetic problems, taste, dyes clothes, and creates long term stomach problems; Only wealthy can afford wells in deep aquifer
15/05	Jan. 15, 2000	10:40 AM	Lalpasa Village, Ward 1, Village outside Birganj	STW	110	3	5	Rural site; Lalpasa Village is agricultural; Population is 3,000 - 4,000, 9 or 10 wells total; There are two aquifers one at about 60 ft. and the other at about 110 feet; The shallow aquifer is contaminated with iron (2.5 - 10 mg/L) which creates aesthetic problems, taste, dyes clothes, and creates long term stomach problems; Only wealthy can afford wells in deep aquifer
15/06	Jan. 15, 2000	11:00 AM	Lalpasa Village, Ward 4, Village outside Birganj	STW	50	10	5	Rural site; Lalpasa Village is agricultural; Population is 3,000 - 4,000, 9 or 10 wells total
15/07	Jan. 15, 2000	2:00 PM	Tajpur Village, Ward 3, Village outside Birganj	STW	130	12	10	Industrial site; Pharmaceutical Industry, 3 yrs old, nearby; Discharge to stream is 250 m away
15/08	Jan. 15, 2000	2:25 PM	Kodyiadoll, Ward 3, Village outside Birganj	STW	110	2	4	Industrial site; Immediately adjacent to medical facility and leather tannery; Textile mill 200 m away

Sample Number:	Date:	Time of Sample:	Location of Well/Water Source:	Water Source / Well Type:	Depth of Well (ft):	Age of Well (yrs):	Number of Households Served:	Comments:
15/09	Jan. 15, 2000	2:40 PM	Powanipu, Ward 6, Village outside Birganj	STW	140	5	Private well + unlimited use	Industrial site; Motor oil and grease manufacturing facility adjacent; Food processing plant adjacent
15/10	Jan. 15, 2000	3:00 PM	Chainpur, Ward 8, Village outside Birganj	STW	150	9	Public well + unlimited use	Industrial site; Gas station adjacent
18/01	Jan. 18, 2000		Dathali Public Water Supply, Intake to sedimentation tank - directly from nearby streams; Near Bhaktapur	Treatment Plant / Stream Intake	NA	Water Supply System is 13 years old		Dathali Water Supply; System is 13 years old which serves a population of about 10,000 people; Two reservoirs - currently only one is working; The only treatment used is a sedimentation tank; The source is from three nearby streams; Yield is 1.5 L/sec; Area has heavy agricultural, heavy use of fertilizers; crops include wheat, potatoes, mustard, tomatoes, garlic, and cauliflower; During rainy season, water quality declines visually; Algae growth in tank; no cover on sedimentation tank - photosynthesis can occur; no tests ever conducted on this water source
18/02	Jan. 18, 2000		Dathali Public Water Supply, Sample from sedimentation tank: Near Bhaktapur	Treatment Plant / Surface Intake	NA	Water Supply System is 13 years old		Dathali Water Supply; System is 13 years old which serves a population of about 10,000 people; Two reservoirs - currently only one is working; The only treatment used is a sedimentation tank; The source is from three nearby streams; Yield is 1.5 L/sec; Area has heavy agricultural, heavy use of fertilizers; crops include wheat, potatoes, mustard, tomatoes, garlic, and cauliflower; During rainy season, water quality declines visually; Algae growth in tank; no cover on sedimentation tank - photosynthesis can occur; no tests ever conducted on this water source

Sample Number:	Date:	Time of Sample:	Location of Well/Water Source:	Water Source / Well Type:	Depth of Well (ft):	Age of Well (yrs):	Number of Households Served:	Comments:
18/03	Jan. 18, 2000		Dathali Public Water Supply, Water tap in distribution system: Near Bhaktapur	Treatment Plant / Surface Intake	NA	Water Supply System is 13 years old		Dathali Water Supply; System is 13 years old which serves a population of about 10,000 people; Two reservoirs - currently only one is working; The only treatment used is a sedimentation tank; The source is from three nearby streams; Yield is 1.5 L/sec; Area has heavy agricultural, heavy use of fertilizers; crops include wheat, potatoes, mustard, tomatoes, garlic, and cauliflower; During rainy season, water quality declines visually; Algae growth in tank; no cover on sedimentation tank - photosynthesis can occur; no tests ever conducted on this water source
18/04	Jan. 18, 2000		Kiwachowk Public Water Supply, Water tap near outflow from above ground tank: Near Bhaktapur	Surface	NA	NA	Population of 1,500	Kiwachowk Water Supply; Water from 5 or 6 springs is collected and pumped into a large covered above ground tank; Spring source is 3.5 km away near cultivated agricultural lands; no water quality testing ever performed
19/01	Jan. 19. 2000	10:00 AM	Thimi Gas Station	HD	42.64	NA		5 - 6 ft. diameter, pumped through hose to gas station, not used for drinking, high iron content
19/02	Jan. 19. 2000	10:00 AM	Thimi household	STW	NA	NA		Tube sticking out of ground with a plunger used to pump water to surface - depth estimated to be consistent with depths of other hand dug wells
19/03	Jan. 19. 2000	10:15 AM	Thimi; Kyung Hee Nepal Health Centre, sink	Piped	NA	NA		Not used for drinking;
19/04	Jan. 19. 2000	10:30 AM	Thimi local market	Piped	NA	NA		Drinking water
19/05	Jan. 19. 2000	10:30 AM	Thimi, Chandramukhi Cabin Restaurant	Store/Restaurant	NA	NA		Drinking water
19/06	Jan. 19. 2000		Kirtipur, Central laboratory tap water	Piped	NA	NA		Drinking water
20/01	Jan. 20, 2000	9:25 AM	Patan	HD	30	NA		Not used for drinking, 5 - 6 ft diameter

Sample Number:	Date:	Time of Sample:	Location of Well/Water Source:	Water Source / Well Type:	Depth of Well (ft):	Age of Well (yrs):	Number of Households Served:	Comments:
20/02	Jan. 20, 2000	9:45 AM	Patan	Traditional Water Spout	NA	NA		Durbar Square water spout; used for drinking and bathing; traditional water source
20/03	Jan. 20, 2000	9:50 AM	Patan	Store/Restaurant	NA	NA		Cafe du Temple Restaurant tap water; used for drinking
20/04	Jan. 20, 2000	10:30 AM	Kathmandu	Store/Restaurant	NA	NA		Kathmandu Guest House tap water; used for drinking; Sonde results showed nitrate concentrations at 14 mg/L
20/05	Jan. 20, 2000	10:35 AM	Kathmandu	Store/Restaurant	NA	NA		Pilgrim Restaurant and Bar Tap water; used for drinking; filtered at restaurant before use
23/01	Jan. 23, 2000	8:30 AM	Naikap, source of water to system from sump well	Sump Well - Underneath Surface Water Source	NA	Treatment system is 3 yrs. Old	762 households served @ about 6 people per household	Naikap treatment system, 762 households, near Balkhu stream (polluted), industrial (automobile, food processing, oil tankers) and agricultural (rice) sites upstream, system provides water 1 - 2 hours per day, Naikap is 5 km from Kathmandu city center, Pump house takes water from 2 sources (1) sump well 2 ft below Balkhu Stream bed and (2) 100 ft. deep tube well in pump house
23/02	Jan. 23, 2000	8:45 AM	Naikap, source of water to system from tube well	STW	100	Treatment system is 3 yrs. Old	762 households served @ about 6 people per household	Naikap treatment system, 762 households, near Balkhu stream (polluted), industrial (automobile, food processing, oil tankers) and agricultural (rice) sites upstream, system provides water 1 - 2 hours per day, Naikap is 5 km from Kathmandu city center, Pump house takes water from 2 sources (1) sump well 2 ft below Balkhu Stream bed and (2) 100 ft. deep tube well in pump house
23/03	Jan. 23, 2000	8:50 AM	Naikap, sample from Balkhu Stream that feeds sump well	Surface	NA	Treatment system is 3 yrs. Old	762 households served @ about 6 people per household	Naikap treatment system, 762 households, near Balkhu stream (polluted), industrial (automobile, food processing, oil tankers) and agricultural (rice) sites upstream, system provides water 1 - 2 hours per day, Naikap is 5 km from Kathmandu city center, Pump house takes water from sump well and deep tube well in pump house

Sample Number:	Date:	Time of Sample:	Location of Well/Water Source:	Water Source / Well Type:	Depth of Well (ft):	Age of Well (yrs):	Number of Households Served:	Comments:
23/04	Jan. 23, 2000	9:20 AM	Naikap, sample from treatment system aeration tank, only deep tube well water, tube well and sump well water combine after aeration	Treatment Plant / Surface and STW Intake	NA	Treatment system is 3 yrs. Old	762 households served @ about 6 people per household	Naikap treatment system, 762 households, near Balkhu stream (polluted), industrial (automobile, food processing, oil tankers) and agricultural (rice) sites upstream, system provides water 1 - 2 hours per day, Naikap is 5 km from Kathmandu city center, Pump house takes water from 2 sources (1) sump well 2 ft below Balkhu Stream bed and (2) deep tube well 100 ft. deep in pump house
23/05	Jan. 23, 2000	9:20 AM	Naikap, after filtration	Treatment Plant / Surface and STW Intake	NA	Treatment system is 3 yrs. Old	762 households served @ about 6 people per household	Naikap treatment system, 762 households, near Balkhu stream (polluted), industrial (automobile, food processing, oil tankers) and agricultural (rice) sites upstream, system provides water 1 - 2 hours per day, Naikap is 5 km from Kathmandu city center, Pump house takes water from 2 sources (1) sump well 2 ft below Balkhu Stream bed and (2) deep tube well 100 ft. deep in pump house
23/06	Jan. 23, 2000	9:20 AM	Naikap, traditional source, people use this water because they think it is better than the municipally supplied treated water	Traditional Water Spout	NA	NA		traditional water source
23/07	Jan. 23, 2000	10:05 AM	Sitapaila, stream surface water source, pipeline takes untreated water from stream for water supply	Surface	NA	NA		
24/01	Jan. 24, 2000	10:15 AM	Kathmandu	Store/Restaurant	NA	NA		Store in front of Royal Palace, municipal tap water, used for drinking
24/02	Jan. 24, 2000	10:50 AM	Kathmandu	Traditional Water Spout	NA	NA		Sundhara public water spout used for bathing & drinking, traditional water source

Sample Number:	Date:	Time of Sample:	Location of Well/Water Source:	Water Source / Well Type:	Depth of Well (ft):	Age of Well (yrs):	Number of Households Served:	Comments:
24/03	Jan. 24, 2000	11:00 AM	Kathmandu	Store/Restaurant	NA	NA		Store near Sundhara
25/01	Jan. 25, 2000	8:25 AM	Kathmandu	Store/Restaurant	NA	NA		Drinking water from a store near Kathmandu Durbar Square
25/02	Jan. 25, 2000	8:30 AM	Kathmandu	Traditional Water Spout	NA	NA		Naradeni Spout; traditional water source for bathing and drinking
25/03	Jan. 25, 2000	8:35 AM	Kathmandu	STW	50	40		Hand pump near Kathmandu Durbar Square
TP01	Jan. 24, 2000		Mahankal	Treatment plant - Intake from DBW	984	15		well - 15 yrs old, 15 L/s, pretreated water called DK5
TP02	Jan. 24, 2000		Mahankal	Treatment plant - Intake from DBW	NA	NA		tank was for pH pretreatment for the water from several wells including the Gokarna and Manohara as well as DK5. We had to remove a great to get to the water. After this, the water goes into a biological reactor to treat with nitrous bacteria.
TP05	Jan. 24, 2000		Balaju	Treatment plant - Intake from DBW	656	20		well - 200 m or more deep, 20 yrs old, 2-3 MLD, called Bishnumati #2, water untreated
29/01	Jan. 29, 2000		Sonbarshi	STW	180	1	3	
29/02	Jan. 29, 2000		Sonbarshi	STW	195	3	15	
29/03	Jan. 29, 2000		Sonbarshi	STW	185	3	10	
29/04	Jan. 29, 2000		Sonbarshi	STW	185	3	10	
29/05	Jan. 29, 2000		Ramawapur	STW	180	1	37	
29/06	Jan. 29, 2000		Ramawapur	STW	180	1	37	
29/07	Jan. 29, 2000		Ramawapur	STW	45	8	5	diarrhea, leucorrhoea, giardia
29/08	Jan. 29, 2000		Sonbarsha	STW	195	1	25	diarrhea, leucorrhoea, dysentery
29/09	Jan. 29, 2000		Sonbarsha	STW	30	NA		
29/10	Jan. 29, 2000		Sonbarsha	STW	25	NA		
30/01	Jan. 30, 2000		New Ramawapur	STW	20	10	6	diarrhea, leucorrhoea
30/02	Jan. 30, 2000		New Ramawapur	STW	195	1	15	
30/03	Jan. 30, 2000		New Ramawapur	STW	35	15	5	yes, health problems

Sample Number:	Date:	Time of Sample:	Location of Well/Water Source:	Water Source / Well Type:	Depth of Well (ft):	Age of Well (yrs):	Number of Households Served:	Comments:
30/04	Jan. 30, 2000		Bhagatpuruwa	STW	140	2	12	abdominal problems
30/05	Jan. 30, 2000		Bhagatpuruwa	STW	100	1	7	
30/06	Jan. 30, 2000		Shivagadiya	STW	75	NA	20	diarrhea, leucorrhoea, dysn, cholera
30/07	Jan. 30, 2000		Shivagadiya	STW	17	15	5	abdominal problems
30/10	Jan. 30, 2000		Chinese Monastery	STW	NA	NA	7 monks	Chinese Monastery
31/01	Jan. 31, 2000		Dhodadwa	STW	350	1	65	
31/02	Jan. 31, 2000		Dhodadwa	STW	35	5	1	
31/03	Jan. 31, 2000		IBS – Outside tube well	STW	80	1	40	
31/04	Jan. 31, 2000		IBS - Across Street	STW	35	1		
31/05	Jan. 31, 2000		IBS - 3rd Floor Tap	Piped	170	3	150 - 200 people/day	abdominal problems
31/06	Jan. 31, 2000		Private – Ramachandra	STW	45	1	1	
31/07	Jan. 31, 2000		Madhuvani Primary School	STW	250	NA	300 children, 150 others	
31/08	Jan. 31, 2000		Mailawari	STW	180	1	12	
31/09	Jan. 31, 2000		Buddhanagar	STW	700	10	30	abdominal problems
1/01	Feb. 1, 2000		Kapilavastu – Palace Gate	STW	120	3	200 people	
1/02	Feb. 1, 2000		Kapilavastu -	STW	95	4	40 people	
1/03	Feb. 1, 2000		Student's Tube well	STW	195	3	500 students	
1/04	Feb. 1, 2000		Teachers Tube well	STW	48	6	40 people	
1/05	Feb. 1, 2000		Private Home – Vihara	STW	80	1	50 people	
1/06	Feb. 1, 2000		IBS - Across Street	STW	35	1		
1/07	Feb. 1, 2000		Siddhartha Hotel	Piped	NA	NA		
EN-1	Jan. 26, 2000		Bara District	STW	120	3		Sample provided by outside government agency for analysis
EN-2	Jan. 26, 2000		Bara District	STW	125	3		Sample provided by outside government agency for analysis
EN-3	Jan. 26, 2000		Bara District	STW	125	3		Sample provided by outside government agency for analysis

Sample Number:	Date:	Time of Sample:	Location of Well/Water Source:	Water Source / Well Type:	Depth of Well (ft):	Age of Well (yrs):	Number of Households Served:	Comments:
EN-4	Jan. 26, 2000		Bara District	STW	116	3		Sample provided by outside government agency for analysis
EN-5	Jan. 26, 2000		Bara District	STW	125	3		Sample provided by outside government agency for analysis
EN-6	Jan. 26, 2000		Bara District	STW	120	3		Sample provided by outside government agency for analysis
EN-7	Jan. 26, 2000		Bara District	STW	112	3		Sample provided by outside government agency for analysis
EN-8	Jan. 26, 2000		Bara District	STW	120	3		Sample provided by outside government agency for analysis
EN-9	Jan. 26, 2000		Bara District	STW	120	3		Sample provided by outside government agency for analysis
EN-10	Jan. 26, 2000		Bara District	STW	120	3		Sample provided by outside government agency for analysis
EN-11	Jan. 26, 2000		Bara District	STW	120	3		Sample provided by outside government agency for analysis
EN-12	Jan. 26, 2000		Bara District	STW	52	3		Sample provided by outside government agency for analysis
EN-13	Jan. 26, 2000		Bara District	STW	90	3		Sample provided by outside government agency for analysis
EN-14	Jan. 26, 2000		Bara District	STW	62	3		Sample provided by outside government agency for analysis
EN-15	Jan. 26, 2000		Bara District	STW	120	3		Sample provided by outside government agency for analysis
EN-16	Jan. 26, 2000		Bara District	STW	100	3		Sample provided by outside government agency for analysis
EN-17	Jan. 26, 2000		Bara District	STW	60	3		Sample provided by outside government agency for analysis
EN-18	Jan. 26, 2000		Bara District	STW	120	3		Sample provided by outside government agency for analysis
EN-19	Jan. 26, 2000		Bara District	STW	75	3		Sample provided by outside government agency for analysis
EN-20	Jan. 26, 2000		Bara District	STW	145	3		Sample provided by outside government agency for analysis
EN-21	Jan. 26, 2000		Bara District	STW	45	3		Sample provided by outside government agency for analysis

Sample Number:	Date:	Time of Sample:	Location of Well/Water Source:	Water Source / Well Type:	Depth of Well (ft):	Age of Well (yrs):	Number of Households Served:	Comments:
EN-22	Jan. 26, 2000		Bara District	STW	68	3		Sample provided by outside government agency for analysis
EN-23	Jan. 26, 2000		Bara District	STW	80	3		Sample provided by outside government agency for analysis
EN-24	Jan. 26, 2000		Bara District	STW	81	3		Sample provided by outside government agency for analysis
EN-25	Jan. 26, 2000		Bara District	STW	120	3		Sample provided by outside government agency for analysis
EN-26	Jan. 26, 2000		Bara District	STW	87	3		Sample provided by outside government agency for analysis
EN-27	Jan. 26, 2000		Bara District	STW	87	3		Sample provided by outside government agency for analysis
EN-28	Jan. 26, 2000		Bara District	STW	115	3		Sample provided by outside government agency for analysis
EN-29	Jan. 26, 2000		Bara District	STW	150	3		Sample provided by outside government agency for analysis
EN-30	Jan. 26, 2000		Bara District	STW	115	3		Sample provided by outside government agency for analysis
EN-31	Jan. 26, 2000		Bara District	STW	112	3		Sample provided by outside government agency for analysis
EN-32	Jan. 26, 2000		Bara District	STW	112	3		Sample provided by outside government agency for analysis
EN-33	Jan. 26, 2000		Bara District	STW	115	3		Sample provided by outside government agency for analysis
EN-34	Jan. 26, 2000		Bara District	STW	110	3		Sample provided by outside government agency for analysis
EN-35	Jan. 26, 2000		Bara District	STW	113	3		Sample provided by outside government agency for analysis
EN-36	Jan. 26, 2000		Bara District	STW	110	3		Sample provided by outside government agency for analysis
EN-37	Jan. 26, 2000		Bara District	STW	112	3		Sample provided by outside government agency for analysis
EN-38	Jan. 26, 2000		Bara District	STW	114	3		Sample provided by outside government agency for analysis
EN-39	Jan. 26, 2000		Bara District	STW	155	3		Sample provided by outside government agency for analysis

Sample Number:	Date:	Time of Sample:	Location of Well/Water Source:	Water Source / Well Type:	Depth of Well (ft):	Age of Well (yrs):	Number of Households Served:	Comments:
EN-40	Jan. 26, 2000		Bara District	STW	62	3		Sample provided by outside government agency for analysis
EN-41	Jan. 26, 2000		Bara District	STW	150	3		Sample provided by outside government agency for analysis
EN-42	Jan. 26, 2000		Bara District	STW	N/A	11.5		Sample provided by outside government agency for analysis
EN-43	Jan. 26, 2000		Bara District	STW	N/A	11.5		Sample provided by outside government agency for analysis
EN-45	Jan. 26, 2000		Bara District	STW	N/A	11.5		Sample provided by outside government agency for analysis
EN-46	Jan. 26, 2000		Bara District	STW	N/A	11.5		Sample provided by outside government agency for analysis
EN-47	Jan. 26, 2000		Bara District	STW	N/A	11.5		Sample provided by outside government agency for analysis
EN-48	Jan. 26, 2000		Bara District	STW	N/A	11.5		Sample provided by outside government agency for analysis
EN-49	Jan. 26, 2000		Bara District	STW	N/A	11.5		Sample provided by outside government agency for analysis
EN-50	Jan. 26, 2000		Bara District	STW	N/A	11.5		Sample provided by outside government agency for analysis
EN-51	Jan. 26, 2000		Bara District	STW	N/A	11.5		Sample provided by outside government agency for analysis
EN-52	Jan. 26, 2000		Bara District	STW	N/A	11.5		Sample provided by outside government agency for analysis
EN-53	Jan. 26, 2000		Bara District	STW	N/A	11.5		Sample provided by outside government agency for analysis
EN-54	Jan. 26, 2000		Bara District	STW	N/A	11.5		Sample provided by outside government agency for analysis
EN-55	Jan. 26, 2000		Bara District	STW	N/A	11.5		Sample provided by outside government agency for analysis
EN-56	Jan. 26, 2000		Bara District	STW	N/A	11.5		Sample provided by outside government agency for analysis
EN-57	Jan. 26, 2000		Bara District	STW	N/A	11		Sample provided by outside government agency for analysis
EN-58	Jan. 26, 2000		Bara District	STW	N/A	11		Sample provided by outside government agency for analysis

Sample Number:	Date:	Time of Sample:	Location of Well/Water Source:	Water Source / Well Type:	Depth of Well (ft):	Age of Well (yrs):	Number of Households Served:	Comments:
EN-59	Jan. 26, 2000		Bara District	STW	N/A	11		Sample provided by outside government agency for analysis
EN-60	Jan. 26, 2000		Bara District	STW	N/A	11		Sample provided by outside government agency for analysis
EN-61	Jan. 26, 2000		Bara District	STW	N/A	11		Sample provided by outside government agency for analysis
EN-62	Jan. 26, 2000		Bara District	STW	N/A	11		Sample provided by outside government agency for analysis
EN-63	Jan. 26, 2000		Bara District	STW	N/A	11		Sample provided by outside government agency for analysis
EN-64	Jan. 26, 2000		Bara District	STW	N/A	11		Sample provided by outside government agency for analysis
EN-65	Jan. 26, 2000		Bara District	STW	N/A	11		Sample provided by outside government agency for analysis
EN-66	Jan. 26, 2000		Bara District	STW	N/A	11		Sample provided by outside government agency for analysis
EN-67	Jan. 26, 2000		Bara District	STW	N/A	11		Sample provided by outside government agency for analysis
EN-68	Jan. 26, 2000		Bara District	STW	N/A	11.5		Sample provided by outside government agency for analysis
EN-69	Jan. 26, 2000		Bara District	STW	N/A	11.5		Sample provided by outside government agency for analysis
EN-70	Jan. 26, 2000		Bara District	STW	N/A	11.5		Sample provided by outside government agency for analysis
EN-71	Jan. 26, 2000		Bara District	STW	N/A	11.5		Sample provided by outside government agency for analysis
EN-72	Jan. 26, 2000		Bara District	STW	N/A	11.5		Sample provided by outside government agency for analysis
EN-73	Jan. 26, 2000		Bara District	STW	180	11.5		Sample provided by outside government agency for analysis
EN-74	Jan. 26, 2000		Bara District	STW	180	11.5		Sample provided by outside government agency for analysis
EN-75	Jan. 26, 2000		Bara District	STW	90	11.5		Sample provided by outside government agency for analysis
EN-76	Jan. 26, 2000		Bara District	STW	125	11.5		Sample provided by outside government agency for analysis

Sample Number:	Date:	Time of Sample:	Location of Well/Water Source:	Water Source / Well Type:	Depth of Well (ft):	Age of Well (yrs):	Number of Households Served:	Comments:
EN-77	Jan. 26, 2000		Bara District	STW	125	11.5		Sample provided by outside government agency for analysis
EN-78	Jan. 26, 2000		Bara District	STW	125	11.5		Sample provided by outside government agency for analysis
EN-79	Jan. 26, 2000		Bara District	STW	100	11.5		Sample provided by outside government agency for analysis
EN-80	Jan. 26, 2000		Bara District	STW	185	4		Sample provided by outside government agency for analysis
EN-81	Jan. 26, 2000		Bara District	STW	190	4		Sample provided by outside government agency for analysis
EN-82	Jan. 26, 2000		Bara District	STW	180	4		Sample provided by outside government agency for analysis
EN-83	Jan. 26, 2000		Bara District	STW	180	4		Sample provided by outside government agency for analysis
EN-84	Jan. 26, 2000		Bara District	STW	155	4		Sample provided by outside government agency for analysis
EN-85	Jan. 26, 2000							Standard solution of 1000ppb

Source Types and Codes:

STW = Shallow Tube Well

HD = Hand Dug Well

DBW = Deep Boring Well

Surface = Surface Water Source

Piped = Tap Water

Restaurant/Store = Source unknown

Treatment Plants

Traditional Water Spouts

Table B-2: Test Results for EM Quant® Test Strips and Affiniti Concentration Kits

Sample #	Merck Result (ppb)	Affiniti Result (ppb)
14/01	100	100
14/02	0	0
14/03	0	0-10
14/04	0	0
14/05	0	0
14/06	0	0
14/07	0	0-10
14/08	0	0-10
14/09	0	0
14/10	0	0
14/11	0	0-10
14/12	0	0-10
15/01	0	0-10
15/02	0	0-10
15/03	0-100	50
15/04	0	0-10
15/05	0	0
15/06	0	0
15/07	0	0
15/08	0	0
15/09	0	0
15/10	0	0
18/01	0	0-10
18/02	0	0-10
18/03	0	0
18/04	0	0-10
19/01	0	0
19/02	0	0-10
19/03	0	0
19/04	0	0
19/05	0	0
19/06	0	0
20/01	0	0-10
20/02	0	0
20/03	0	0
20/04	0	0
20/05	0	0
23/01	0	0
23/02	0	0-10
23/03	0	0
23/04	0	0-10
23/05	0	N/A
23/06	0	N/A
23/07	0	N/A
24/01	0	0
24/02	0	0
24/03	0	0

Sample #	Merck Result (ppb)	Affiniti Result (ppb)
25/01	0	0
25/02	0	0-10
25/03	0	0-10
TP01	0	N/A
TP02	0	N/A
TP05	0	N/A
29-01	0	0
29-02	0	0
29-03	0	0
29-04	0	0
29-05	0	0
29-06	0	0
29-07	0	0
29-08	0	0
29-09	0	0
29-10	0	0
30-01	0	0
30-02	0	0
30-03	0	0
30-04	0	0
30-05	0	0
30-06	0	0
30-07	0	0
30-08	0	0
30-09	0	0
30-10	0	0
31-01	0	0
31-02	0	0
31-03	0	0
31-04	0	0-10
31-05	0	0
31-06	0	0
31-07	0	0
31-08	0	0
31-09	0	0
1-01	0	0
1-02	0	0
1-03	0	0
1-04	0	0-10
1-05	0	0
1-06	0	0
1-07	0	0
EN-1	0	N/A
EN-2	0	N/A
EN-3	0	N/A
EN-4	0	N/A
EN-5	0	N/A
EN-6	0	N/A
EN-7	0	N/A

Sample #	Merck Result (ppb)	Affiniti Result (ppb)
EN-8	0	N/A
EN-9	0	N/A
EN-10	0	N/A
EN-11	0	N/A
EN-12	0	N/A
EN-13	0	N/A
EN-14	0	N/A
EN-15	0	N/A
EN-16	0	N/A
EN-17	0	N/A
EN-18	0	N/A
EN-19	0	N/A
EN-20	0	N/A
EN-21	0	N/A
EN-22	0	N/A
EN-23	0	N/A
EN-24	0	N/A
EN-25	0	N/A
EN-26	0	N/A
EN-27	0	N/A
EN-28	0	N/A
EN-29	0	N/A
EN-30	0	N/A
EN-31	0	N/A
EN-32	0	N/A
EN-33	0	N/A
EN-34	0	N/A
EN-35	0	N/A
EN-36	0	N/A
EN-37	0	N/A
EN-38	0	N/A
EN-39	0	N/A
EN-40	0	N/A
EN-41	0	N/A
EN-42	0	N/A
EN-43	0	N/A
EN-44	N/A	N/A
EN-45	0	N/A
EN-46	0	N/A
EN-47	0	N/A
EN-48	0	N/A
EN-49	0	N/A
EN-50	0	N/A
EN-51	0	N/A
EN-52	0	N/A
EN-53	0	N/A
EN-54	0	N/A
EN-55	0	N/A
EN-56	0	N/A

Sample #	Merck Result (ppb)	Affiniti Result (ppb)
EN-57	0	N/A
EN-58	0	N/A
EN-59	0	N/A
EN-60	0	N/A
EN-61	0	N/A
EN-62	0	N/A
EN-63	0	N/A
EN-64	0	N/A
EN-65	0	N/A
EN-66	0	N/A
EN-67	0	N/A
EN-68	0	N/A
EN-69	0	N/A
EN-70	0	N/A
EN-71	0	N/A
EN-72	0	N/A
EN-73	0	N/A
EN-74	0	N/A
EN-75	0	N/A
EN-76	0	N/A
EN-77	0	N/A
EN-78	0	N/A
EN-79	0	N/A
EN-80 (M-1)	0	N/A
EN-81 (M-2)	0	N/A
EN-82 (M-3)	0	N/A
EN-83 (M-4)	0	N/A
EN-84 (M-5)	0	N/A
EN-86 (Standard)	1000	N/A

Table B-3: GFAAS Results

Sample Group	Calibration	Peak Area	Concen (ppb)	Sample ID	Peak Area	Concen (ppb)	Duplicate Peak Area	Duplicate Concen (ppb)	Triplicate Peak Area	Triplicate Concen (ppb)	Average Concen (ppb)	Classification
3/21/00 1	5% HNO3	0.001	0	14/01	0.188	115.644382	0.186	106.3302296			111	> 100 ppb
	5 ppb	0.011	5	14/02	0.004	-1.252916001					0	ND
	10 ppb	0.019	10	14/03	0.034	17.80642606	0.033	17.49680643			18	10ppb - 20ppb
	25 ppb	0.051	25	14/04	0.006	0.017706803					0	ND
	50 ppb	0.086	50	14/05	0.009	1.923641009					2	ND
	75 ppb	0.133	75	14/06	0.006	0.017706803					0	ND
	100 ppb	0.167	100	14/07	0.018	7.641443628					8	5ppb-10ppb
	150 ppb	0.233	150	14/08	0.058	33.05389971	0.065	35.28890581			34	20ppb - 50ppb
	slope:		intercept:	14/09	0.014	5.10019802					5	5ppb-10ppb
	635.3114021		-3.79416161	14/10	0.001	-3.158850208					0	ND
2	5% HNO3	0.004	0	14/11	0.014	3.185191455					3	ND
	5 ppb	0.011	5	14/12	0.017	4.974709686					5	ND
	10 ppb	0.024	10	15/01	-0.001	-5.762399702					0	ND
	25 ppb	0.055	25	15/02	0.028	11.53627653	0.03	12.54148638			12	10ppb-20ppb
	50 ppb	0.096	50	15/04	0.036	16.30832515	0.034	14.74581639			16	10ppb-20ppb
	75 ppb	0.146	75	15/05	0.001	-4.569387548					0	ND
	100 ppb	0.181	100	15/06	0.028	11.53627653	0.028	11.43932137			11	10ppb-20ppb
	150 ppb	0.248	150	15/07	0.007	-0.990351085					0	ND
	slope:		intercept:	15/08	-0.003	-6.955411856					0	ND
	596.5060771		-5.165893625	15/09	0.008	-0.393845008					0	ND
3	5% HNO3	0	0	15/10	-0.002	-4.957869649					0	ND
	5 ppb	0.009	5	18/01	0	-3.814063468					0	ND
	10 ppb	0.02	10	18/03	0.002	-2.670257286					0	ND
	25 ppb	0.056	25	18/04	0.001	-3.242160377					0	ND
	50 ppb	0.103	50	19/01	-0.002	-4.957869649					0	ND
	75 ppb	0.152	75	19/02	0.001	-3.242160377					0	ND
	100 ppb	0.187	100	19/03	-0.001	-4.385966558					0	ND
	150 ppb	0.252	150	19/04	0.001	-3.242160377					0	ND
	slope:		intercept:	19/05	0.002	-2.670257286					0	ND
	571.9030908		-3.814063468	19/06	0.004	-1.526451104					0	ND
4	5% HNO3	-0.001	0	20/01	0	-4.539914968					0	ND
	5 ppb	0.012	5	20/02	0.005	-1.601638147					0	ND
	10 ppb	0.021	10	20/03	-0.001	-5.127570332					0	ND
	25 ppb	0.056	25	20/04	0.002	-3.364604239					0	ND
	50 ppb	0.102	50	20/05	0.001	-3.952259604					0	ND
	75 ppb	0.15	75	23/01	0.006	-1.013982782					0	ND

Sample Group	Calibration	Peak Area	Concen (ppb)	Sample ID	Peak Area	Concen (ppb)	Duplicate Peak Area	Duplicate Concen (ppb)	Triplicate Peak Area	Triplicate Concen (ppb)	Average Concen (ppb)	Classification
	100 ppb 150 ppb	0.18 0.248 slope: 587.6553642	100 150 intercept: -4.539914968	23/02 23/03 23/04 23/05	0.017 0 0.015 0.004	5.450226224 -4.539914968 4.274915496 -2.189293511					5 0 4 0	5ppb-10ppb ND ND ND
5	5% HNO3 5 ppb 10 ppb 25 ppb 50 ppb 75 ppb 100 ppb 150 ppb	-0.001 0.014 0.024 0.058 0.097 0.15 0.192 0.255 slope: 571.8678723	0 5 10 25 50 75 100 150 intercept: -4.525468907	23/06 23/07 24/01 24/02 24/03 25/01 25/02 25/03 TP/01 TP/02	0.002 -0.002 0.002 0.001 0 0.002 0.004 0.007 0 0.012	-3.381733162 -5.669204652 -3.381733162 -3.953601035 -4.525468907 -3.381733162 -2.237997418 -0.522393801 -4.525468907 2.336945561					0 0 0 0 0 0 0 0 0 2	ND ND ND ND ND ND ND ND ND ND
6	5% HNO3 5 ppb 10 ppb 25 ppb 50 ppb 75 ppb 100 ppb 150 ppb	0.001 0.012 0.023 0.056 0.102 0.156 0.193 0.26 slope: 559.4835016	0 5 10 25 50 75 100 150 intercept: -4.283156476	TP/05 29/01 29/02 29/03 29/04 29/05 29/06 29/07 29/08 29/09	0.013 0.01 0.008 0.004 0.003 0.005 0 0.001 0.006 0	2.990129045 1.31167854 0.192711537 -2.04522247 -2.604705971 -1.485738968 -4.283156476 -3.723672975 -0.926255466 -4.283156476					3 1 0 0 0 0 0 0 0 0	ND ND ND ND ND ND ND ND ND ND
3/22/00 7	5% HNO3 5 ppb 10 ppb 25 ppb 50 ppb 75 ppb 100 ppb 150 ppb	-0.001 0.009 0.02 0.056 0.096 0.144 0.184 0.248 slope: 584.9481631	0 5 10 25 50 75 100 150 intercept: -3.402601412	29/10 30/01 30/02 30/03 30/04 30/05 30/06 30/07 30/10 31/01	0.002 -0.001 0 -0.001 0.009 0.002 0.001 0 0.002 -0.003	-2.232705086 -3.987549576 -3.402601412 -3.987549576 1.861932055 -2.232705086 -2.817653249 -3.402601412 -2.232705086 -5.157445902					0 0 0 0 2 0 0 0 0 0	ND ND ND ND ND ND ND ND ND ND
8	5% HNO3 5 ppb 10 ppb	-0.001 0.011 0.017	0 5 10	31/02 31/03 31/04	-0.001 0.001 0.042	-3.487931411 -2.360950619 20.74215562	0.04	18.0523114			0 0 19	ND ND 10ppb-20ppb

Sample Group	Calibration	Peak Area	Concen (ppb)	Sample ID	Peak Area	Concen (ppb)	Duplicate Peak Area	Duplicate Concen (ppb)	Triplicate Peak Area	Triplicate Concen (ppb)	Average Concen (ppb)	Classification
	25 ppb	0.055	25	31/05	0	-2.924441015					0	ND
	50 ppb	0.099	50	31/06	0.01	2.710462946					3	ND
	75 ppb	0.155	75	31/07	0.001	-2.360950619					0	ND
	100 ppb	0.185	100	31/08	0	-2.924441015					0	ND
	150 ppb	0.257	150	31/09	0	-2.924441015					0	ND
	slope:		intercept:	1/01	0.001	-2.360950619					0	ND
	563.490396		-2.924441015	1/02	0.002	-1.797460223					0	ND
9	5% HNO3	-0.005	0	1/03	-0.001	-3.272080622					0	ND
	5 ppb	0.012	5	1/04	0.026	11.27220438	0.028	11.43932137			11	10ppb-20ppb
	10 ppb	0.019	10	1/05	0	-2.7334034					0	ND
	25 ppb	0.056	25	1/06	0.041	19.35236271	0.042	19.15447641			19	10ppb-20ppb
	50 ppb	0.11	50	1/07	-0.001	-3.272080622					0	ND
	75 ppb	0.159	75	EN-1	0.004	-0.578694511					0	ND
	100 ppb	0.191	100	EN-2	0.001	-2.194726178					0	ND
	150 ppb	0.269	150	EN-3	0.003	-1.117371733					0	ND
	slope:		intercept:	EN-4	0.001	-2.194726178					0	ND
	538.6772222		-2.7334034	EN-5	-0.003	-4.349435066					0	ND
10	5% HNO3	0	0	EN-6	0.003	-1.426193161					0	ND
	5 ppb	0.009	5	EN-7	0.004	-0.875987297					0	ND
	10 ppb	0.02	10	EN-8	0.001	-2.526604891					0	ND
	25 ppb	0.059	25	EN-9	0	-3.076810756					0	ND
	50 ppb	0.101	50	EN-10	0.002	-1.976399026					0	ND
	75 ppb	0.157	75	EN-11	-0.002	-4.177222486					0	ND
	100 ppb	0.185	100	EN-12	0.005	-0.325781432					0	ND
	150 ppb	0.268	150	EN-13	0.008	1.324836163					1	ND
	slope:		intercept:	EN-14	0.001	-2.526604891					0	ND
	550.2058649		-3.076810756	EN-15	0.002	-1.976399026					0	ND
11	5% HNO3	0	0	EN-16	0.003	-1.865543869					0	ND
	5 ppb	0.01	5	EN-17	0.002	-2.452872218					0	ND
	10 ppb	0.021	10	EN-18	-0.001	-4.214857263					0	ND
	25 ppb	0.056	25	EN-19	0.002	-2.452872218					0	ND
	50 ppb	0.096	50	EN-20	-0.001	-4.214857263					0	ND
	75 ppb	0.143	75	EN-21	0	-3.627528914					0	ND
	100 ppb	0.177	100	EN-22	0.001	-3.040200566					0	ND
	150 ppb	0.253	150	EN-23	0.004	-1.278215521					0	ND
	slope:		intercept:	EN-24	0	-3.627528914					0	ND
	587.3283483		-3.627528914	EN-25	0.005	-0.690887173					0	ND

Sample Group	Calibration	Peak Area	Concen (ppb)	Sample ID	Peak Area	Concen (ppb)	Duplicate Peak Area	Duplicate Concen (ppb)	Triplicate Peak Area	Triplicate Concen (ppb)	Average Concen (ppb)	Classification
12	5% HNO3	-0.001	0	EN-26	0.003	-2.386674702					0	ND
	5 ppb	0.011	5	EN-27	0.005	-1.257693174					0	ND
	10 ppb	0.023	10	EN-28	-0.001	-4.644637759					0	ND
	25 ppb	0.057	25	EN-29	0.003	-2.386674702					0	ND
	50 ppb	0.101	50	EN-30	0.001	-3.515656231					0	ND
	75 ppb	0.156	75	EN-31	0.004	-1.822183938					0	ND
	100 ppb	0.189	100	EN-32	0.002	-2.951165466					0	ND
	150 ppb	0.257	150	EN-33	0.004	-1.822183938					0	ND
	slope:		intercept:	EN-34	0.002	-2.951165466					0	ND
	564.4907641		-4.080146995	EN-35	0.004	-1.822183938					0	ND
13	5% HNO3	-0.003	0	EN-36	0.003	-0.921490834					0	ND
	5 ppb	0.009	5	EN-37	-0.001	-3.138666302					0	ND
	10 ppb	0.018	10	EN-38	0.001	-2.030078568					0	ND
	25 ppb	0.057	25	EN-39	-0.002	-3.692960169					0	ND
	50 ppb	0.102	50	EN-40	-0.001	-3.138666302					0	ND
	75 ppb	0.155	75	EN-41	-0.002	-3.692960169					0	ND
	100 ppb	0.187	100	EN-42	0.047	23.46743932	0.053	25.21638394			24	20ppb-50ppb
	150 ppb	0.261	150	EN-43	0.002	-1.475784701					0	ND
	slope:		intercept:	EN-45	-0.001	-3.138666302					0	ND
	554.293867		-2.584372435	EN-46	0.033	15.70732518	0.032	13.64365138			15	10ppb-20ppb
3/23/00 14	5% HNO3	0	0	EN-47	0.054	29.83769643	0.049	26.89938928	0.053	29.250035	29	20ppb-50ppb
	5 ppb	0.009	5	EN-48	0.102	58.045445	0.097	55.10713786	0.095	53.931815	56	50ppb-100ppb
	10 ppb	0.016	10	EN-49	0.046	25.136405	0.047	25.72406643			25	20ppb-50ppb
	25 ppb	0.047	25	EN-47	0.049	26.89938928						
	50 ppb	0.093	50	EN-48	0.097	55.10713786						
	75 ppb	0.143	75	EN-49	0.047	25.72406643						
	100 ppb	0.176	100	EN-50	0.06	33.363665	0.06	33.363665			33	20ppb-50ppb
	150 ppb	0.248	150	EN-51	0.045	24.54874357	0.047	25.72406643			25	20ppb-50ppb
	slope:		intercept:	EN-52	0.042	22.78575928	0.039	21.022775			22	20ppb-50ppb
	587.6614286		-1.896020719	EN-53	0.044	23.96108214	0.047	25.72406643			25	20ppb-50ppb
				EN-47	0.053	29.250035						
				EN-48	0.095	53.931815						
				EN-50	0.06	33.363665						
				EN-51	0.047	25.72406643						
				EN-52	0.039	21.022775						
				EN-53	0.047	25.72406643						
				EN-54	0.023	11.62019214	0.02	9.857207854			11	10ppb-20ppb
				EN-55	0.027	13.97083785	0.025	12.795515			13	10ppb-20ppb
				EN-56	0.031	16.32148357	0.032	16.909145			17	10ppb-20ppb

Sample Group	Calibration	Peak Area	Concen (ppb)	Sample ID	Peak Area	Concen (ppb)	Duplicate Peak Area	Duplicate Concen (ppb)	Triplicate Peak Area	Triplicate Concen (ppb)	Average Concen (ppb)	Classification
				EN-54 EN-55 EN-56 14/03	0.02 0.025 0.032 0.033	9.857207854 12.795515 16.909145 17.49680643						
15	5% HNO3 5 ppb 10 ppb 25 ppb 50 ppb 75 ppb 100 ppb 150 ppb	-0.001 0.014 0.025 0.057 0.102 0.161 0.196 0.267	0 5 10 25 50 75 100 150	EN-57 EN-58 EN-59 EN-60 EN-61 EN-62 EN-63 EN-64	0.005 0.002 0.001 0.004 0.001 -0.001 0 0.001	-1.470915984 -3.110227102 -3.656664142 -2.017353023 -3.656664142 -4.749538221 -4.203101181 -3.656664142					0 0 0 0 0 0 0 0	ND ND ND ND ND ND ND ND
		slope: 546.4370395	intercept: -4.203101181	EN-65 EN-66	0.001 -0.001	-3.656664142 -4.749538221					0 0	ND ND
16	5% HNO3 5 ppb 10 ppb 25 ppb 50 ppb 75 ppb 100 ppb 150 ppb	-0.002 0.011 0.022 0.055 0.103 0.162 0.197 0.265	0 5 10 25 50 75 100 150	EN-67 EN-68 EN-69 EN-70 EN-71 EN-71 EN-72 EN-73	0.044 0.047 0.003 0.038 0.016 0.02 0.007 0.004	20.67162868 22.29609921 -1.529468478 17.42268764 5.509903793 7.675864492 0.636492221 -0.987978303	0.049 0.05 0.036 0.02	22.99755664 23.55023498 15.8127382 7.675864492			22 23 0 17 7	20ppb-50ppb 20ppb-50ppb ND 10ppb-20ppb 5ppb-10ppb
		slope: 541.4901747	intercept: -3.153939002	EN-74 EN-75 EN-76	-0.001 -0.003 0	-3.695429177 -4.778409526 -3.153939002					1 0 0 0 0	ND ND ND ND ND
17	5% HNO3 5 ppb 10 ppb 25 ppb 50 ppb 75 ppb 100 ppb 150 ppb	-0.002 0.012 0.017 0.049 0.096 0.152 0.178 0.244	0 5 10 25 50 75 100 150	EN-77 EN-78 EN-79 EN-80 EN-81 EN-82 EN-83 EN-84	0.001 -0.003 0.014 0 0 -0.001 -0.004 -0.001	-2.286670422 -4.635143936 5.3458685 -2.8737888 -2.8737888 -3.460907179 -5.222262314 -3.460907179					0 0 5 0 0 0 0 0	ND ND 5ppb-10ppb ND ND ND ND ND
		slope: 587.1183786	intercept: -2.8737888	14/01 14/08	0.186 0.065	106.3302296 35.28890581						
18	5% HNO3 5 ppb	0.001 0.011	0 5	15/03 18/02	0.112 0	57.73025159 -3.990988698	0.113	58.36897052			58 0	50ppb-100ppb ND

Sample Group	Calibration	Peak Area	Concen (ppb)	Sample ID	Peak Area	Concen (ppb)	Duplicate Peak Area	Duplicate Concen (ppb)	Triplicate Peak Area	Triplicate Concen (ppb)	Average Concen (ppb)	Classification
	10 ppb	0.022	10	15/02	0.03	12.54148638						
	25 ppb	0.056	25	15/04	0.034	14.74581639						
	50 ppb	0.102	50	15/06	0.028	11.43932137						
	75 ppb	0.166	75	31/04	0.04	18.0523114						
	100 ppb	0.193	100	1/04	0.028	11.43932137						
	150 ppb	0.26	150	1/06	0.042	19.15447641						
		slope: 551.0825026	intercept: -3.990988698	EN-42	0.053	25.21638394						
				EN-46	0.032	13.64365138						
19	5% HNO3	-0.002	0	EN-67	0.049	22.99755664						
	5 ppb	0.011	5	EN-68	0.05	23.55023498						
	10 ppb	0.022	10	EN-70	0.036	15.8127382						
	25 ppb	0.06	25	15/03	0.113	58.36897052						
	50 ppb	0.106	50									
	75 ppb	0.158	75									
	100 ppb	0.194	100									
	150 ppb	0.261	150									
		slope: 552.6783418	intercept: -4.083682106									

TOTALS:	# SAMPLES
ND	140
5ppb-10ppb	5
10ppb-20ppb	12
20ppb-50ppb	10
50ppb-100ppb	2
> 100ppb	1
	<hr/> 170

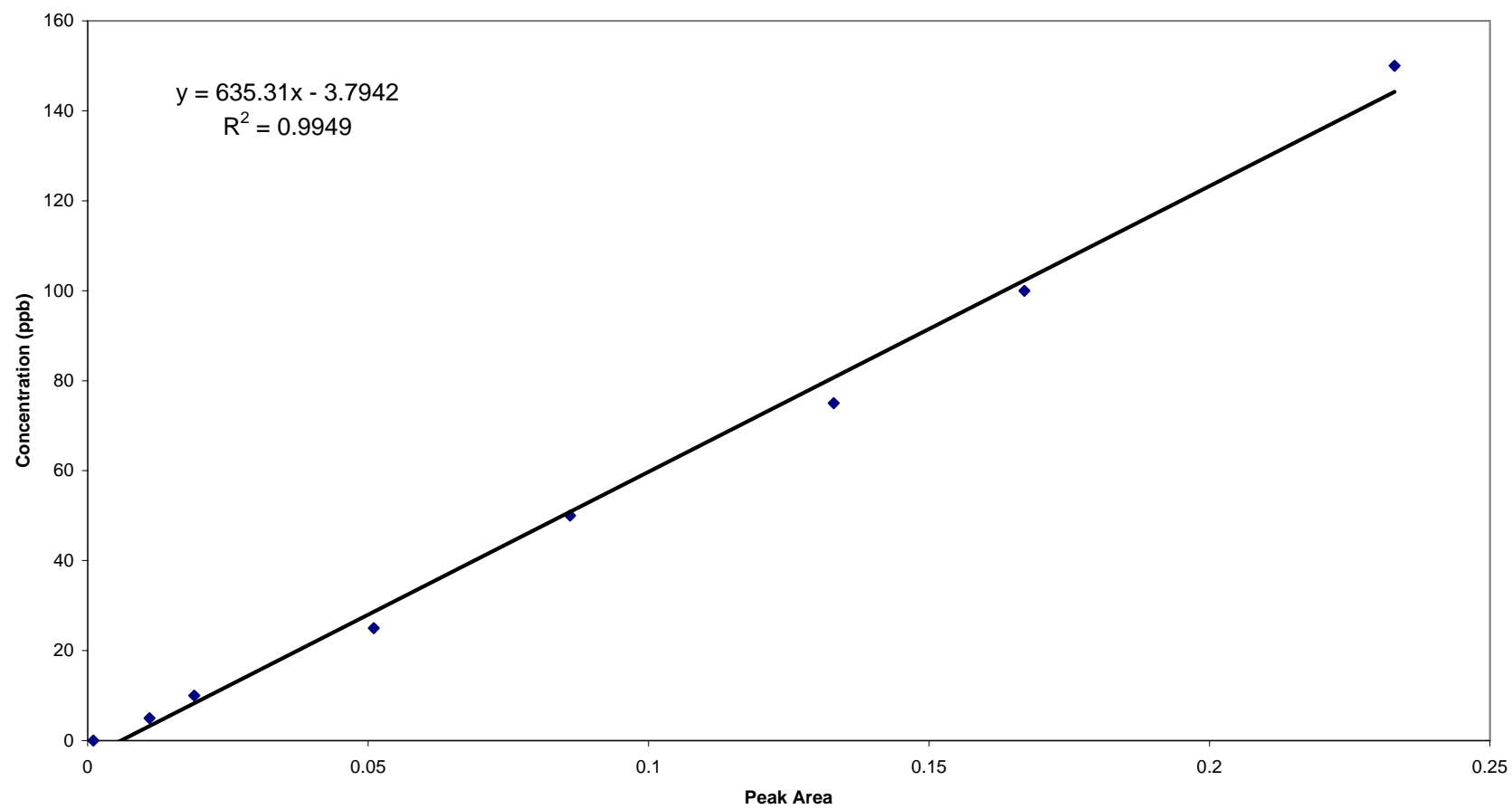


Figure B-1: Calibration Curve for Sample Group 1

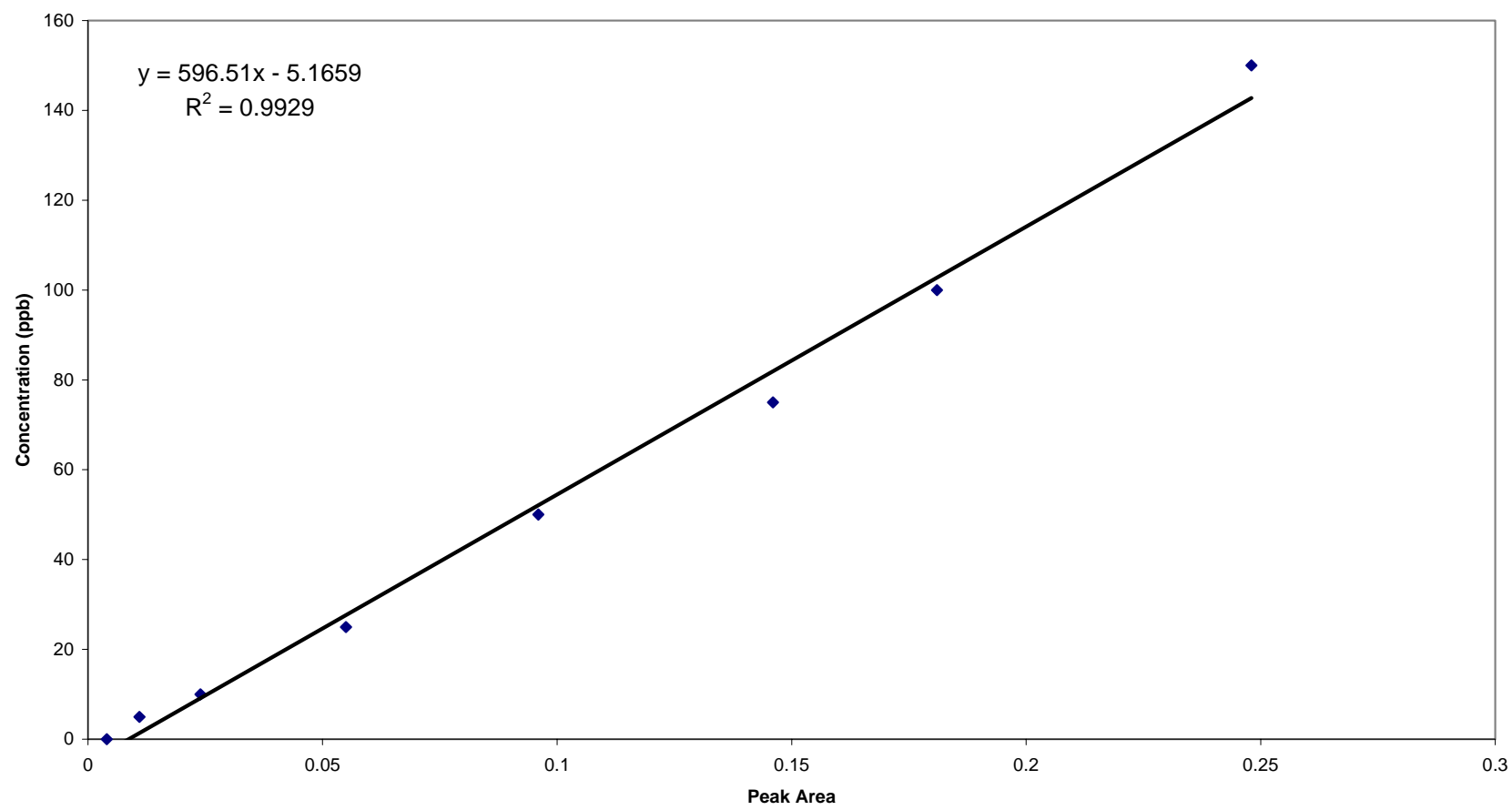


Figure B-2: Calibration Curve for Sample Group 2

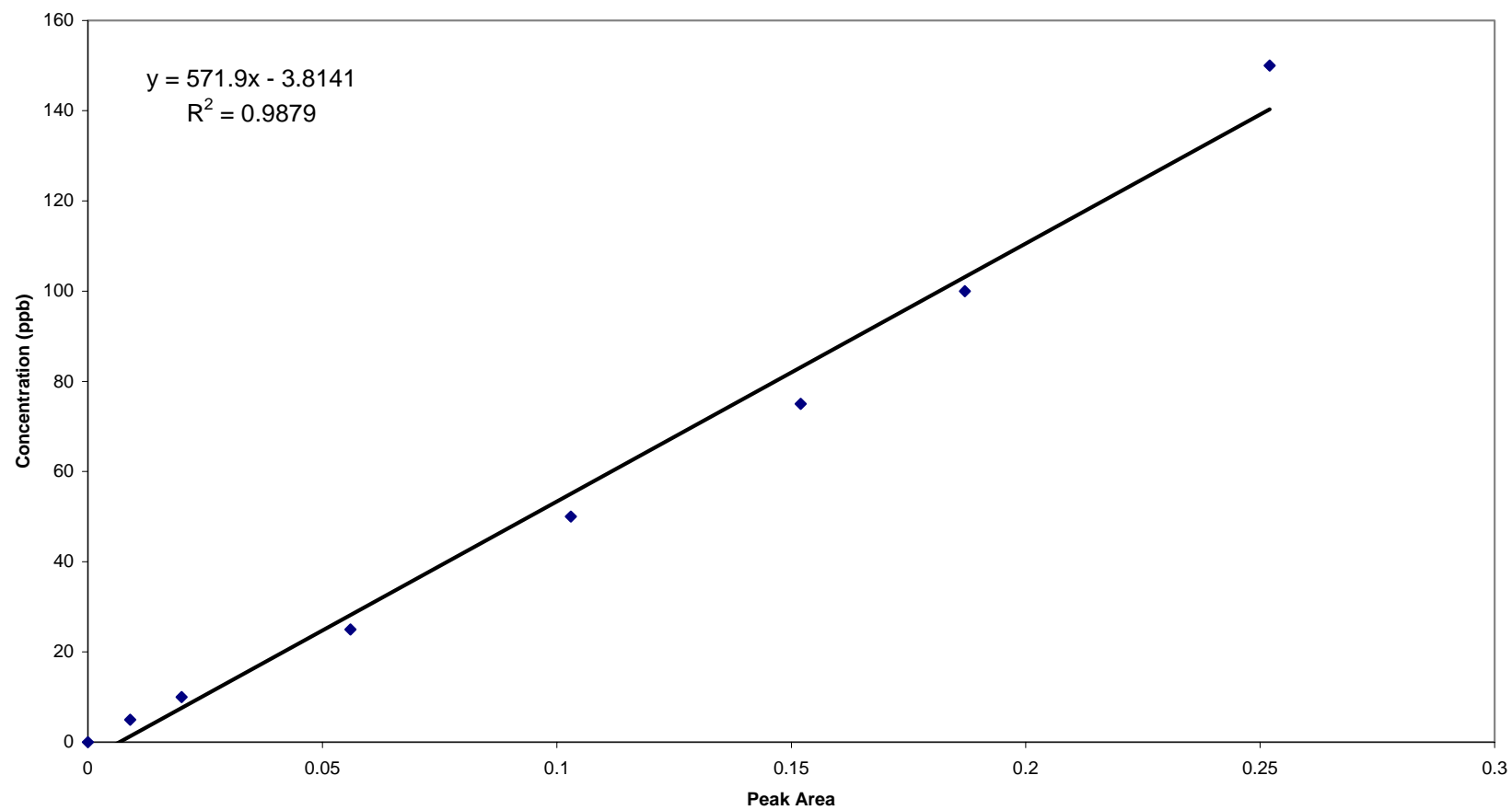


Figure B-3: Calibration Curve for Sample Group 3

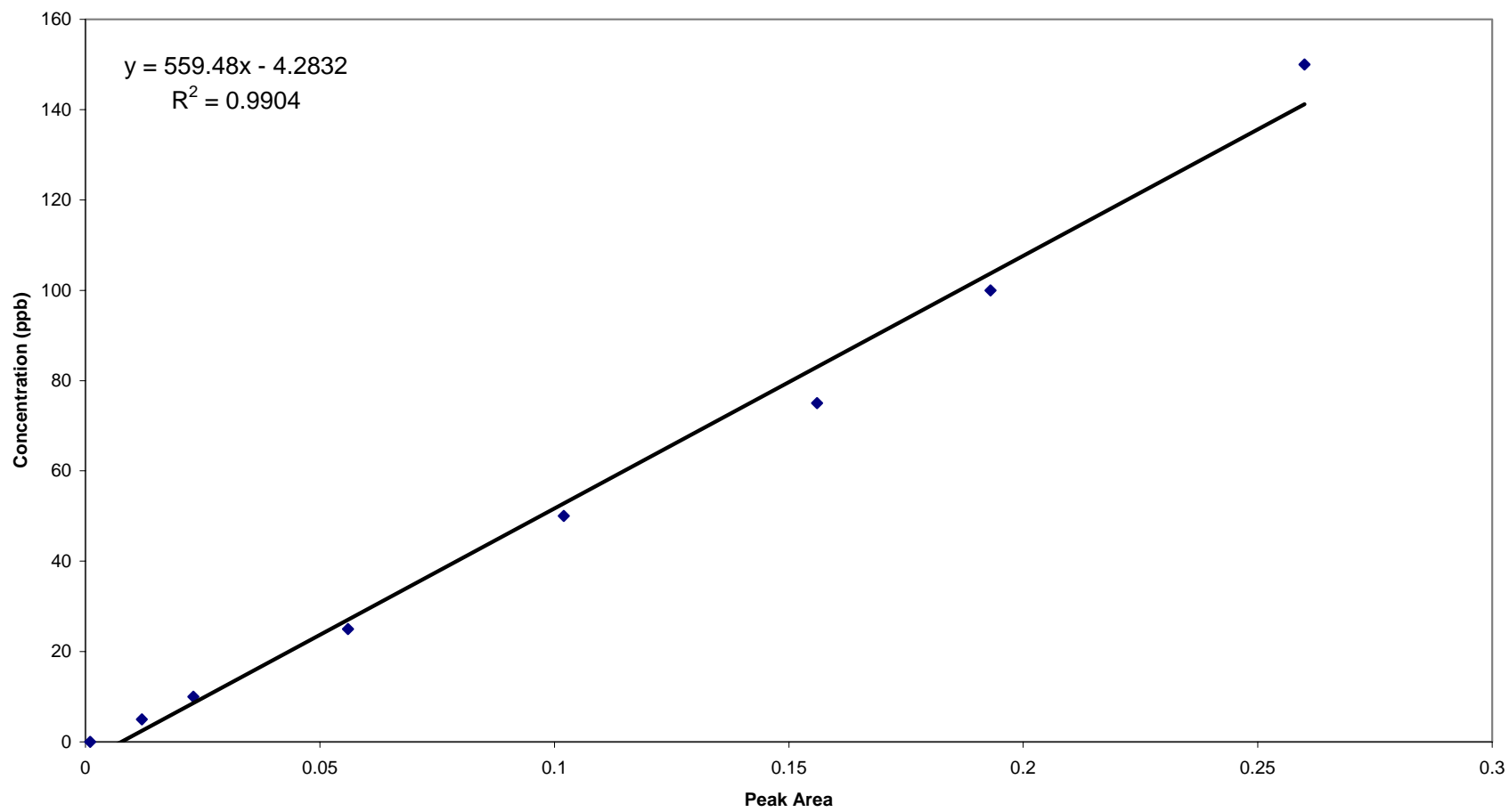


Figure B-4: Calibration Curve for Sample Group 4

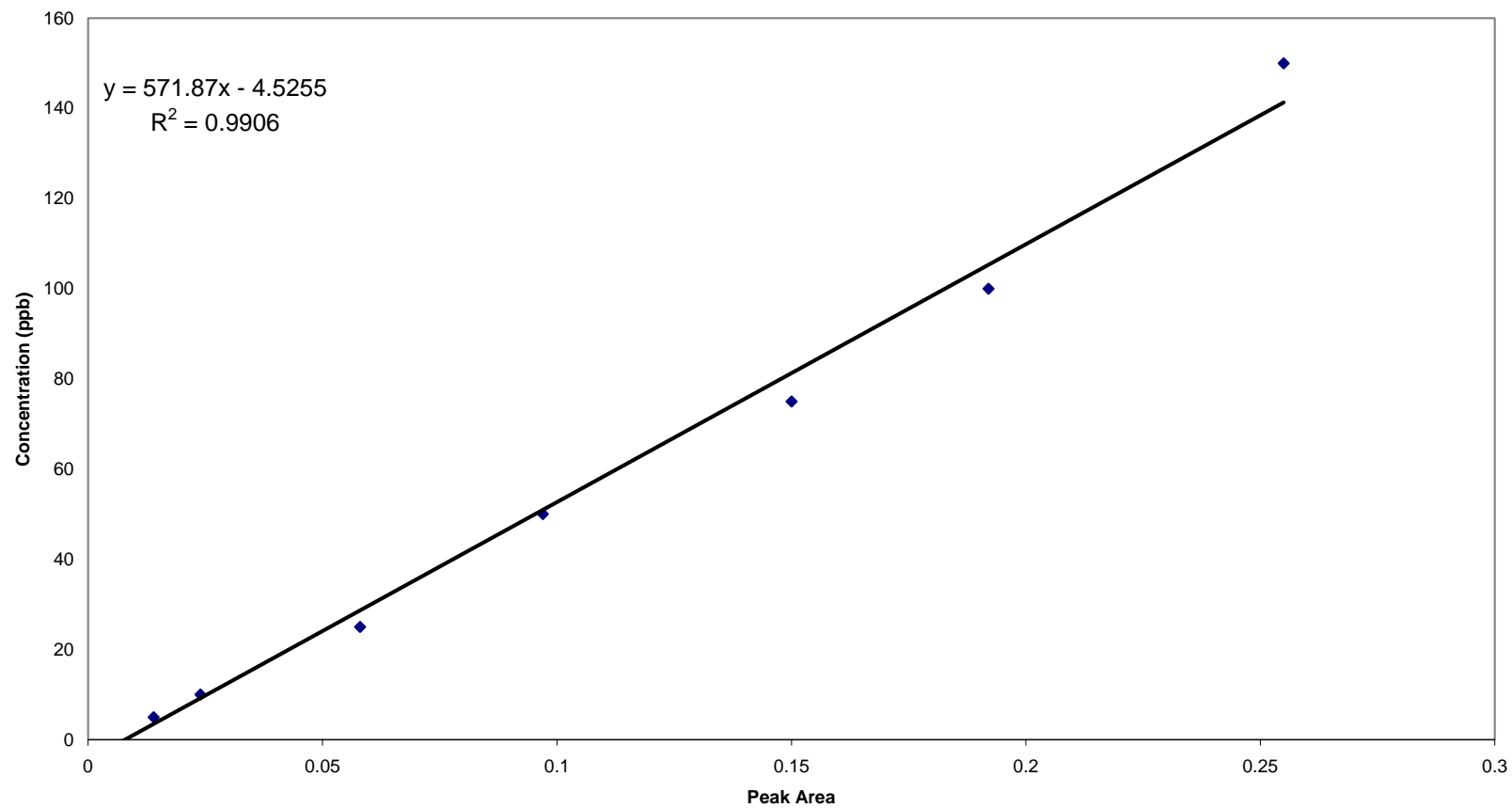


Figure B-5: Calibration Curve for Sample Group 5

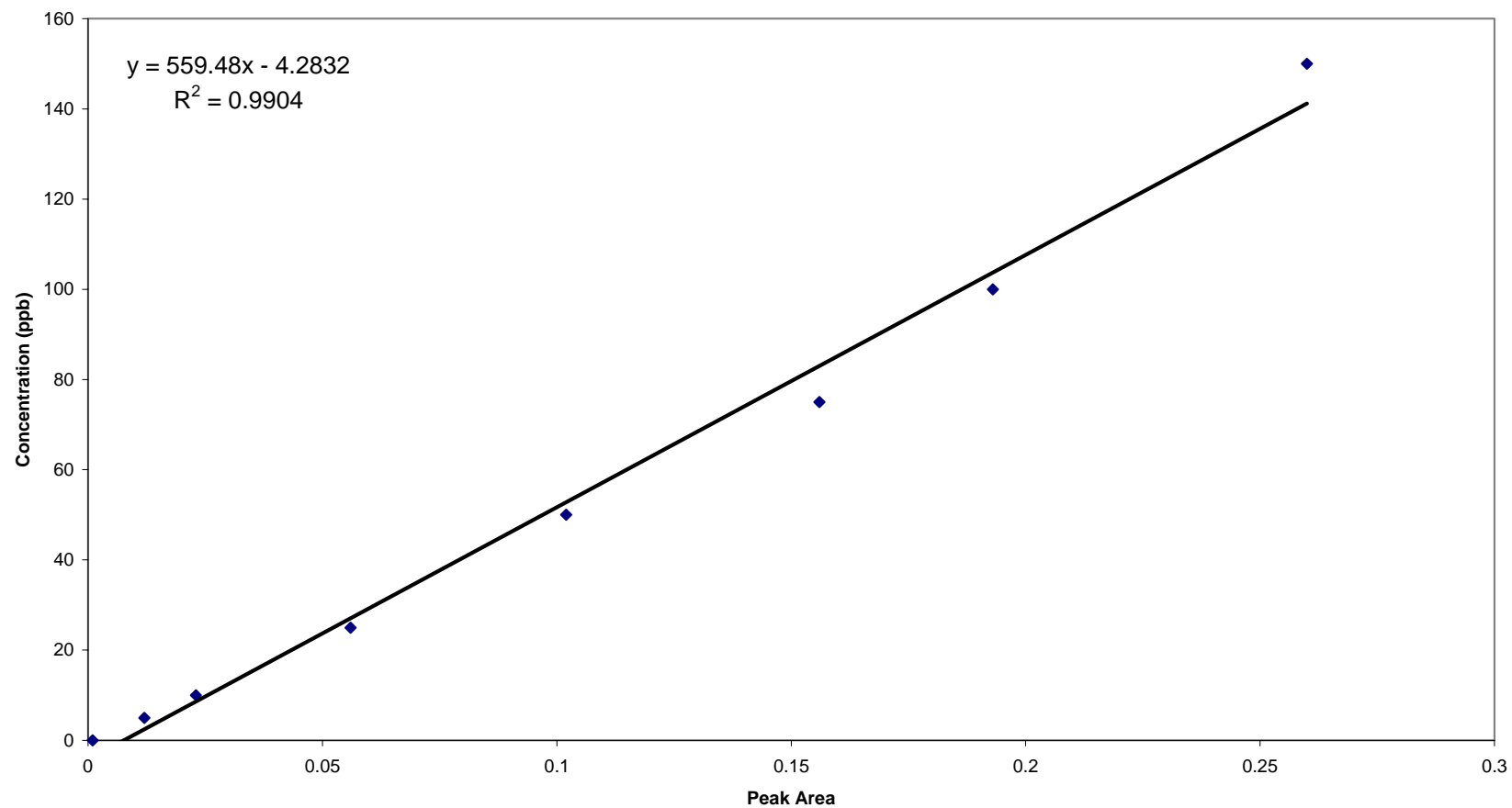


Figure B-6: Calibration Curve for Sample Group 6

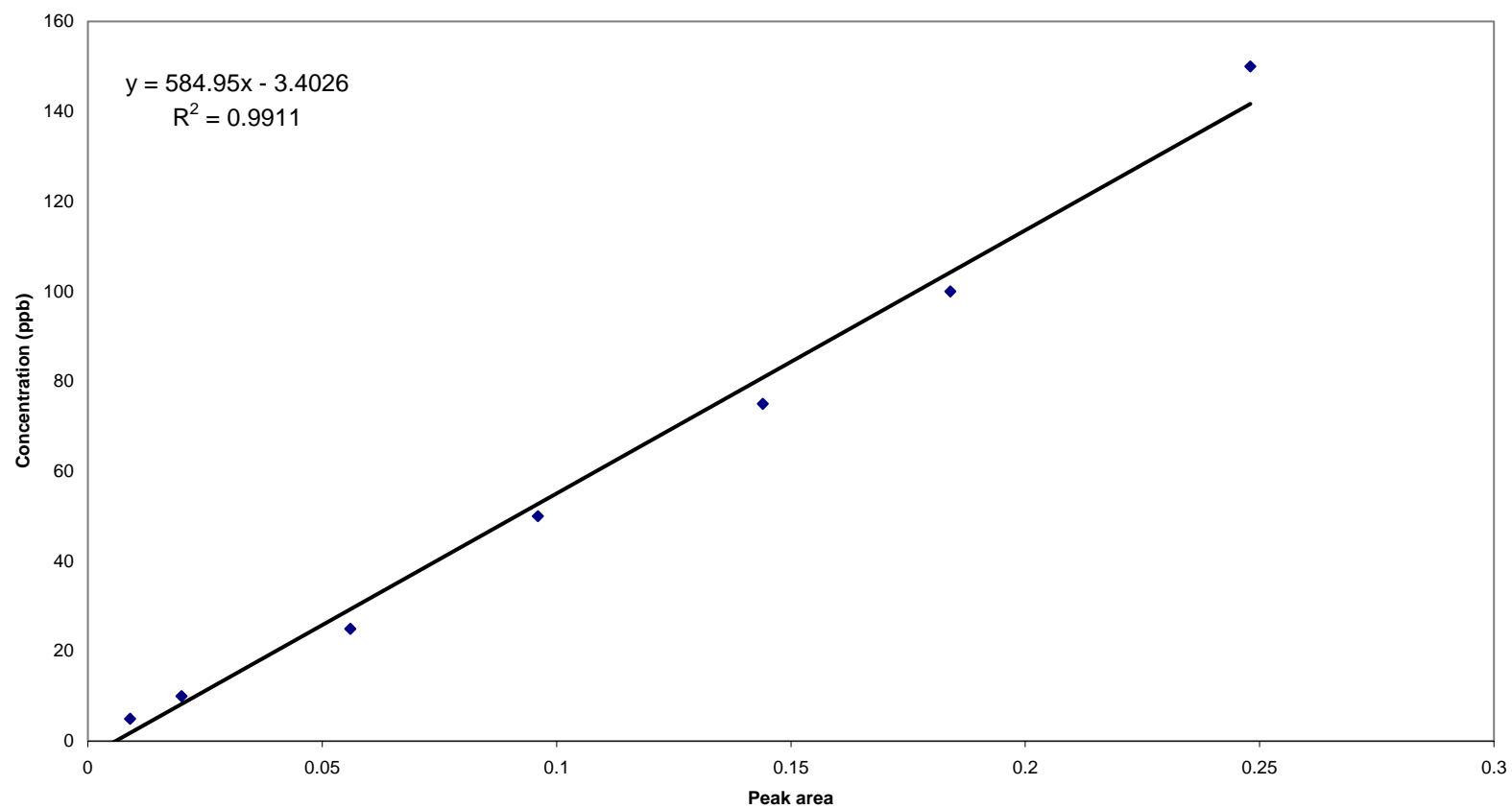


Figure B-7: Calibration Curve for Sample Group 7

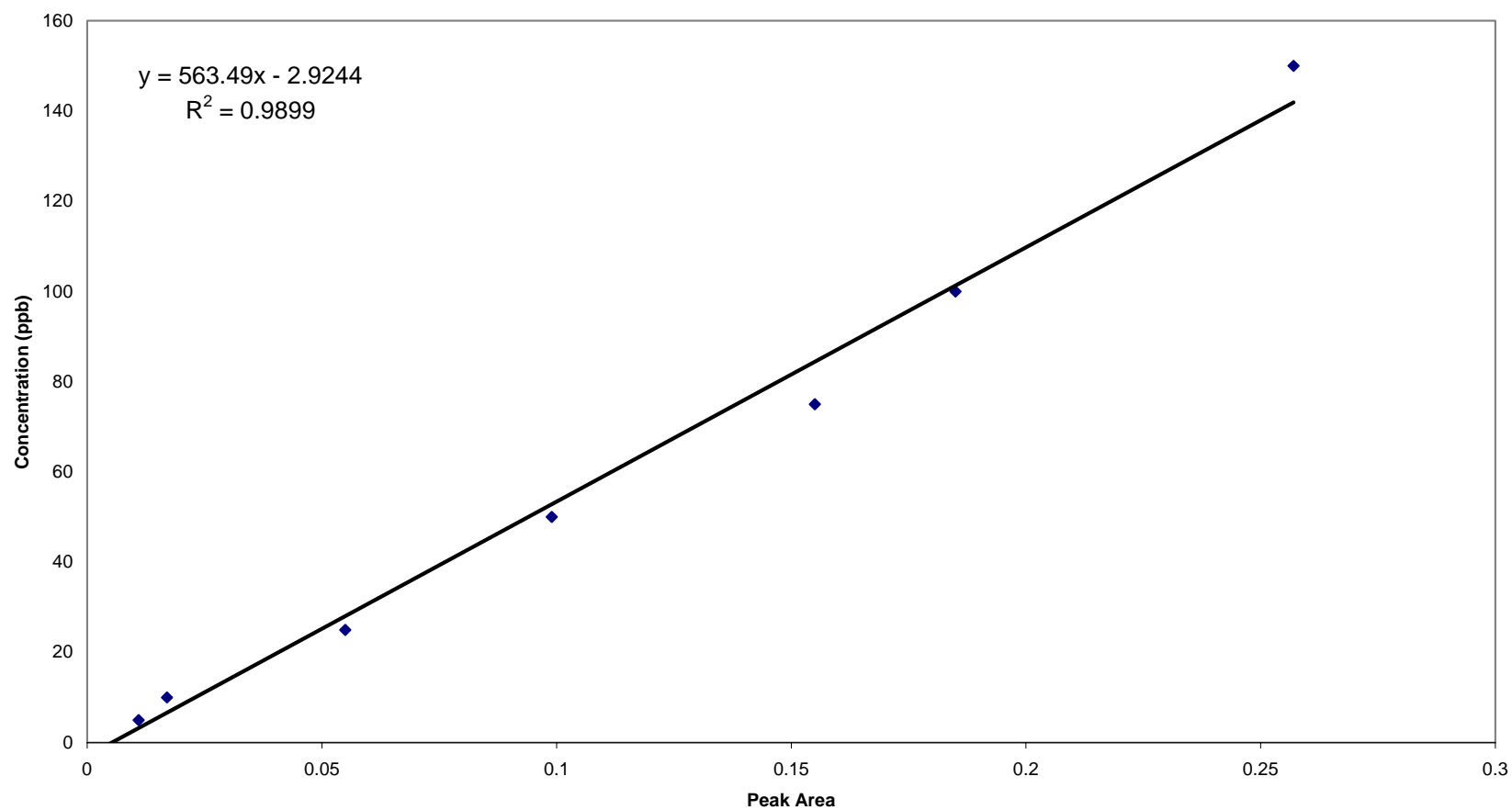


Figure B-8: Calibration Curve for Sample Group 8

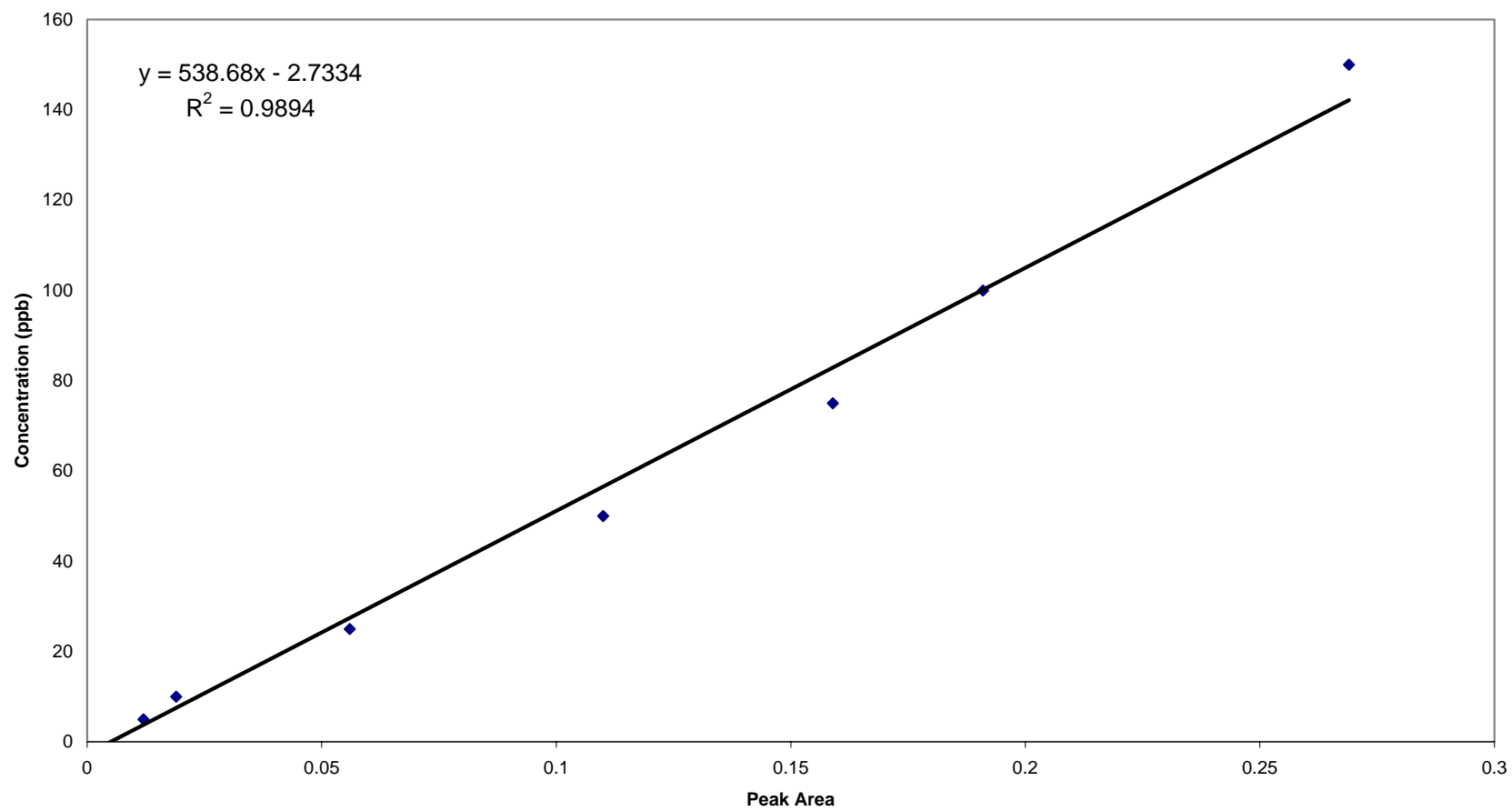


Figure B-9: Calibration Curve for Sample Group 9

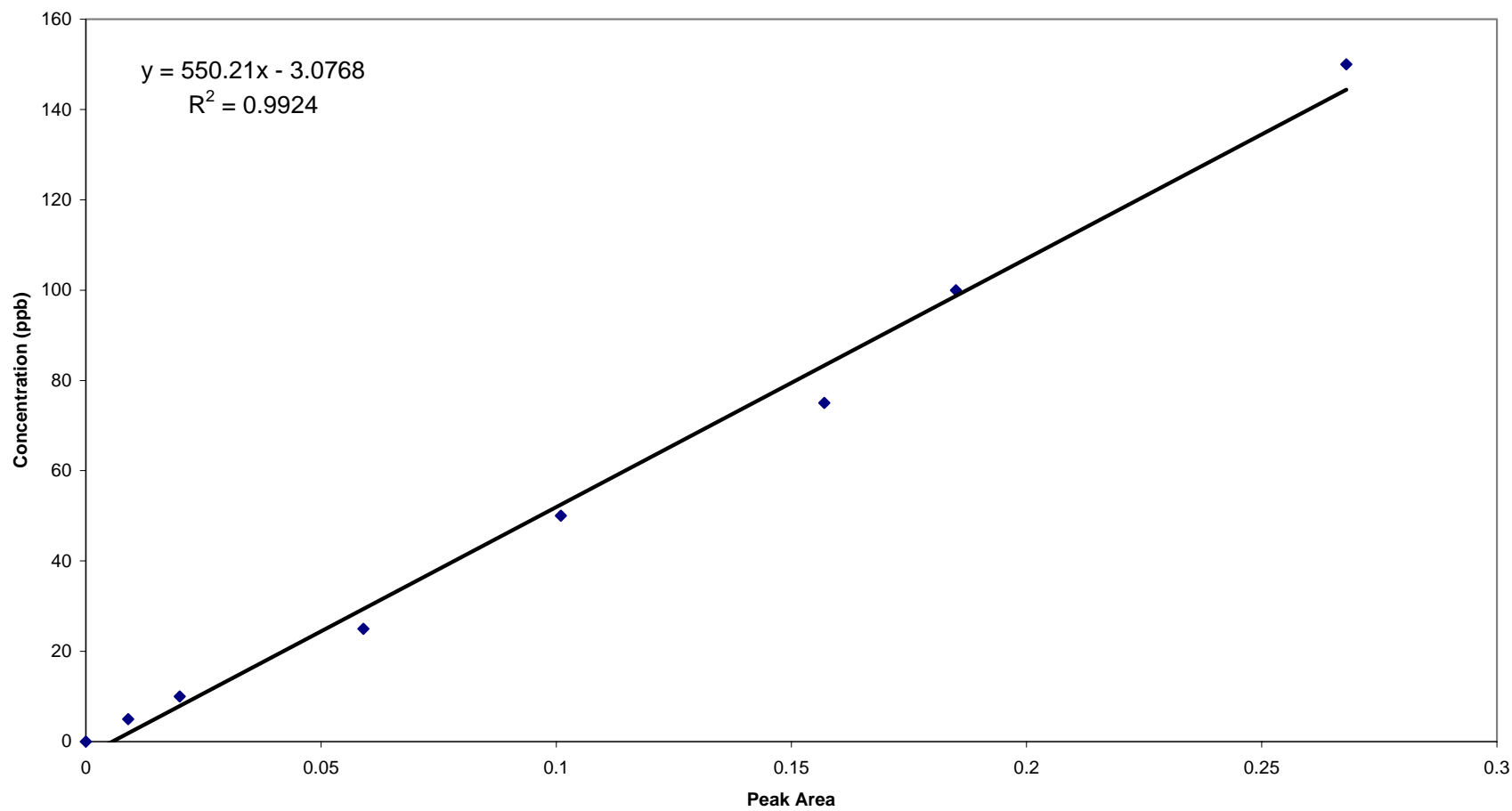


Figure B-10: Calibration Curve for Sample Group 10

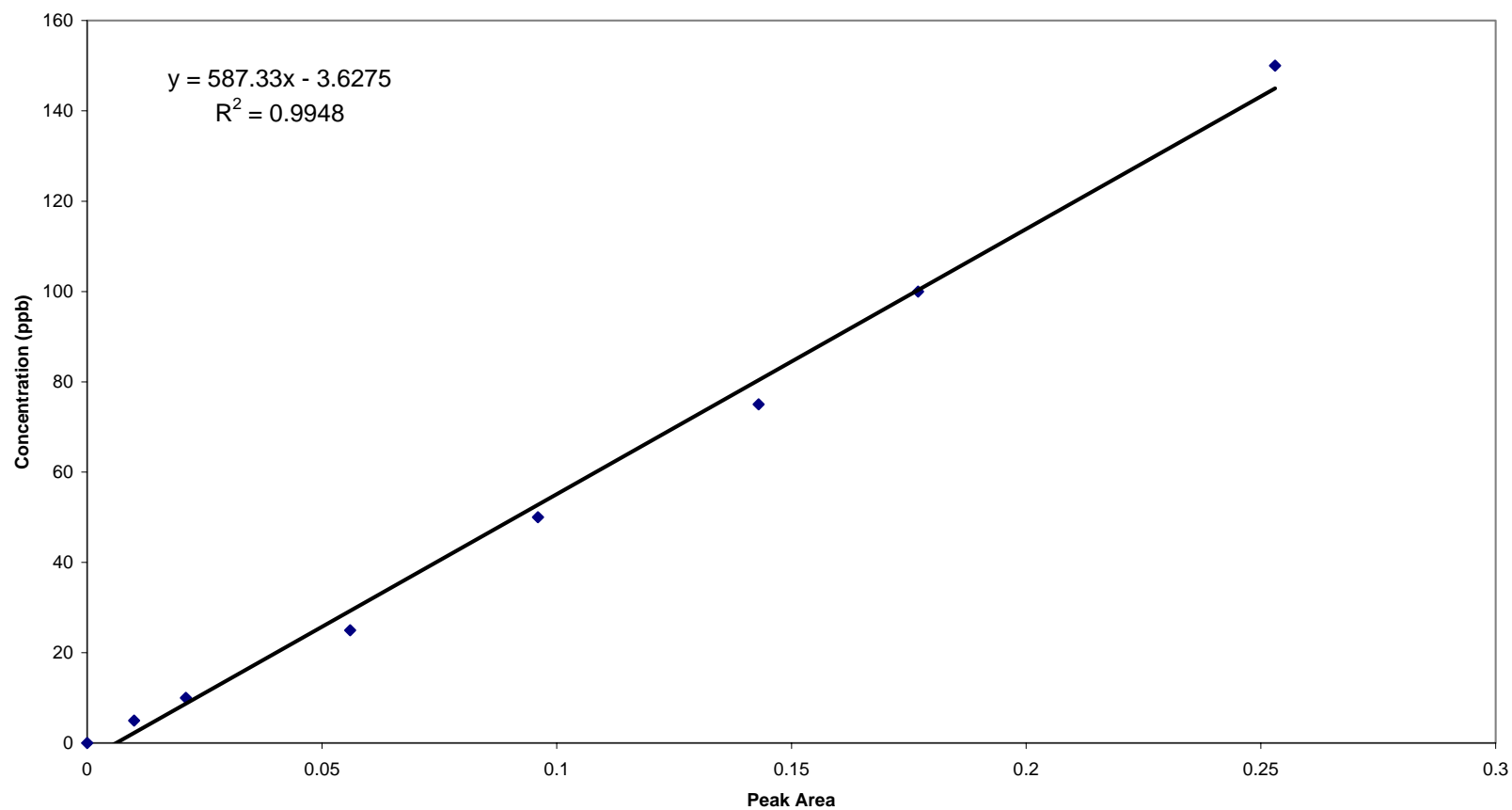


Figure B-11: Calibration Curve for Sample Group 11

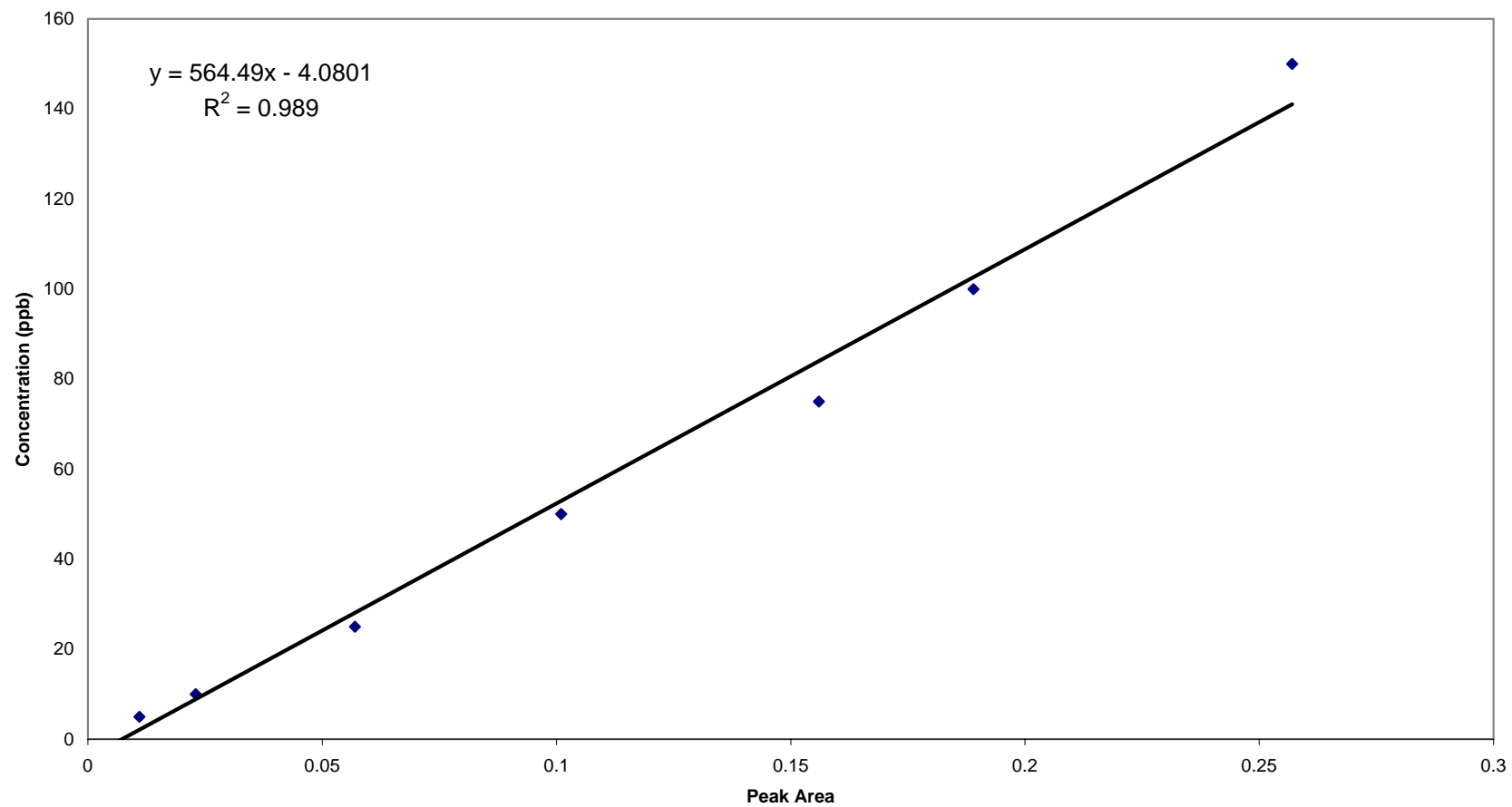


Figure B-12: Calibration Curve for Sample Group 12

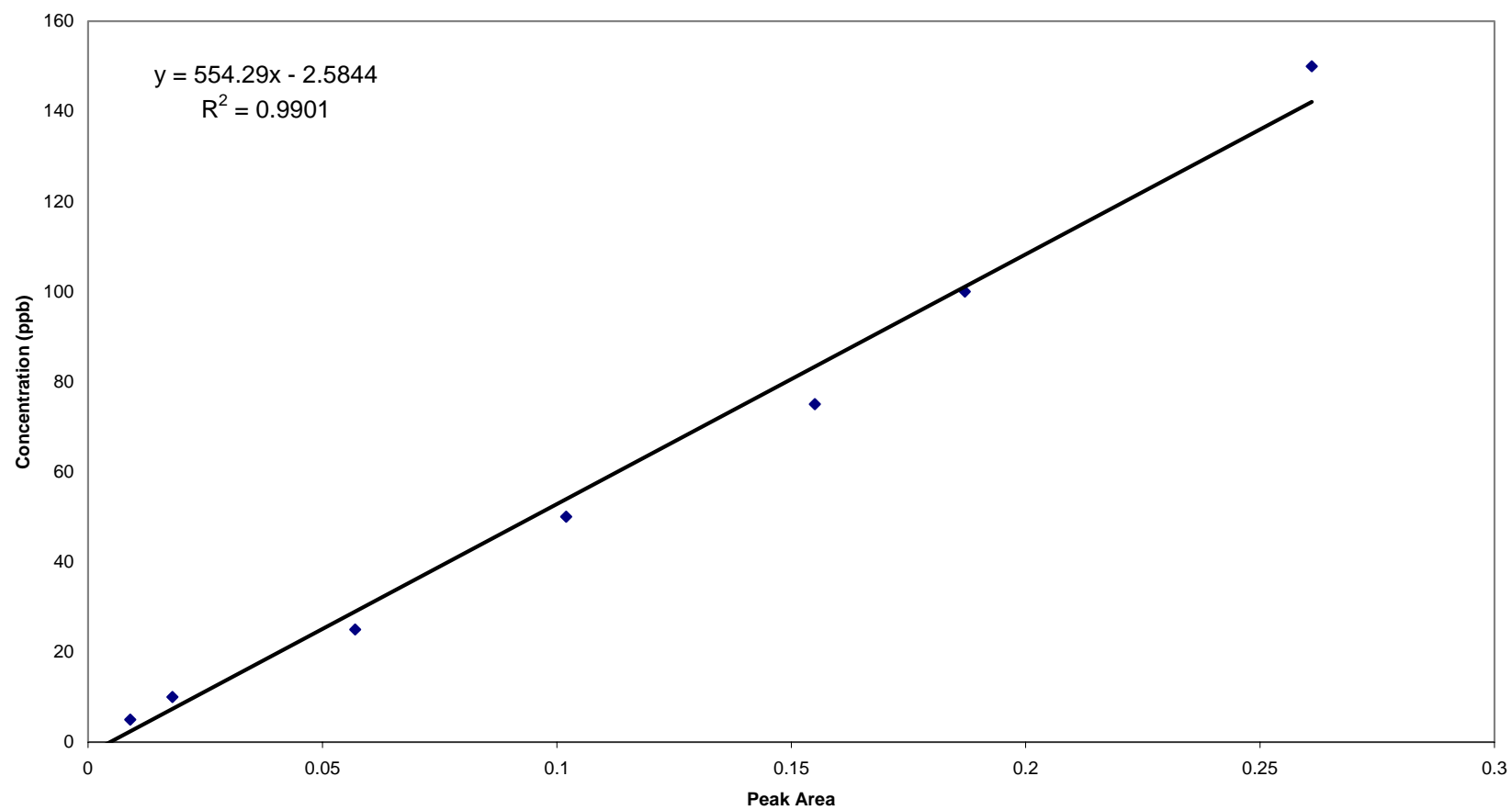


Figure B-13: Calibration Curve for Sample Group 13

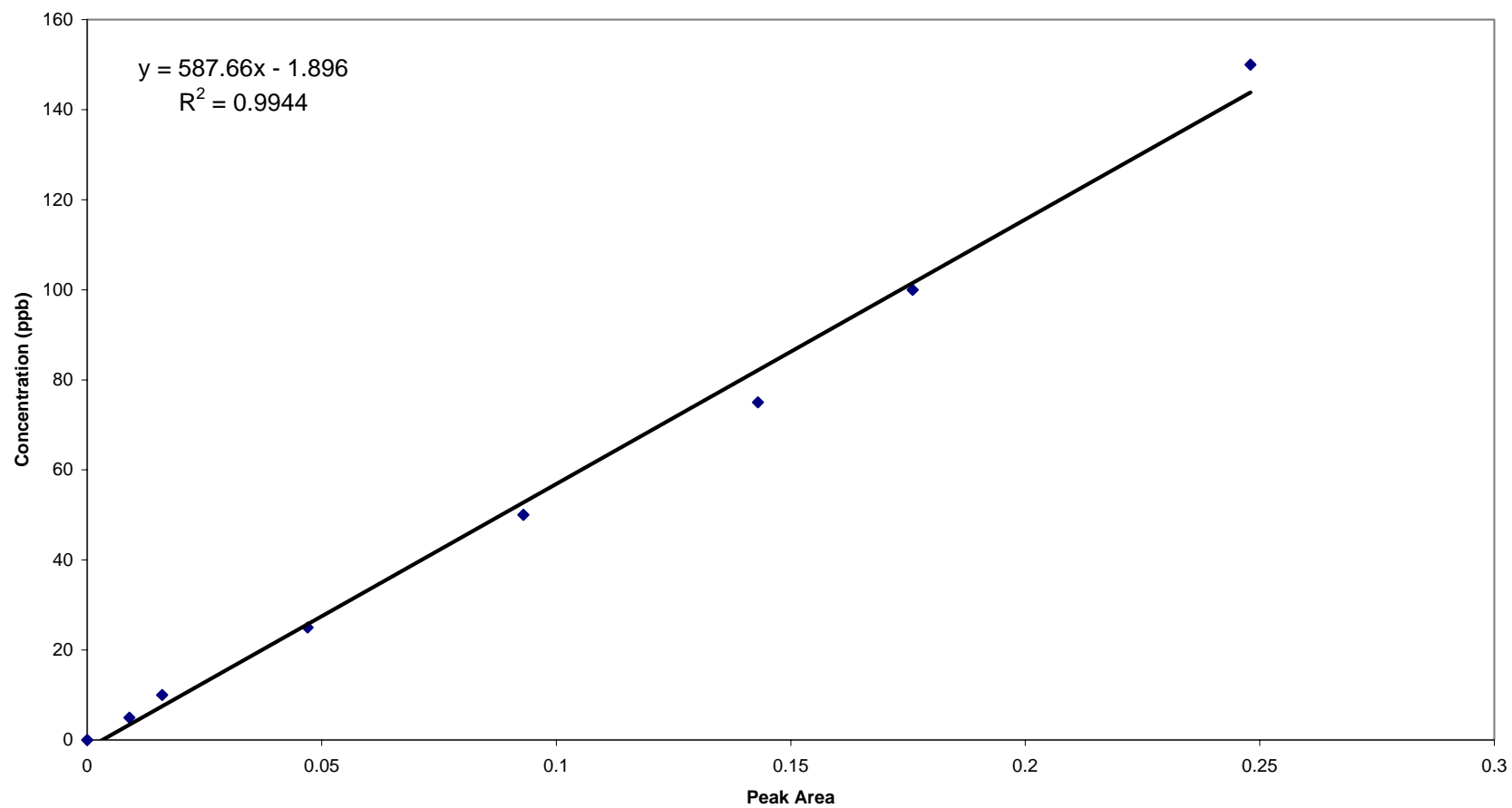


Figure B-14: Calibration Curve for Sample Group 14

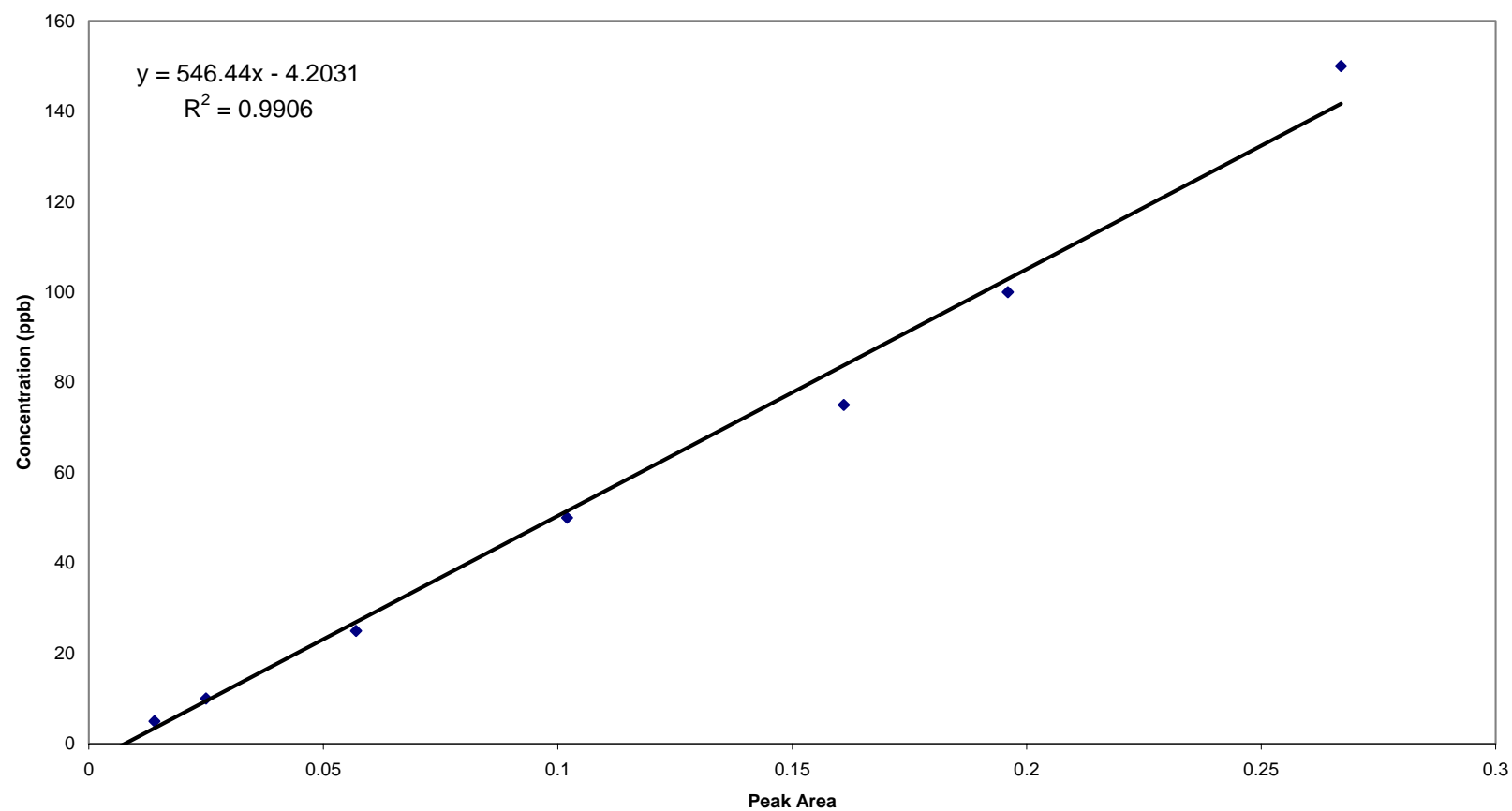


Figure B-15: Calibration Curve for Sample Group 15

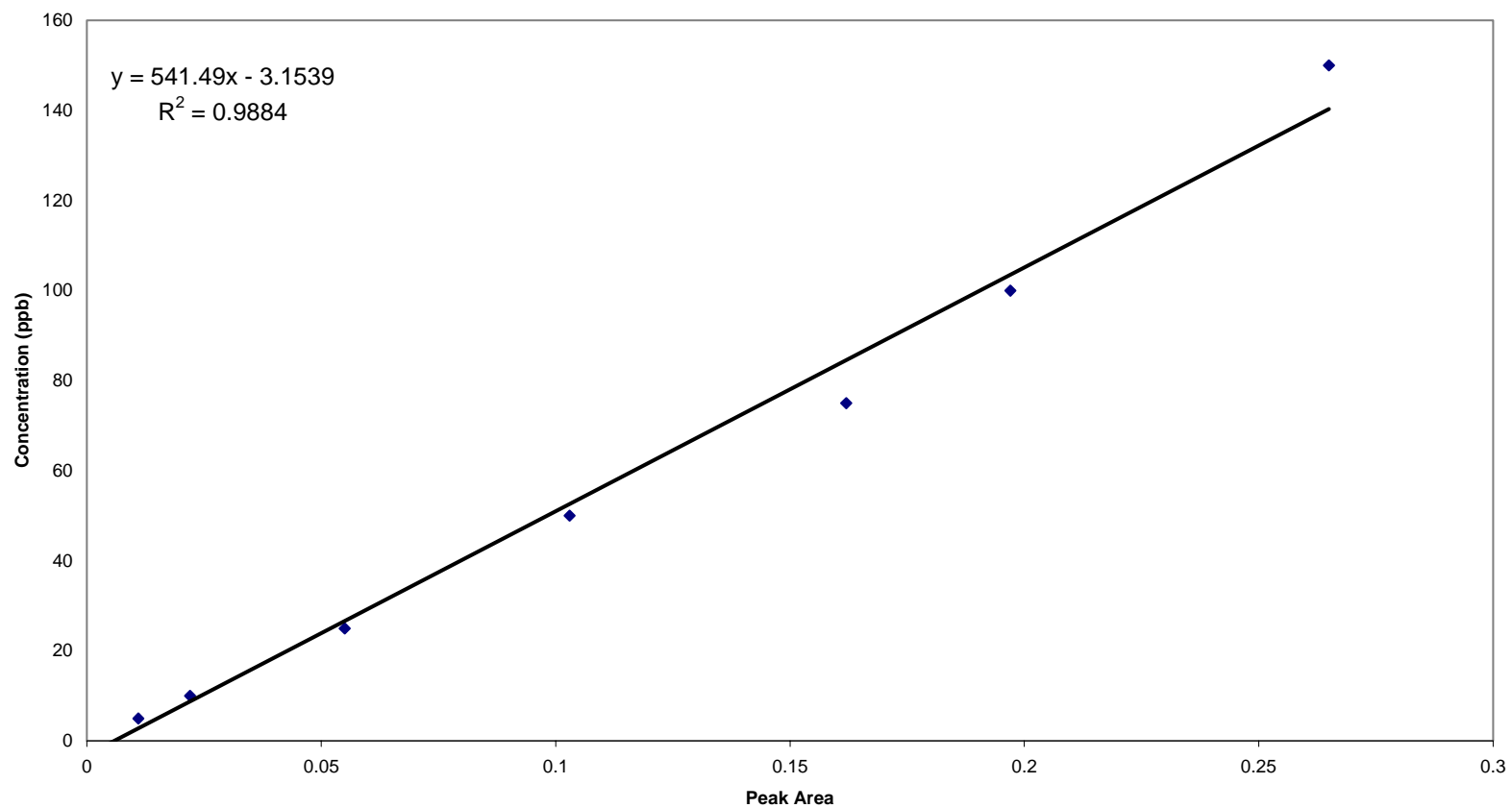


Figure B-16: Calibration Curve for Sample Group 16

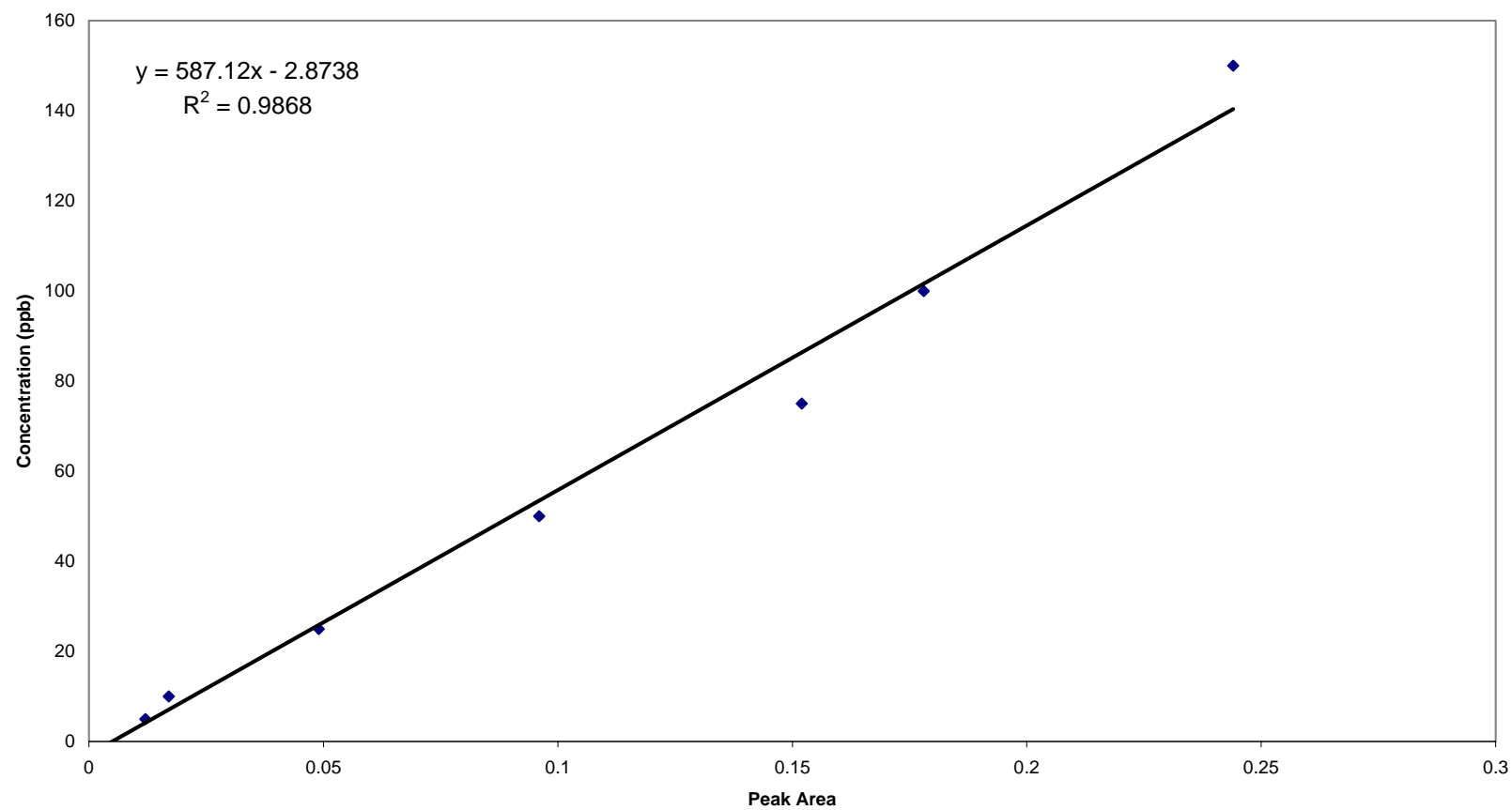


Figure B-17: Calibration Curve for Sample Group 17

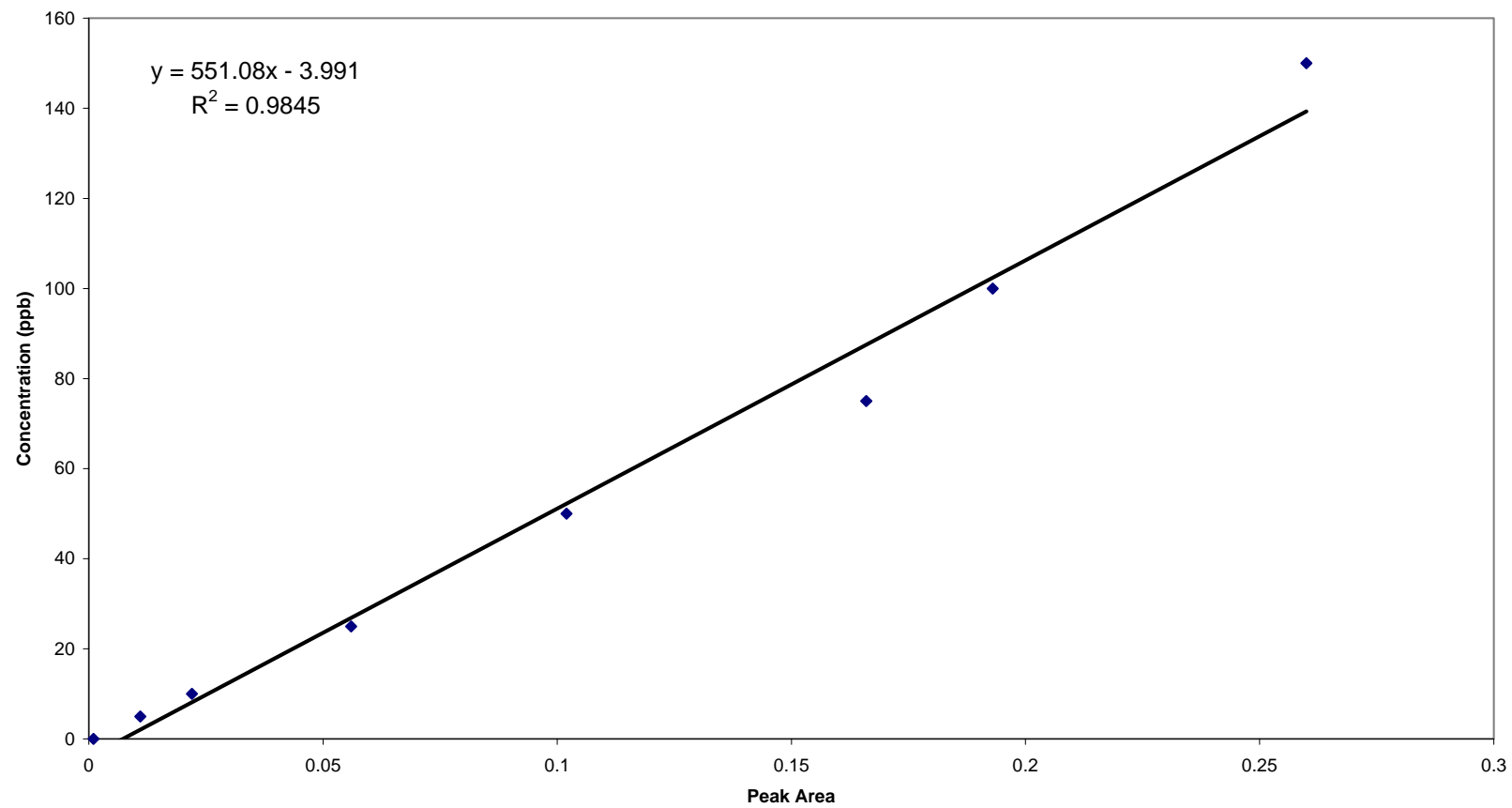


Figure B-18: Calibration Curve for Sample Group 18

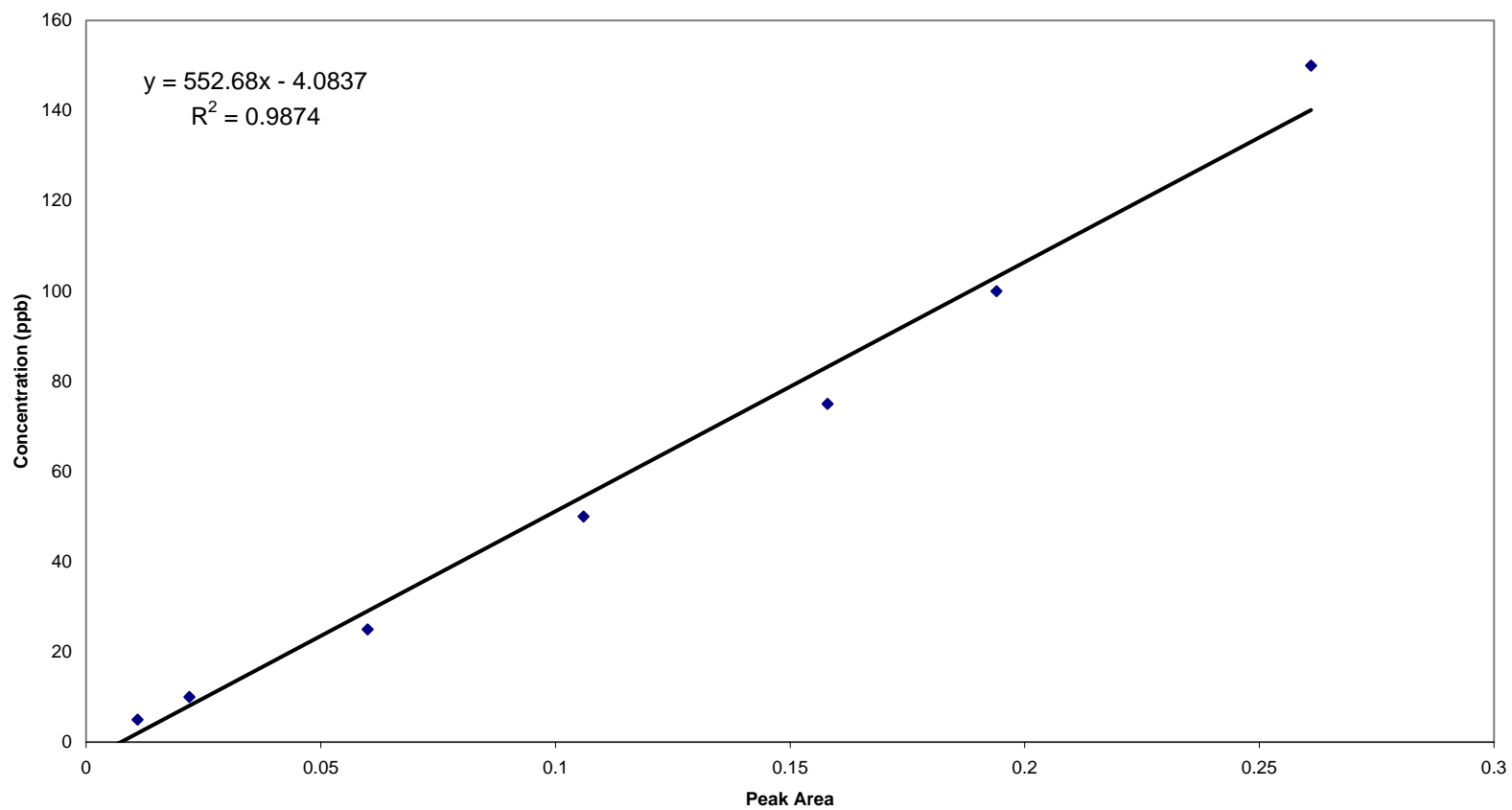


Figure B-19: Calibration Curve for Sample Group 19

Appendix C - List of Acronyms

MIT	Massachusetts Institute of Technology
DWSS	Department of Water Supply and Sewerage, Royal Government of Nepal
NWSC	Nepal Water Supply Corporation
UNICEF-Nepal	United Nations Childrens Fund, Nepal Chapter
MMAA	Monomethylarsonic Acid
DMAA	Dimethylarsonic Acid
WHO	World Health Organization
USEPA	United States Environmental Protection Agency
AES	Atomic Emission Spectroscopy
ICP-AES	Inductively Coupled Plasma Atomic Emission Spectroscopy
ICP-MS	Inductively Coupled Plasma Mass Spectroscopy
MS	Mass Spectroscopy
GFAAS	Graphite Furnace Atomic Absorption Spectrometry
STP-GFAAS	Stabilized Temperature Platform Graphite Furnace Atomic Absorption Spectrometry
GHAA	Gaseous Hydride Atomic Absorption
ASV	Anodic Stripping Voltammetry
NIPSOM	National Institute of Preventative and Social Medicine, Dhaka, Bangladesh