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Nepal Water for Health



Figure 1: Symptom of Arsenic Contamination on Foot, Nawalparesi, Nepal.

The Arsenic Contamination of the Drinking Water in Nepal

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The Arsenic Contamination of the Drinking Water in Nepal

DRAFT version 1

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July 2002

Acknowledgement

This document has been prepared by Nepal Water for Health (NEWAH). The task order project officers were Kim R. Adamsen, Advisor and Anil Pokhrel, Head of Technical Division NEWAH. Different drinking water stakeholders in Nepal have helped to supply data, especially Department of Water, Sanitation and Sewage by R.L. Chitrakar and N. Tandukar. Environmental and Public Health Organisation, (Enpho) by Director Dr. Roshan R. Shresta. Furthermore valuable information have been supplied by Mrs. Kalawati Pokhrel, Rural Water Supply and Sanitation Fund Development Board (RWSSFDB). Mr. Padam K.Khadka, Nepal Red Cross Society (NRCS) have supplied important information on the mitigation process.

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Abstract

Arsenic has been known for years to be a very poisonous element. Only 60 milligram can kill an adult human being instantly. Due to an assumed reduction of the microbiological contamination of the drinking water in developing countries, most stakeholders recommended and started to construct tube wells in rural areas to improve the microbiological contamination. On a worldwide scale these wells and the hand pumps are constructed in a variety of ways and extract groundwater from aquifers in different depths. Similarly private persons have the last two decades constructed millions of such tube wells. The improvement of the bacterial contamination have been shown to be questionable, since many tube wells in the third world are not constructed correct, and furthermore the last ten years have shown, that some aquifers are chemically contaminated by for example Fluoride and Arsenic compounds. Especially in South East Asia - Bangladesh, West Bengal and now also the lowlands of Nepal, the Arsenic concentration in the pumped "drinking" water have shown to be of such a magnitude that the population in these areas, by switching from surface water to groundwater, can be said to have come from the frying-pan into the fire. Millions will in the future develop a slowly killing cancer in the internal organs due to unhealthy Arsenic concentrations in the drinking water. What began as a benevolent attempt to provide safe drinking water to impoverished countries has turned into one of the worst environmental catastrophes of the 20th century, a disaster still awaiting a solution.

Relative to the Arsenic crisis the microbiological contamination of drinking water can be said to be acute or instantly, whereas the effect of the former develops over periods up to thirty years and hence can be referred to as chronic. This fact can give some financial and awareness type of problems, since an effective mitigation of the Arsenic contamination will only be seen after several years.

Lately measurements in the affected areas of Nepal have revealed concentrations almost double the highest measured in Bangladesh, the country which worldwide is believed to be the worst affected. Furthermore initial measurements the last two years in Nepal have shown that the average percentage of the contaminated wells is rising with the number of wells measured. Hence today, where less than 5 percent of the total number of wells have been measured, and most only once, the actual number of affected tube wells in Nepal is largely unknown.

By mathematical calculations and predictions based on several factor like the Nepali migration towards the lowlands, the population increase, the risk analysis, and the rising number with access to groundwater, the Arsenic calamity can be shown in future to reach similar levels of death rates in Nepal as the microbiological contamination, if and only if an effective measuring program, a throughout information campaign and the subsequent mitigation program is started immediately and "finished" within a few years. The later we start such effective programs the more the population will inevitability suffer, and since the effects of such mitigation programs is delayed up to thirty years, Nepal may reach a point, where the death rate curves, due to this problem, will be impossible or very difficult to bend.

In Nepal the very constructive co-operation between the Nepali Government and the different stakeholders on the Arsenic issue, have the last two years succeeded in an understanding and incipient action plans on the measuring, the awareness raising and the following mitigation. Furthermore the Nepali written press have the last months shown some interest for the Arsenic case, which will help to inform the broader population on the Nepali countryside. However the main problem in Nepal, presumably in contradiction to other countries in South East Asia and

elsewhere, is the lack of financial resources. Hence the very poor majority of the population in Nepal, can be said to be sitting on a ticking time bomb, as the internal cancer incidents accelerates, and although such Arsenic effects on the population in the affected areas is difficult to prove today, they will in the years to come be of such a magnitude that the country will be looking at death rates that best can be designated as a catastrophe.

No proven cure is known for the chronic arsenicosis, especially not in a poor country like Nepal. The only durable advice is to cease consuming the poisoned water immediately. After some time the relatives to this individual will know, if that advice came too late.

The situation in Nepal can be mitigated, and a proposal on how to do this is discussed below. However there is no doubt that this will involve a major cooperative effort from all stakeholders, both in terms of manpower, but naturally also in terms of financial input from the Nepali government hopefully by the help of foreign donors. These efforts should be intensified immediately to continue the initial attempts and to exploit the constructive atmosphere among the present stakeholders for the benefit of the Nepali population.

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List of Abbreviations and Acronyms

AAS	=	Atomic Absorption Spectrophotometer
app.	=	Approximately
Aquifer	=	The water bearing sandy underground from which it in principle is possible to pump sterile drinking water.
As	=	Chemical notation of the element Arsenic
As(III)	=	As ₂ O ₃ , Arsenic trioxide.
As(V)	=	As ₂ O ₅ , Arsenic pentoxide
Arsenate	=	AsO ₃ ⁻ , pentavalent Arsenic
Arsenite	=	AsO ₂ ⁻ , trivalent Arsenic
Avg	=	Average
BAL	=	dimercaprol
BGS	=	British Geological Society
Cf.	=	Confer; Compare with, See.
conc.	=	Concentration or concentrated.
Copernicus	=	Search software, which searches on 10 search machines at the same time. A 2 Mb exe file must be downloaded first to install the special Copernicus search browser (www.copernic.com).
CRO	=	Central Regional NEWAH Office
DWSS	=	Department of Water, Sanitation and Sewage.
DFID	=	Department for International Development, England
DoMG	=	Department of Mines and Geology.
DTW	=	Deep Tube Well. (For example a 6 inch borehole drilled by a constructor to 110 meters or more
EC	=	European Community
e.g.	=	Exempli Gratia = For example
EDCD	=	Epidemiology and Decease Control Division
Epidemiology Section / DHS		
Enpho	=	Environmental and Public Health Organisation, Funded by Italy.
ERO	=	Eastern Regional NEWAH Office
etc.	=	Etcetera, And so on.
Fe	=	Chemical notation for Iron
ff	=	And the following pages
Finnida	=	Finish Government Organisation for Developing Countries.
FWRO	=	Far Western Regional NEWAH Office
GPS	=	Global Positioning System. A satellite system on which the latitude and longitude can be found all over the earth.
HQ	=	NEWAH Headquarter in Kathmandu
HCl	=	Hydrochloric acid.
IDS	=	Integrated Development Society. Funded by Plan International, Works in Banke and Makawanpur districts. Measures with Merck.
JICA	=	Japanese International Co-orporation Agency
JRCS	=	Japanese Red Cross Society
Kg	=	kilo gram = 1000 grams
KI	=	Potassium Iodine
km ²	=	Square kilometre.
l	=	liter
lab	=	Laboratory

µg/l	=	One millionth of a gram per litre.
m	=	Meter
mg	=	Milli Gram. One thousand of a gram.
µg/l.	=	Micrograms per litre. One millionth of a gram per litre.
MBT	=	Main Boundary Thrust
MCT	=	Main Central Thrust
MoH	=	Ministry of Health.
MoPE	=	Ministry of Population and Environment.
MWPP	=	Ministry of Water Resources, Physical Planning & Public works.
MWRO	=	Mid Western Regional NEWAH Office
NASC	=	National Arsenic Steering Committee
NEWAH	=	Nepal Water for Health, Funded by DFID and Wateraid.
NIGAM	=	NGO's Informal Group for Arsenic Mitigation
NGO	=	Non Government Organization.
NPC	=	National Planning Commission
NRCS	=	Nepal Red Cross Society, Funded by JRCS.
Nrps	=	Nepali Rupees. 1 US\$ ~ 78 Nrps.
NWSC	=	Nepal Water Supply Corporation
ppb	=	Parts per billion. The usual unit used in popular literature. The correct unit is µg/l
RONAST	=	Royal Nepal Academy of Science and Technology
RWSSFDB	=	Rural Water Supply and Sanitation Fund Development Board.
RWSSSP	=	Rural Water Supply and Sanitation Support Project, Funded by Finnida.
sec	=	Seconds
sludge	=	A hand technique to drive a pipe into the aquifer using the pressure of the water.
STW	=	Shallow Tube Well often only named a Tube Well. (For example a 1½ inch pipe hammered or sludged (se "sludge") into the ground not below the suction limit of 10 meters. NEWAH uses both methods to install Tube Wells.)
Terai	=	The Southern Lowlands of Nepal.
TW	=	Tube Well. See STW and DTW.
VDC	=	Village Development Committee. Nepal is divided up into 73 VDC's
WHO	=	World Health Organisation.
WRO	=	Western Regional NEWAH Office
UNICEF	=	United Nations Children's Fund
USEPA	=	United States Environmental Protection Agency.
>	=	Greater than or above
<	=	Less than or below
± 10 %	=	Plus or minus 10 %
~	=	Approximately equal to.
=	=	Equal to.

Further chemical abbreviations on different elements are used in 0, page 70. As (Arsenic), Al (Aluminium), B (Boron), Ba (Barium), Ca (Calcium), Co (Cobalt), Cr (Chromium), Cu (Copper), Fe (Iron), K (Potassium), Li (Lithium), Mg (Magnesium), Mn (Manganese), Na (Sodium), P (Phosphorous), Si (Silicon), SO₄ (Sulphate), Sr (Strontium), V (Vanadium), and Zn (Zinc).

Notation

A consequent notation has been used throughout this paper:

Abbreviations

The first time an abbreviation is used the full name is shown in the text, followed by the abbreviation in parentheses. Like for example: Nepal Water for Health (NEWAH) is a Non Governmental Organisation (NGO). On page 9 above a list is shown of all abbreviations and acronyms used in this text.

References

On page 69 a list of the references is shown. Only books and texts referred to in the text is shown on this list. Referring to such a reference is done in square brackets like. [**United Nations**: Geology and Mineral Resources of Nepal, New York 1993. page 75 ff.] The Author is first shown bolded, thereafter the title and the publication place, and at last the year.

Footnotes

In 0 Appendix 4:, and Appendix 5: footnotes are used to refer to the many Acute and chronic health implications mentioned in the literature. Each footnote is denoted by an "x" and the note is shown at the bottom of the page. The footnotes are numbered consecutive according to appearance.

The Unit of Measurement and the Chemical Notation

The Arsenic compounds, which occurs in water are measured in one millionth of a gram per litre (micrograms per litre = $\mu\text{g/l}$). In popular literature this is often shortened to the dimensionless unit: ppb = parts per billion. This indicated that Arsenic is difficult to measure and that very small amounts are hazardous for not only the human life but for all life-forms on our mutual planet. Both of these indications are true. In the professional literature Arsenic is often abbreviated as the chemical notation: "As".

Division of Internet Addresses

Some of the Internet Addresses referred to in the text are too long for one line. They are divided by a "-". This is to be deleted, before the address is copied into the address line of the browser. This is the reason why divided addresses are not in the original file made as hyperlinks. Not divided addresses are shown as hyperlinks. Some addresses might furthermore after some time be out of date, as the Internet is constantly developed and therefore change continuously. If this is the case it is recommended to search for specific words in the reference using a search machine like Copernicus (www.copernic.com). A not complete version of this browser is free of charge and has been used to prepare this document.

Document Organization

This document contains the following chapters:

Chapter 1: Introduction, page 15.

This chapter explains about safe drinking water as a human right and introduces to the element of Arsenic. It explains about the prevalence in the environment and the difference between the industrial deposits and the natural occurrence.

Chapter 2: The Adverse Health Effects, page 17.

The Health consequences by intake of Arsenic compounds in acute and chronic amount are explained. A more throughout direct list of observations from the effects is presented in 0 The Acute and Appendix 4: The chronic effects.

Chapter 3: The Origin of Arsenic in Ground Water. The Worldwide Situation, page 19.

Four different theories on the chemical and geological origin of the problem on a worldwide scale. These theories are put into the context of the situation in Nepal. And in the end of the chapter the situation in other parts of the world is briefly mentioned. The situation in Bangladesh is discussed in 0.

Chapter 4: The Arsenic Problem in Nepal, page 22.

The specific situation in Nepal is discussed in detail. The location of the problem, the total number of tube wells in Nepal, the percentage of the affected wells in Nepal, and the problems of determining these percentages. An analysis of the depths where the Arsenic concentration decreases is shown and compared to a similar investigation of the data from Bangladesh.

Chapter 5: NEWAH's initiative of testing Thermal Springs, page 27.

In order to support the research on the origin of the Arsenic problem in all of South East Asia, it is necessary to conduct investigations in the Himalayan parts of Nepal, where most large rivers feeding the countries south of Nepal. NEWAH have performed measurements in the hot springs of the mountains, where the concentration is presumed to be highest.

Chapter 6: The Organizational Setup in Nepal, page 29.

In Nepal different committees have been initiated on the national, the NGO, and the regional level. This organizational setup involving all the important stakeholders is important to coordinate the arsenic and other guideline value investigations.

Chapter 7: Guideline Values, page 32.

An explanation of the latest development on the international discussions of the drinking water guideline values, and different countries levels endorsed by parliaments and national environmental agencies. The interim arsenic guideline value in Nepal is discussed and compared to other neighbouring countries. Latest the NEWAH guideline value policy is explained.

Chapter 8: A Mathematical Model, page 36.

Based on the international risk analysis, the migration in Nepal towards the lowlands, the population growth, the increases usage of tube wells and the assumption of the effectiveness of the mitigation program in Nepal, the calculation of the number of the future cancer incidents and the prevalence of skin disorders is done.

Chapter 9: Proposed Solution to the Arsenic Problem, page 38.

The discussion so far in NEWAH, Nepal and internationally have a tendency to concentrate on the reason and the magnitude of the arsenic problem. The necessary plans involving awareness raising among local and international agencies, fundraising, measuring programs, mitigation and plans for the disposal of the arsenic rich waste is discussed and formulated as an overall proposal.

Chapter 10: The Measuring Program in Nepal, page 39.

The discussion of whether for example Iron could give a hint on the occurrence of Arsenic in the groundwater, and the problem of "ownership" of the water installations, since a typical Nepali village have tube wells installed and funded by more than one agency Furthermore a list of all the available field kits is shown and the individual products are briefly evaluated. The modified Gutziet method is shown in detail, and an explanation of why NEWAH uses three methods to measure the samples is done. A list of the equipment to be brought to do field investigations, and a list of the equipment in the NEWAH regional laboratories is shown.

Chapter 11: The Mitigation Plan, page 48.

Chapter 12: The Microbiological problem in Nepal, page 51.

Chapter 13: Conclusion, page 52.

Chapter 14: Recommendation and further work to be done, page 53.

Appendix 1: Location of the Thermal Springs in Nepal., page 54.

Table of the thermal springs in Nepal. The GPS location and the name. Table of the discharge and temperature of different thermal spring in Nepal.

Appendix 2: List of Internet sites, page 56.

A list of the Internet sites of the guideline value stakeholders in Nepal. Furthermore lists of different international drinking water agencies.

Appendix 3: Pathological Picture of Acute effects of Arsenic Compounds , page 58.

The known internationally described effects of acute poisoning of patients. A list of the breakdown of different organs in the body.

Appendix 4: Pathological Picture of Chronic effects of Arsenic, page 63.

The internationally describe effects of arsenic poisoning classified as chronic. Description in medical terms of different effects in different parts of the body.

Appendix 5: Cures, Medical, and Industrial Usage of Arsenic, page 66.

The internationally investigations on different medical preparations, which have had some effect on patients treated for acute and chronic intakes of arsenic compounds. The former medical usage and the former and present industrial usage is described.

Appendix 6: The Tube Wells installed by NEWAH in Terai, page 69.

A list of the approximately 6000 tube wells which over the years have been installed by NEWAH. The list is divided up into the five Nepali regions and furthermore in the districts.

Appendix 7: The Arsenic Problem in Bangladesh, page 70.

An explanation of the situation in Bangladesh, a map produced by NEWAH on the basis of a throughout 3500 datasets from DFID / G, the Arsenic concentration, GPS location, Iron content, depth of well, etc. Further discussion on the basis of the data from Bangladesh concerning the origin of the Arsenic problem is done. The number of wells constructed over the years is shown, and that the awareness campaign in Bangladesh have stopped construction of new wells. The wash out effect of Arsenic on wells used for more that 60 years is shown not to have any effect on the concentration. Finally it is shown that the Arsenic bearing layers in Bangladesh are 175 meter thick.

1 Introduction

1.1 Safe Water

Water is the most essential element for all beings and plays a vital role for the entire life cycle on our mutual planet. Life needs water. Human beings needs *safe* drinking water. Thus presence of unwanted and unfortunate contaminants in drinking water makes it unacceptable to drink for humans from both an aesthetic and a health aspect, and can have severe implications for all life forms. In order to be used as a healthful fluid for human consumption, water must be free from organisms that are capable of causing a number of diseases and from minerals and organic constituents that produces various, adverse physiological health effects. Hence we have in the later years witnessed a justified raising demand for *safe* drinking water in the World, and today this is by most organizations regarded as a Human Right.

Unfortunately water is a universal solvent, which can dissolve a variety of solids. None known solvent can dissolve the same number of different substances as water. Such dissolutions of myriad of solids cause the contamination of especially the drinking water by various harmful contaminants. One of the substances that water can dissolve is various chemical combinations of the element *Arsenic*.

1.2 Arsenic

Arsenic is considered as one of the oldest, most dangerous poisons, and is a well defined contaminant, which has various acute and chronic health effects on the human health. Cf. chapter 2. The Adverse Health Effects and [Kim R. Adamsen: Arsenic Impact, Internal NEWAH note, 2001]

Arsenic is a shiny metalloid, but dissolved in water or on gaseous form, humans cannot detect its presence. We cannot see, taste, or smell, if the water or food we drink or eat is contaminated with Arsenic compounds. We can however feel it, since Arsenic compounds depending on the intake severely damages human health, and the sight of its effects is not pleasant. Ultimately infected persons die, either immediately and acutely from a variety of effects caused by the very poisonous substance or indirectly after a chronic exposure, which eventually causes skin and internal cancers, since Arsenic by the US Environmental Protection Agency (USEPA) have been classified as a highly carcinogenic compound. [WHO: Environmental Health Criteria 224, Arsenic and Arsenic Compounds, <http://www.inchem.org/documents/ehc/ehc/ehc224.htm>, 2001], [USEPA: Proposed Arsenic in Drinking Water Rule: Regulatory Impact Rule, 2000]

1.3 Arsenic Compounds in the Environment

Various Arsenic compounds occur naturally in the environment in different concentrations. Activities by humans can furthermore lead to an unintentional release of Arsenic components considered unhealthy for life in general and specifically for humans. These activities includes among others (Cf. this chapter below) the industrial activities (Cf. Appendix 5:page 66) and the activities to provide safe drinking water to the population. (Cf. chapter 3.1, explanation A, page 19.)

Arsenic is ubiquitous in nature and occurs in all environments. The concentration in the earth's crust is on average 2 mg/kg. The well known natural processes like weathering of rocks, biological and volcanic activities are the dominant natural processes of arsenic release in the environment, whereas smelting of non-ferrous metals, manufacture of various arsenic compounds, burning of fossil fuel, incineration of arsenic containing substances and the

extensive use of arsenical pesticides, fertilizers, herbicides and pharmaceuticals cause the anthropogenic release of arsenic in the earth's environment. Since arsenic is indestructible in nature it can travel through the various pathways and can enter from one segment to another segment of the environment. [**Kim R. Adamsen**: Arsenic memo, Internal NEWAH note, 2001]

1.4 Industrial Contamination of the Groundwater

Groundwater is the dominant source of potable water. The anthropogenic processes of arsenic contamination are the seepage of arsenic enriched industrial effluents through the ground, leaching of solid wastes, rich in arsenic and intrusion of contaminated water into the groundwater aquifer through the contaminated water bodies like lake, river and sea. Furthermore, extensive use of arsenical pesticides, herbicides, fertilizers, etc. in agricultural land as well as the continuous dry and wet depositions of arsenic into the ground from contaminated air will enrich the soil with arsenic compounds. Leaching of enriched soil by precipitation create the contamination of groundwater with arsenic. Cf. Appendix 5:, page 66. [**Kim R. Adamsen & Dinesh Bajracharya**: Arsenic memo, Internal NEWAH note, 2001]

1.5 The Natural Contamination of the Groundwater

Despite all these prevailing anthropogenic activities, the dominant source of arsenic contamination in ground water throughout the world is still the natural processes. As the earth's crust consists of arsenical compounds in trace levels, the rock - water interactions lead to the contamination of groundwater with arsenic compounds. Dissolution of arsenic in groundwater however, primarily influenced by the oxic and anoxic conditions of the groundwater aquifers (See. chapter 3 page 19) as well as secondarily affected by the level and type of arsenic compounds present in the adjoin rock of the particular region. [**Kim R. Adamsen & Dinesh Bajracharya**: Arsenic memo, Internal NEWAH note, 2001]

2 The Adverse Health Effects

Arsenic can be exposed to the human body through inhalation, ingestion and dermal absorption. Inhalation takes place through respiration whereas ingestion occurs by the digestion of contaminated water and food. This latest is the primary route of exposure. Dermal absorption takes place due to the direct contact of arsenic compounds with the skin. Whatever the sources and modes of exposure, the total impact depends upon the duration of absorption, excretion and thereby retention in the body, the arsenic substance in question, the concentration, and furthermore the chemical nature of the intake process.

Arsenic is not a physiological constituent of human body and no firm evidence is found to show that arsenic in any form is essential to the human body. Some animal studies suggest according to [USEPA: Technologies and Costs for Removal of Arsenic from Drinking Water, Report, Dec. 2000.] that Arsenic compounds in low concentration may be an essential nutrient for some animals. Arsenic compounds have formerly been used as a medical treatment of maladies like Leukaemia, Syphilis and Psoriasis, but most not with any profound effect. Cf. Appendix 5: Cures, Medical, and Industrial Usage of Arsenic, page 66. Today almost all medical usages have been replaced by other modern drugs. The United States Environmental Protection Agency (USEPA) has classified arsenic as a human carcinogen.

The symptoms of the adverse health effects can be divided up into the **acute health effects** and the **chronic effects**. The former are those that occur directly after a brief exposure of high concentrations. The chronic effects occur gradually over time, and develop after a long term exposure of low levels of arsenic concentrations. Such effects are often difficult to obtain an overview over, in order to e.g. calculate the cost for the population in Nepal, since a variety of other diseases disturbs the health picture of the individual. NEWAH is in the process of combining statistical data of cancer incidents with high concentrations of total Arsenic intakes in the affected district of Nepal. [Kim R. Adamsen: Calculation Cancer Incidents, Internal spreadsheet and notes, 2001.]

In 0, page 58, the acute effects found in the literature is listed, similarly Appendix 4:, page 63, lists the chronic effects. The medical cures after high Arsenic intakes, the former medical usages and the industrial usages are listed in Appendix 5:, page 66.

2.1 Acute Levels

Different severe adverse health effects have been reported in the literature. The acute poisoning of arsenic involves effects on the central nervous system, leading to coma and for doses from 60 to 180 mg, for an adult human being, to death. It can cause gastrointestinal and cardiac damage and can affect the respiratory tract, the skin of the body, and numerous other severe health problems as reported in 0

Arsine gas, which usually is not the problem talking about drinking water, except when using certain measuring methods, is even more poisonous than solid As compounds, with a threshold limit value of 50 ppb. 20 – 50 ppb of arsenic gas inhaled for 30 minutes is lethal. Inorganic arsenic compounds are also extremely toxic. USEPA has established a reference dose of 0.3 ?g/kg/d for inorganic arsenic compounds.

2.2 Health Effects of Chronic Contamination

Chronic doses can cause vascular disorders, such as black - foot disease. Epidemiological studies in Chile and Taiwan have linked arsenic with skin and lung cancer. Sodium arsenate and arsenite

have shown several teratogenic potentials in different mammalian species. Various manifestations, such as hyperpigmentation, keratoses, and lung cancer have been observed where high occupational exposure to arsenic has occurred. Cf. Appendix 4:, page 63, for a throughout list.

When arsenic compounds are introduced into the body, it will to some extent accumulate until an injurious state is reached. Supposing these arsenic compounds are not expelled, it can easily be calculated that it takes $60.000 / 50 = 3.3$ years to reach a deadly concentration, if an adult drinks 1 litre of water containing a 50 µg/l level of arsenic compounds. However this calculation is only shown here in order to indicate and give an idea of the minimum number of years to reach a deadly dose. Arsenic compounds are expelled through e.g. urine and faeces. The amount expelled given a certain dose have not been measured in Nepal, however the concentration in fingernails and hair is being measured for the time being by the leading scientific laboratory in Nepal: Environmental and Public Health Organisation (Enpho). The chronic poisoning of arsenic compounds can therefore be considered as a slow killer, and it is difficult to compare the health effects to e.g. more acute microbiological contaminations. No direct data is available for the long term arsenic effects on the Nepali population to date. [**Kim R. Adamsen:** The Arsenic Concentration Impact on the Nepali Population, Internal NEWAH rapport, 2001.] NEWAH is working on this in a co-operation with the Tribuwan University, Kathmandu.

After the graduate build up in tissues, organs, hair and nails the first symptoms are different sorts of skin disorders, leading to dark spots, particularly on the extremities. Later the skin problems become worse, and leads to open sores all over the body.

The chemical is also believed to cause several types of cancer in the internal organs. USEPA has classified inorganic arsenic compounds as a class A carcinogen. Prolonged exposure to arsenic is believed to cause tumours in the bladder, kidney, liver and lungs, and depending on the dose these adverse effects do not manifest in the exposed individual until after several years of exposure. See Appendix 4: Pathological Picture of Chronic effects of A, page 63 for a throughout list of maladies. [**Kim R. Adamsen:** Medical Effects of Arsenic Ingestion, Internal note, 2002.]

Compared to Bangladesh and India, which are known to have high arsenic concentrations in the groundwater the Nepali incidence rates of liver cancer, lung cancer, melanoma of skin, bladder cancer, and kidney cancer are all higher, giving reason to believe, that the arsenic problem in Nepal is severe. This is naturally not a “proof”, since the mentioned cancer types can originate from other sources. Lung cancer e.g. also comes from smoking.

NEWAH regards the chronic arsenic issue with outmost seriousness, and is certainly not happy to have been able to provide over 6000 wells to unsuspecting villagers, with the possibility of these supplies having such serious health effects.

3 The Origin of Arsenic in Ground Water. The Worldwide Situation

The arsenic release mechanism into the ground water is rather poorly understood. Many studies have been carried out by various scientists in India and Bangladesh, who claim that the arsenic released to the groundwater and sediments are carried by the Himalyan Ganga Rivers which originates and flows from Nepal. However, no studies have been carried out in Nepal to verify this hypothesis.

3.1 The Chemical Explanation

There are two main chemical theories as to how arsenic is released into the groundwater. A and B, below. And a third C, which debates the usage of phosphate fertilizers:

- A. **Pyrite oxidation.** In response to pumping groundwater to the surface for irrigation or drinking water usage, air or water with dissolved oxygen penetrates into the ground, leading to decomposition of the sulphide minerals and release of arsenic. As the water table recharges after rainfall, arsenic leaches out of the sediment into the aquifer.
- B. **Oxyhydroxide reduction.** Arsenic was naturally transported by the river systems of Himalaya and adsorbed onto fine-grained iron or manganese oxyhydroxides. These were deposited in flood plains and buried in the sedimentary column. Microbial oxidation of organic carbon has depleted the dissolved oxygen in the groundwater and created a strongly reducing condition. The Arsenic compounds are today present in the sediments and groundwater of the low regions south of the Himalaya. See furthermore chapter 3.2, page 20, and chapter 0, page 70, below.
- C. **Fertilizers may have increased the Arsenic mobility.** During the past 30 years the use of phosphate fertilizers has increased threefold in the West Bengal and Bangladesh region. The widespread withdrawal of groundwater may have mobilized phosphate derived from fertilizers and from the decay of natural organic materials in shallow aquifers. The increase in phosphate concentration could have promoted the growth of sediment biota and the desorption of arsenic from sediments, and the combined microbiological and chemical process might have increased the mobility of arsenic [WHO: Environmental Health Criteria 224, Arsenic and Arsenic Compounds, <http://www.inchem.org/documents/ehc/ehc/ehc224.htm>, 2001], [S.K. Acharyya, et al: Arsenic poisoning in the Ganges delta. *Nature* **401**(6753): 545, 1999.]
- D. **Relation to seawater.** As the Bangladesh arsenic deposits mainly lies in the southern part of the country close to the major rivers, some speculations that the arsenic concentrations had relation to the seawater, seems now dubious since the problem unfortunately also is present in Nepal and the Northern parts of West Bengal.

There seems to be little doubt that the major origin of the Arsenic concentrations in the groundwater of Nepal and south of the border is geological, as the explanation involving anthropogenic contamination ("A" and "C" explanation) cannot account for the regional magnitude and extent of the groundwater contamination alone.

If explanation "B" above is more correct, or accounts for the major release mechanism, then aeration of the ground water will help to remove the arsenic. Aeration would induce the formation of iron hydroxides that would scavenge the arsenic and precipitate it as arsenic-rich iron hydroxides, which would reduce the arsenic levels to around 50 µg/l. However, this would present the problem of disposing of the arsenic loaded precipitate. Removing of the arsenic from

the groundwater is not enough. We need to develop plans, for the precipitate also. [Flynn: Arsenic and the law of Unintended Consequences: The Environmental Disaster in Bangladesh, http://www.sunybroome.edu/~flynn_b/arsenic.htm, 2002]

The release mechanism is still hotly debated, since evidence exists to support both oxidation and reduction theories. The theory "B", above is thought to be the more likely explanation in South East Asia, whereas the others is believed to cause the Arsenic release in certain parts of North and South America. There has, however, been a large amount of debate with reference to the source and release mechanism of the Arsenic in South East Asia. It is now widely accepted that it is of natural, geological origin and the arsenic compounds is thought to be closely associated with iron oxides. Natural processes of groundwater flushing will eventually wash the arsenic "away" but this will take thousands or tens of thousands of years. See 0, **¡Error! No se encuentra el origen de la referencia.**, page 72 for a further discussion of this. The flushing is particularly slow in the Terai areas in general, because the land surface is flat and the groundwater flow is therefore close to 0. The question is also where these Arsenic concentrations are washed "away" to.

3.2 The Iron Oxide Reduction Hypothesis supported by DFID and BGS

According to a technical report from the British Geological Society (BGS) and Department for International Development, England (DFID) on the Arsenic contamination in ground water in Bangladesh, the explanation B, above as supported: "The release appears to be associated with the burial of fresh sediment and the generation of anaerobic ground water conditions." This occurred thousands of years ago. The arsenic is thought to be desorbed and dissolved from iron oxides as written above, which had earlier scavenged the arsenic from river water during their transport as part of normal sediment load. BGS/DFID continues: "Natural variations in the amount of iron oxide at the time of sediment burial may be a key factor in controlling the distribution of high arsenic ground waters. There is no evidence to support the proposition that the ground water arsenic problem is caused by the recent seasonal draw down of the water table due to a recent increase in irrigation abstraction."

3.3 Variations of depth and surface distribution

Local variations in the rate of groundwater movement due to the location of rivers and variations in topography or type of sediment (clay, silt or sand) probably account for much of the local Arsenic concentration variations. Natural processes of sedimentation and sediment transport create variations in the arsenic problem within the region of South East Asia.

3.4 The Worldwide Scenario of the Arsenic Problem

Arsenic is not a newly discovered poison. Many episodes of arsenic poisoning have been reported throughout the world. [Kim R. Adamsen: Medical Effects of Arsenic Ingestion, Internal note, 2002.] In Argentina the arsenic problem was notified in the beginning of 20th century where the "Bell Villa Disease" was diagnosed and the cause was seen to be the toxicity of arsenic compounds. In Taiwan the problem of arsenicism (Arsenic poisoning) has been reported since 1968 and the disease was named as "Black Foot Disease". This symptom is only seen on Taiwan. Arsenic poisoning in Mongolia and China was discovered in 1990. Similarly, the problem of arsenic substances in the groundwater has also been reported from Thailand, Chile, Mexico and USA. However, probably the worst natural occurring Arsenic contamination of the groundwater and food is today seen in Bangladesh and West Bengal (India). The situation in Bangladesh based on 3500 dataset is discussed in 0, page 70.

4 The Arsenic Problem in Nepal

There have been many investigations and recommendations by international scientists that the drinking water derived from the groundwater - the aquifers - in Nepal, shows similar characteristics to those of the Bengal Basin, the Gangetic flood plains and the areas adjoining West Bengal. The Terai belt of Nepal (Cf. **¡Error! No se encuentra el origen de la referencia., ¡Error! No se encuentra el origen de la referencia.**) lies close to these areas and recently the same problem has been discovered in the groundwater of Nepal.

Department for Water, Sanitation and Sewage (DWSS) initiated the Arsenic investigations in Nepal in year 2000, by measuring 268 drinking water samples in Terai, (Cf. **¡Error! No se encuentra el origen de la referencia. Page ¡Error! Marcador no definido.**) This investigation was done in Eastern Terai in the districts Jhapa, Morang & Sunsari. [**Nirmal Tandukar: Arsenic Contamination in Groundwater in Rautahat District of Nepal – An Assessment and Treatment, M.Sc. Thesis, Institute of Engineering, Lalitpur, Nepal. 2000**]. The data revealed that some ground water samples from the areas was contaminated with arsenic. The report showed that about 9 % of the total analyzed samples exceeded the WHO guideline value of 10 µg/l and the maximum concentration of arsenic was found to be 75 µg/l.

Nepal Red Cross Society (NRCS) supported by the Japanese Red Cross (JRCS) soon followed up in May 2000 and have so far been the leading stakeholder in Nepal in the measuring of the Arsenic crisis, having measured more than 12, samples using an Atomic Absorption Spectrophotometer (AAS). This expensive but accurate measuring method can only be done in well equipped laboratories, which at present only are available in Kathmandu. This method raises the question of conserving the samples days or weeks. Cf. Chapter 10.7: Conservation of samples from the field. Page 45.

Today where an adequate and systematic monitoring programme for arsenic in groundwater in Nepal is the process of being carried out, and as around 17.000 wells have been measured, it is a well known fact that different Arsenic poisonous compounds are released into the groundwater, which is consumed by the largely unaware Nepali population.

4.1 The administrative organization in Nepal

4.2 The Location of the problem

The gravity flow schemes in the hills and the water supply in cities, which uses open water sources from open streams and rivers, piped to the users and tapped through a stopcock, are not affected to the same extent as the tube wells of the Terai belt of Nepal. However this needs to be investigated further and NEWAH have therefore started a research program to measure in the hills and in the cities to ensure the safety of these supplies.

Thus, as the problem of arsenic contamination is believed to be more severe in the installed tube wells of the Terai area, and the present national efforts are concentrated in this area. Cf. **¡Error! No se encuentra el origen de la referencia., ¡Error! No se encuentra el origen de la referencia.** To date it is uncertain whether the arsenic problem in Nepal is only related to tube wells, as seems to be the case in Bangladesh. Geological speculations based on data from Bangladesh suggest that the arsenic problem in the Terai and south of Nepal may originate in the Himalayan mountain range. Cf. Chapter 3.1: The Chemical Explanation Page 19 and 0, page 70. The testing of certain surface sources, developed by NEWAH, at the foothills of the Himalayas, will reveal, whether this is a significant source of arsenic contamination. Especially the many

thermal springs in Nepal should attract attention, if not for the hazardous effects, then for the research possibility to clarify if the Arsenic compounds in Terai and in the southern countries have connection to the Himalayan areas. One thermal source in the Jomosom area have a discharge of 30 litre/sec. This spring may cause health problems to the villagers below, if the water is not diluted sufficiently by arsenic free rivers before the water is used for human consumption, and the spring contains hazardous levels of Arsenic concentrations. Cf. Chapter 5: NEWAH's initiative of testing Thermal Springs, page 27.

4.3 The number of Tube Wells in Nepal

Investigations in Nepal have so far shown that the numerous wells in the southern lowlands – the Terai belt of Nepal are most seriously affected. The actual number of tube wells in these areas is unknown, since the major part is unregistered private wells, often of a poor construction. From an extrapolation of the Nawalparasi district, where the population is app. 600,000 and the number of wells have been counted to 34,000, [Kalawati Pokharel: RWSSSP paper, Internal communication, 2002] it can be estimated that 12 million people in the rural areas of the Terai presumably owns more than 650.000 hand pumped tube wells, equivalent to on average of 18-20 persons per well. Other estimates notes 300.000 wells (40 persons per well). The agency installed tube wells of a higher quality often calculates with the latter figure per well. Direct observation shows that today most households owe their own well, giving reason to believe that the former number is more correct.

As there until further are not developed any method to predict the concentrations in a well (See chapter 4.4, page 23 and Chapter 10.1: Correlation with other Substances, page 39) a strategic aim must therefore be to measure all or most of the wells both in Bangladesh, West Bengal and in Nepal for arsenic. In Bangladesh there are approximately 4.5 million public (installed by Government departments) and a total 9 million tubewells. An estimated 97% of the Bangladesh population of 120 million drink well water. Piped water supplies are available only to a small portion of the total population in Bangladesh.

4.4 All Wells to be Tested

Unfortunately all wells in Terai needs to be systematically tested, since investigations so far have revealed that it is impossible to predict the individual contamination, even if the adjacent wells 5 meters away have been tested. The concentration variations of adjacent wells have been shown by NEWAH to range from 10 to 600 µg/l. In Chapter 10.1: Correlation with other Substances, page 39 a discussion is done on the possibility to measure Iron in order to acquire an indication of the concentration of Arsenic.

4.5 The Percentage of Affected Wells in Nepal

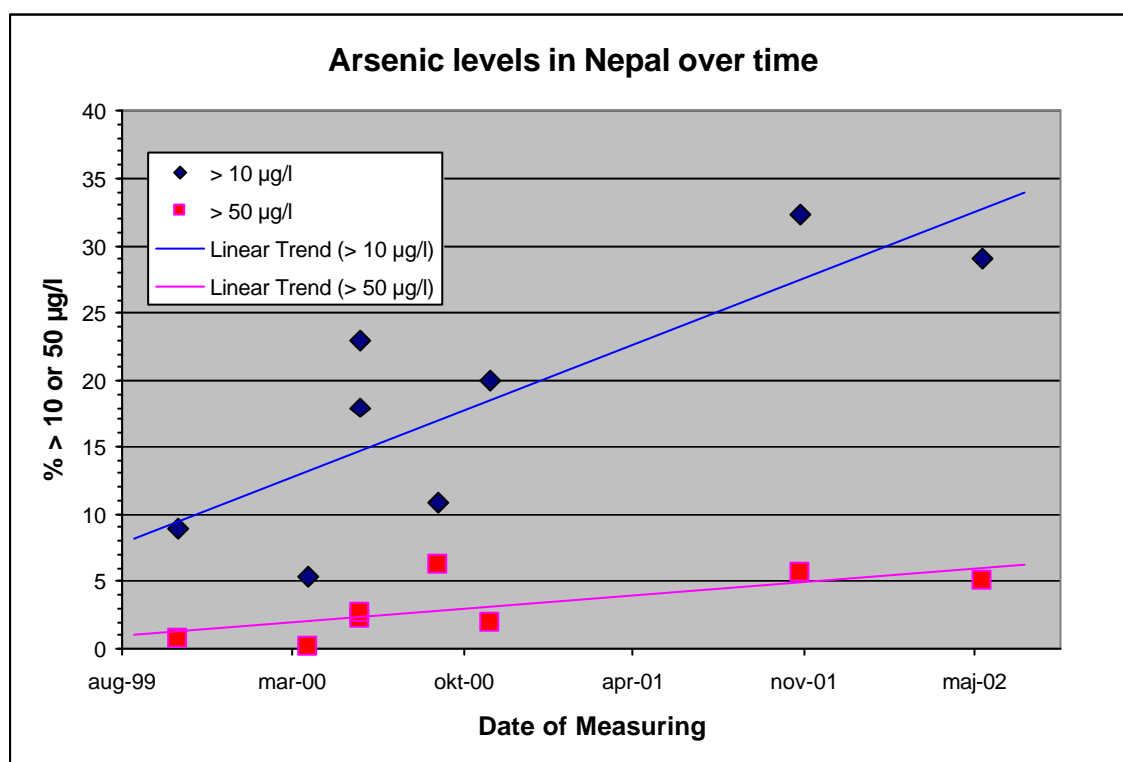
On the basis of approximately 17,000 data sets collected and measured in Nepal by concerned stakeholders. Cf. Table 3, page 31, and partly processed by NEWAH, it can be estimated that a minimum of 30 % of all installed tube wells have arsenic levels above 10 µg/l. A minimum of 5 % have serious long-term health damaging concentrations of over 50 µg/l. The health implications of this can be seen in Chapter 2: The Adverse Health Effects, page 17, and from [Kim R. Adamsen: Medical Effects of Arsenic Ingestion, Internal note, 2002.]

4.6 The Percentage goes up as more and more wells are measured.

The latest two years (2000-2002) intensified measuring gives rise to severe concern for another reason. Having participated actively and followed the debates and papers released from the Nepali stakeholders for the last two years, it seems that the percentage of the infected wells have increased over time. In year 2000 the percentages of tube wells above 10 and 50 µg/l was 17 and

2 % respectively. At that time approximately 1500 wells had been measured. It seems that the more the different stakeholders co-operate to measure, the higher these percentages becomes. This fact is indicated on **¡Error! No se encuentra el origen de la referencia.**, below, as NEWAH have collected all papers and circulars the last two years. Naturally this might also be an effect of an increased knowledge among the stakeholders, where the Arsenic problems are most severe, and that we in a co-operation naturally try to measure the highest risk areas first.

Hence the precise percentages in Nepal should today be regarded as relatively unknown, but as can be seen from the figure a guess on 5 % above 50 $\mu\text{g/l}$, and that 30 % of all tube wells in Nepal are above 10 $\mu\text{g/l}$ seems reasonable. Only when all wells, private, public and others have been measured these figures will be known more precisely. Never exactly, since the concentration in each well varies with season, pumped water prior to sampling, measuring method, conservation method etc.



The Arsenic level Increases over time. The more wells we measure, the higher the national average percentages seems to be.

If we in Nepal want to know these percentages without measuring all wells, a mathematical random selection spread equally over the country and a subsequent measuring of only these wells should be done. The Department of Water, Sanitation and Sewage (DWSS) are in the process of doing this, as a decision by The National Arsenic Steering Committee (NASC) of measuring two wells - randomly distributed - per km^2 was taken late in 2001.

4.7 Very High Concentrations

The preliminary investigations in Nepal have shown that some samples collected in the villages situated close to the Indian border in the southern part of Nepal have even higher levels of Arsenic contamination that have been seen in the presumed worldwide worst affected areas: Bangladesh and West Bengal. The highest concentration in Bangladesh in groundwater is 1600 $\mu\text{g/l}$. The highest concentration in Nepal so far has been measured in Rupandehi district to 2600 $\mu\text{g/l}$.

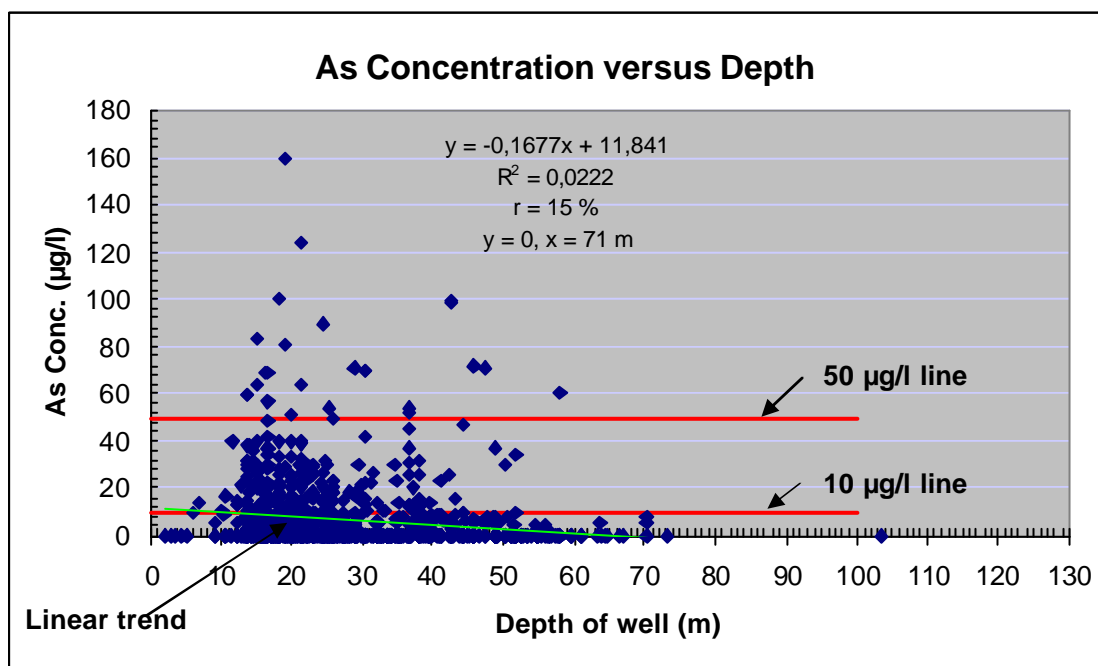
4.8 The Seasonal Arsenic Variation

The picture of the contaminated wells should also take the seasonal variation into consideration. NEWAH have shown that the individual Arsenic concentration in one well varies over time. The full picture of this investigation is yet to be finished, however DWSS [Nirmal Tandukar: Scenario of Arsenic Contamination in Groundwater of Nepal, M.Sc.(Environmental Engineering) Institute of Engineering, Nepal, 2000.] have shown that the number of affected wells above 10 µg/l is lower after the monsoon in November, possibly due to a dilution effect by the rainwater, which seeps fast down to the aquifer along the tube well pipe. This indication is, however based on data from only 121 wells and needs to be investigated further.

4.9 The Variation with Depth of Tube Well

Furthermore a variation with the amount of water pumped prior to sampling is also to be expected, since this is an indication of the Arsenic concentration variation with depth of pumped up groundwater. The exact relationship between pump strokes prior to sampling and precise ground water depth will be difficult to determine, as different pumps are not constructed the same way. In Nawalparasi district NEWAH measured one well, which was said to pump water from 25 feet below to 10-50 µg/l total Arsenic. The neighbouring well 5 meters apart drew water from 65 feet down and showed a concentration of app. 300 µg/l. The depth of the two wells was not verified.

The Arsenic variation with depth can be seen on **¡Error! No se encuentra el origen de la referencia.** below. This figure shows that

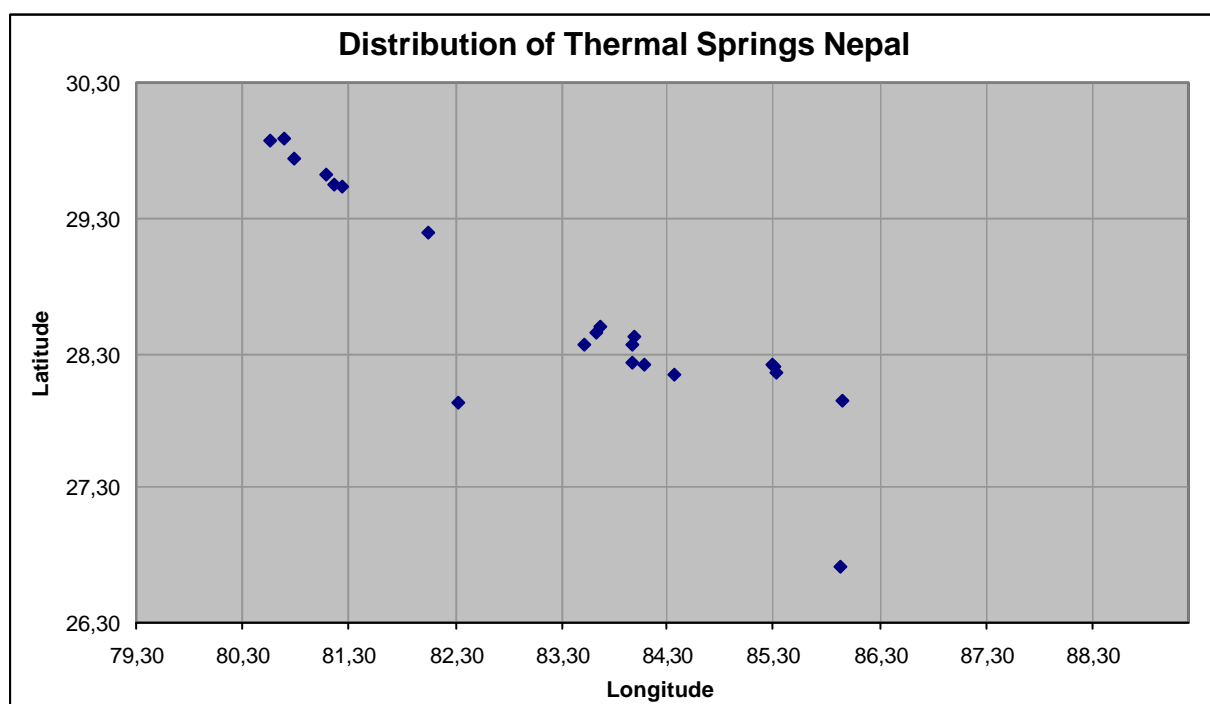


The Concentration versus Depth of well. The linear trend line shows that wells above 71 meters have a lower probability of high As concentration. The fit of the data to a linear trend is poor.

[Nirmal Tandukar: Scenario of Arsenic Contamination in Groundwater of Nepal, M.Sc.(Environmental Engineering) Institute of Engineering, Nepal, 2000.] have - on the basis of app. 50 dataset - shown that depths between 20 and 150 feet (6 to 45 m) are to be considered as the highest risk area.

5 NEWAH's initiative of testing Thermal Springs

In many countries, the arsenic contamination has been present in geothermal springs. This have lead NEWAH to investigate the water samples from some of the Thermal springs in the Himalayan areas of Nepal. This is the first time such tests have been done in the country. Until further the test was confined to a particular locality in the Annapurna region of the Western Region. The results showed that the arsenic concentration varies rapidly over time - within an hour - ranging from 0 - 70 $\mu\text{g/l}$ from a single source. Though this finding cannot be generalized, it can be clearly inferred that a thorough testing of all the Nepali Thermal springs should be carried out. NEWAH is in the process of doing this, however some sources carries only small amount of hot water compared to the often nearby larger rivers. Thus the dilution effect will be taken into consideration, when a prioritized list of the Nepali thermal springs is made. The exact Geographic locations of the Nepali Thermal springs can be seen in Appendix 1:Location of the Thermal Springs in Nepal. Page 54, which has been plotted on **¡Error! No se encuentra el origen de la referencia.**, below. At least 21 Thermal springs are present in Nepal. [United Nations : Geology and Mineral Resources of Nepal, New York 1993.]



Main Central and Boundary Thrusts. Distribution of the Thermal Springs.

Most thermal springs - 17 out of 21 - lie along the fault breccia, called the Main Central Thrust, which runs East-West through the Himalayan zone of the country. The remaining springs lie south of the Main Boundary Thrust in the Sub-Himalayan or Siwalik zone.

The absence of geological known magmatic intrusions and absence of volcanic rocks and activities, excludes a magmatic induced heating of these springs. Thus the heat is believed to be transported by deeply circulated groundwater along faults and fractures associated with the Main Central and Main Boundary Thrusts (MCT and MBT), shown in **¡Error! No se encuentra el origen de la referencia.** Part of the heat may be due to the natural geothermal gradient, radioactive heat, and above all frictional heat due to tectonic along the MCT and MBT.

Thus knowledge of the composition of this thermal water, may give information on especially the Arsenic concentration in deep groundwater.

6 The Organizational Setup in Nepal

Most of the stakeholders in the Drinking Water area in Nepal have joined forces and are today co-operating constructively in order to solve not only the Arsenic problems, but also the general drinking water quality problems in Nepal.

6.1 NEWAH

NEWAH is a countrywide NGO, with regional offices in all five regions of Nepal: Eastern Regional Office (ERO), Central Regional Office (CRO), Western Regional Office (WRO), Mid West Regional Office (MWRO), and Far Western Regional Office (FWRO). Furthermore NEWAH have a Headquarter (HQ) in Kathmandu. The phone numbers, name of regional co-ordinator etc. is seen in Table 1, below.

Table 1: The NEWAH Organization

Region	Town/Title	Name of Person	E-mail	Telephone
HQ	KTM, Director	Mr. Umesh Pandey	upnewah@mos.com.np	417603/418248
	Technical Head	Mr. Anil Pokhrel	fogwater@mos.com.np	
	Social Head	Mrs. Renuka	socnewah@mos.com.np	
	Technical Division	Mr. Eurasi	tecnewah@mos.com.np	
	Technical Division	Mr. Santosh Basnet		
	Fund Raising	Mr. Kumar	frnewah@mos.com.np	
		Mr. Govinda Bhetwal		
ERO	Biratnagar	Mr. Himal Pandey	newahero@mail.com.np	021-27912
CRO	Kathmandu	Mrs. Laxmi Paudyal	newahcro@mail.com.np	246474
WRO	Pokhara	Mr. Manuj	newahwro@mail.com.np	061-23866
MWRO	Nepalgunj	Mr. Kumar Silva	mrnewah@mos.com.np	081-21261
	Advisor	Mr. Kim R. Adamsen	kadamsen@mos.com.np	525219
FWRO	Danghadi		newah@ecomail.com.np	091-23142

6.2 The Arsenic Committees formed in Nepal.

A National Arsenic Steering Committee (NASC) was formed in the beginning of year 2001, and shortly after the Non Government Organizations (NGO's) Informal group for Arsenic mitigation (NIGAM) was formed. These two working groups calls today for meetings every month, and these meetings are open for all interested. Usually the NGO committee have meetings a day before the National Steering Committee. Furthermore regional committees are in the process of being initiated. Cf Chapter 6.5, page 31, below.

6.3 The National Arsenic Steering Committee

The present members of the National Arsenic Steering Committee (NASC) are shown in Table 2 below. The NASC meeting are open, and several constructive decisions have been taken so far.

An important decision on how to identify hand pumps giving Arsenic water to the users above 50 µg/l. The spout is to be painted white with a black cross, and the knowledge of this signal is to be sent via the press and directly to the rural population.

Table 2: Present members of the National Arsenic Steering Committee.

Name	Org.	E-mail	Telephone
Mr. S. S. Shrestha	MWPP		
Mr. D.B. Shrestha	DWSS		
Mr. G.P. Shrestha	DWSS	dwss@nmip.mos.com.np	413744
Mr. I.M. Tamrakar	DWSS		413744
Mr. R.L. Chitrakar	DWSS		413744
	National Planning Commission Ministry of Population and Environment		
Mr. D. Gyawali	Ronast	ronast@mos.com.np	547714-547718
Mr. J. Speets	WHO	speets@who.org.np	523200/228078
Mr. S. Adhikari	WHO		
Mr. H. Spruijt	UNICEF	hspruijt@unicef.org	523200/526921
Mr. M.S. Khadka	Groundwater Project (Dol)		
Dr. K.D. Shrestha	Epidemiology Section / DHS		
Mr. B. Jnawali	DoMG		
Mr. N.M. Pradhan	NWSC		
Ms. K. Pokhrel	RWSSSP	rwsspbtw@wlink.com.np	071-40782
Mr. D Khadki	RWSSFDB		
Mr. Prakash Raj Lamsal	RWSSFDB	tech@khaskosh.wlink.com.np	414525, 410761
	Helvetas	po@helvetasnepal.org.np	524925, 524926
Mr. A. Pokhrel	NEWAH	anilpokhrel@newah.org.np	
Mr. T.R. Onta	NRCS	nrcs@kalimati.mos.com.np	
Mr. T. Tenzing	World Bank		
Mr. N. Pradhan	Plan - Nepal		

6.4 The NGO's Informal Arsenic Mitigation Group

The members in the NGO's Informal Arsenic mitigation group are:

Name	Org.	E-mail	Telephone
Mr. Kim R. Adamsen	NEWAH	kadamsen@mos.com.np	417603 / 418248
Mr. Anil Pokhrel	NEWAH	fogwater@mos.com.np	417603 / 418248
Dr. Roshan R. Shrestha	Enpho	rshrestha@mos.com.np enpho@mos.com.np	491052
Mr. Padam K. Khadka	NRCS	dwsp@ntc.net.np	272761 / 270650
Mr. Mike Naoto Usami	JRCS	jrcsdn@mail.com.np	285089, 285090
Mr. Nirmal Tandukar	DWSS	tndkar@enet.com.np	413744
Mr. Pradiumna P. Dahal	IDS	etadd@ccsl.com.np pradiumnad@hotmail.com	427329
Mr. Manoj Lal	IDS	itadd@ccsl.com.np	427329
Mr. Prakash R. Lamsal	RWSSFDB	tech@khaskosh.wlink.com.np	414525, 410761
Ms. Kalawati Pokharel	RWSSSP	rwsspbtw@wlink.com.np	071-40782

Table 3: Present members of the NGO's Informal Arsenic Mitigation Group.**6.5 The Regional Guideline Value Discussion Forums**

Furthermore NEWAH have taken initiative to establish regional forums to interact on issues and problems concerning water supply including the problems of arsenic. the regional groups have started up with the Arsenic problem, and the intension is that other problems like the microbiological problem in a pragmatic way The formal setup of these committees varies from region to region, but NEWAH have seen that there is a need for co-operation on the pragmatic Arsenic measuring and mitigation programs, not only on a national level in Kathmandu. In Nawalparasi for example the different NGO's are co-operating and have divided the district up into different areas, in order to measure all wells in this severely affected district.

It cannot be stressed enough that the co-operation that we today see in Nepal is vital for the further mitigation plans, awareness raising etc. for the population of Nepal. Opposed to other countries and experiences from work in other countries the Nepali devotedness and spirit of co-operation appears very positive, when looking into the future work on not only the Arsenic problem, but also other Drinking water Guideline Values like for example the microbiological predicament.

7 Guideline Values

The worldwide discussion of the Guideline Value for Arsenic varies from country to country. In general it can be said that the countries who can afford to have a low value is moving towards lower and lower concentrations in concurrence with the fact that more and more serious chronic effects are discovered. Rich countries can afford to focus exclusively on the environment and health aspects, which contradicts the situation in the developing world, where the drinking water and environmental guideline value discussions are closely related to economic considerations. Cf. below.

7.1 Debate on the guideline value

Drinking water guidelines values vary significantly on a country to country basis. As have been indicated in Chapter 2: The Adverse Health Effects, page 17, above and spelled out in 0 and Appendix 4: the National Guideline Value on Arsenic seen from a health point of view should be as low as possible.

There is no indication in the literature that a low level of Arsenic intake is a necessity for the human body, like for example Selenium. Cf. Chapter 2, page 17 This debate is furthermore occasionally confused by the fact that Arsenic compounds have been used as a so to speak last resort for a medical cure, for certain severe diseases. Cf. Appendix 5: Cures, Medical, and Industrial Usage of Arsenic, page 66. Arsenic is carcinogenic also in low concentrations. There are, however, other reasons for not setting National Guideline Values solely from a health point of view:

- 1) The Economic considerations.
- 2) The Technical Ability to measure below 50 µg/l in the field.
- 3) The Health aspects
- 4) Focus on coverage rather than quality
- 5) Lack of expertise and knowledge of the implementing agents

1) The Economic considerations.

A Government should set the value considering all facts in the individual case, meaning that if the financial resources are relatively too high to mitigate for example the Arsenic problem down to 10 µg/l, then a 50 µg/l level is better than nothing, since the health considerations of the population, should be the concern of any responsible government. Setting the guideline value at any level should not be done thoughtlessness, as the following legislation should give the poor population some right to seek help to mitigate the water quality down to the national guideline value agreed on by the government. A low National Guideline Value will be relatively expensive.

2) The Technical Ability to measure below 50 µg/l in the field.

Some sources mention the measuring limitations, as it takes experience to measure below 10 µg/l even 50 µg/l. Financially it is naturally more expensive to measure accurately around 10 than 50 µg/l. However, technically this is possible, by the new kits available on the market today, and hence there are no technical limitations on the setting of the guideline value.

3) The Health aspects

This is discussed in Chapter 2: The Adverse Health Effects, page 17, above.

4) Focus on coverage rather than quality

In a country, where the coverage of **safe** drinking water installations is low, it might seem natural to prioritise an increased coverage rather than the quality of the drinking water. The former uncritical installations of tube wells and gravity flow schemes mainly in order to bring water closer to the household to release the work burden by specifically women and children, have to some extent changed today. The realization that for example tube wells do not necessarily improve the water quality relative to a nearby river, or that gravity flow systems might be polluted due to animals and other effects in the catchment area. This situation is not recommended by NEWAH, who prefers to deliver **safe** drinking water and a professional service, similar to most stakeholders in the drinking water business in Nepal today. In Chapter 8 on **¡Error! No se encuentra el origen de la referencia.**, page 37, an estimation of the population with access to a water installation is shown.

It should be noted that access to a gravity flow schemes or tube wells not necessarily means access to microbiological safe water. According to NEWAH's measurements it is more the rule than the exception that these water sources are polluted with bacteria. Especially the private tube wells are not constructed correct.

5) Lack of expertise and knowledge of the implementing agent

If most stakeholders within the drinking water sector are not aware of any guideline dilemma and furthermore lack the expertise to administrate, measure or mitigate such, the health status of the population will naturally generally be low. This was the case in South East Asia ten years ago, concerning the Arsenic calamity. In Nepal the awareness among the elite stakeholders on the Arsenic problem have especially the last two years increased dramatically, and the genuine concernedness from all professionals in Nepal helps significantly to mitigate the crisis.

7.2 The guideline values of other countries

Bangladesh and India have set the maximum contaminant value to 50 µg/l, mainly due to the economic considerations, mentioned above. Other developing countries have also adopted this level.

The chronic guideline levels established by the World Health Organisation (WHO) of aqueous arsenic species is presently strictly set on 10 µg/l, with discussions of lowering this value. The WHO guideline value for Arsenic in drinking water was provisionally reduced in 1993 from 50 µg/l to 10 µg/l, seen from a health point of view. The new recommendation is based largely on the difficulties of analytical capability, since field measurements below 10 µg/l especially in a developing country is technical possible but difficult and relatively expensive. Cf. Chapter 10, The Measuring Program in Nepal, page 39.

The European Community (EC) maximum admissible concentration for As in drinking water have been reduced to 10 µg/l in line with the current health evidence. The Japanese limit is also 10 µg/l.

In 1976 USEPA issued a National Interim Primary Drinking Water Regulation for Arsenic at 50 µg/l, [USEPA: Technologies and Costs for Removal of Arsenic from Drinking Water, Report, Dec. 2000.]. This level was in year 2000 by USEPA lowered from 50 to 10 µg/l. [USEPA: Proposed Arsenic in Drinking Water Rule: Regulatory Impact Rule, 2000], [USEPA: Implementation Guidance for the Arsenic Rule, 2000] Prior to this lowering an intense debate took place, since some interests in the financial sphere claimed that it would be too expensive to do this. [USEPA: Report to congress: Small systems Arsenic Implementation Issue, 2002] Furthermore business interests in USA have opposed to this lowering, since they claim that USA

would not be able to compete on the international market. As the rest of the industrial world already had adopted a 10 µg/l level, this point of view is only justified, if the industrial and natural Arsenic concentrations in America are significantly higher than for example in Europe. This seems not to be the case, and the ongoing argumentation in USA seems to be founded on the differences of the political systems, where a clean and healthy environment in Europe is valued higher.

However the professional American lobbyists did not succeed. The Arsenic Guideline value in USA has been set by United States Environmental Protection Agency (USEPA) at 10 µg/l since the agency could prove the adverse health impacts. [USEPA: National Primary Drinking Water Regulations: Arsenic and Clarifications to Compliance and new source Contaminants Monitoring, (File: Notice of Data availability), 2000.]

7.3 The guideline value of Arsenic in Nepal

Nepal has not currently in a legal sense set any value on any water quality parameter, but a 50 µg/l interim level has been proposed in 1996, and ratified by DWSS in 2001. [NASC: Nepal's Interim Arsenic Policy Preparation Report, May 2001] The government authorities are in the process of passing this guideline value through the parliament as an interim value, which can be changed, if the funds to do this will be available. Unfortunately it seems necessary and pragmatic to set the guideline value in Nepal from an economic point of view, not the health effects for the Nepali population, however the interim status is welcomed by NEWAH.

The experience from the administrative, technical and legislative work of the Arsenic issue in Nepal can hopefully set the level of necessary co-operation for all other following guideline values.

7.4 The Arsenic Guideline Value in NEWAH

Due to the above considerations and naturally the known health consequences for the Nepali population, mentioned in chapter 2 and Appendix 4, NEWAH have adopted the following:

NEWAH defines a level of under 10 µg/l as acceptable, and no further actions should be taken. An Arsenic level between 10 and 50 µg/l is defined as problematic and such wells should be monitored regularly, to investigate the seasonal variation. Levels above 50 µg/l are highly endangering the health standards of the population, and water from these sources should not be used for drinking or cooking purposes. The users of such drinking water installations will be advised properly and these water supply constructions made by NEWAH, will be mitigated as soon as possible.

NEWAH have adopted an interim guideline value of 10 µg/l on new and present wells. As we have constructed more than 5000 wells, (Cf. Appendix 6: The Tube Wells installed by NEWAH in Terai, page 69.) NEWAH will focus on the highly problematic wells above 50 µg/l first. [Kim R. Adamsen & Anil Pokhrel: The NEWAH arsenic Testing Protocol, Internal NEWAH Report, 2002.]

8 A Mathematical Model

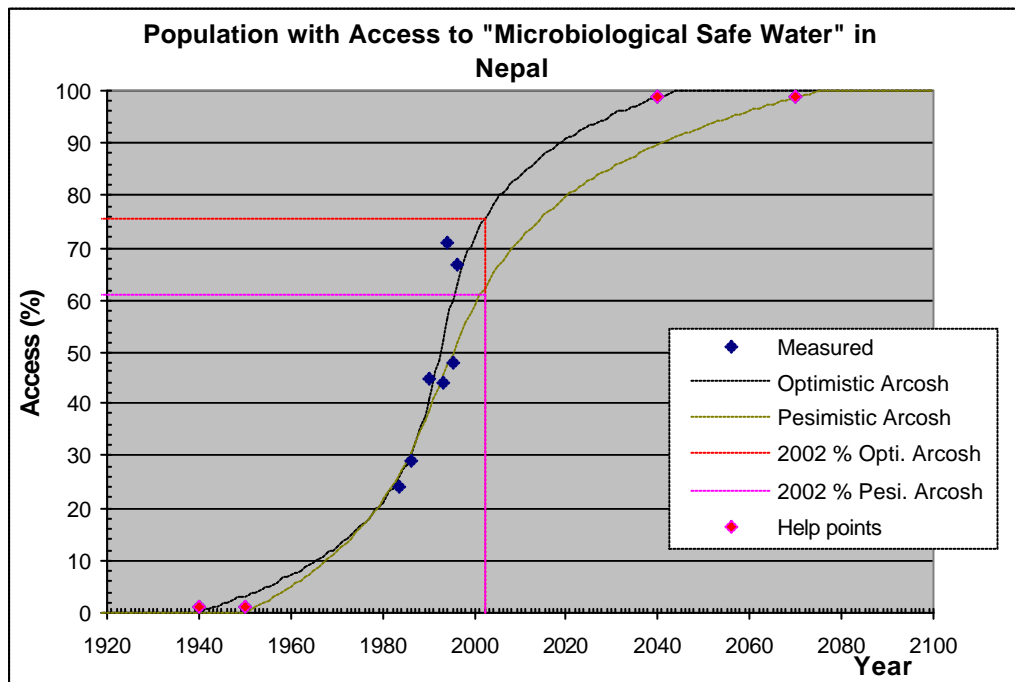
A mathematical model to study the risk analysis, carried out by NEWAH has revealed that there will be 20 to 40 thousand cancer incidents per year related to arsenic contamination from today and up to thirty years from now. These cases are inevitable, as part of the Nepali population already have been exposed to hazardous arsenic concentrations. Only if the Nepali stakeholders seriously start to co-operate on mitigation plans immediately, we will be able to bend the cancer curves in the future. The total number of tube wells constructed in Nepal is unknown, and a guess of 300,000 is probably conservative, since in Nawalparasi alone, there are more than 35,000 tube wells. This includes all private and agency supported public wells.

5 While this EHC was in the press, a cohort study from north-eastern Taiwan (Chiou et al., 2001) also reported an exposure-dependent increase in the risk of bladder cancer in exposure categories 10–50, 50–100, and > 100 µg/litre, with relative risks of transitional cell carcinoma of 1.0, 1.9 (CI 0.1–32.5), 8.2 (0.7–99.1) and 15.3 (1.7–139.9). Unlike all earlier Taiwanese studies, this study used estimates of individual (rather than village average) drinking-water arsenic concentrations, and incidence rather than mortality as the end-point. Arsenic measurements in the well-water were performed using a hydride-generation atomic absorption method, and the results were adjusted for age, sex and cigarette smoking. [WHO: Environmental Health Criteria 224, Arsenic and Arsenic Compounds, <http://www.inchem.org/documents/ehc/ehc/ehc224.htm>, 2001] allersidst.

Arsenic has been shown to be mutagenic in several bacterial test systems,

It is documented that even at a 10 µg/l threshold, 4 people out of every 10000 have a chance of getting cancer. This value surely rises exponentially (Well Anil that is the big question. This is what Risk analysis is about, and there is a big international discussion on how the risk increases with increasing exposure) with the increase in the level of contamination.

Insertion of the below figure is referred to in Chapter 7.1, page 32



The Access to Tube Wells or Gravity Flow Water Supply in Nepal. The curves are based on a mathematical Arcus Cosinus Hyperbolic function. From the model it can be seen that between 60 and 75 % of the population have access such to water installations in year 2002.

9 Proposed Solution to the Arsenic Problem

Awareness campaign

Fundraising

Measuring program

Mitigation program

The getting rid of the waste.

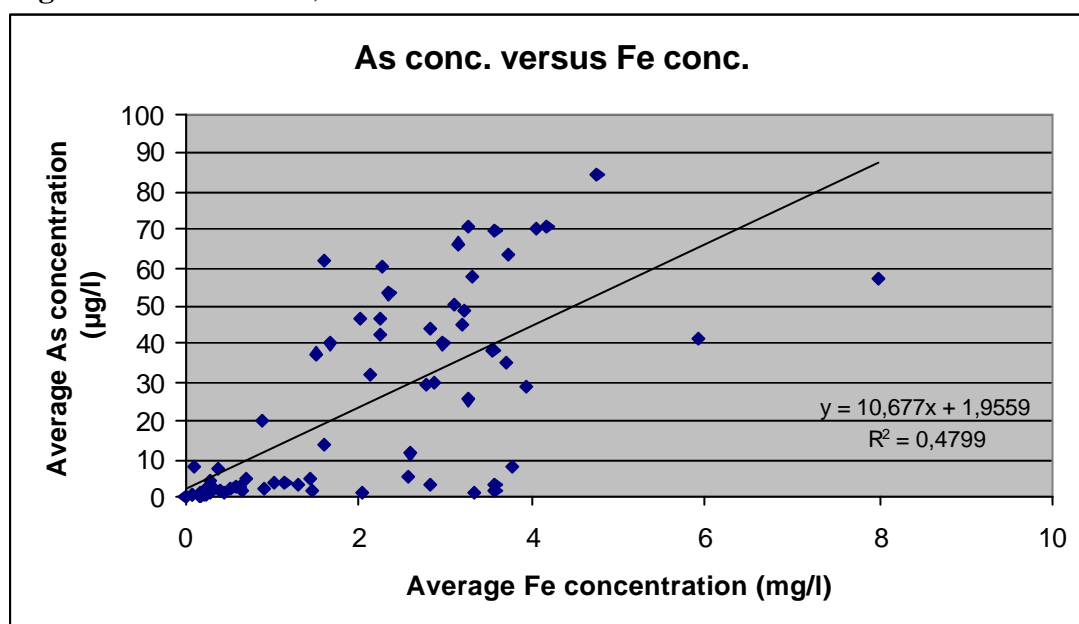
Continuous measuring and mitigation.

10 The Measuring Program in Nepal

Due to the random scattering of naturally occurring arsenic compounds in the ground, it is difficult to accurately predict the location of contaminated wells at the village scale without direct measuring. Two wells 5 meters apart can have quite different Arsenic concentrations, depending on the water extraction, depth and a variety of other factors. As the potential health implications are significant, as seen in Chapter 2: The Adverse Health Effects, page 17 and in the absence of any reliable statistical method that would reduce the number of wells necessary to check in order to find the hot spots, the only responsible course is eventually to measure all tube wells.

10.1 Correlation with other Substances

NEWAH have investigated whether certain other easier measurable natural occurring chemicals could provide information on, which wells would have a higher probability to contain high amounts of Arsenic compounds. It is well known that for example Iron and Manganese are correlated. Investigating the data received from Bangladesh, it can be shown that there is only a certain correlation between natural occurring Arsenic and Iron. Cf. **¡Error! No se encuentra el origen de la referencia.**, below.



The Average Arsenic versus the Iron Concentration. Figure is based on 3533 dataset from Bangladesh.

This figure shows that the concentration correlation between Iron and Arsenic is not very good, but it is positive. The figure suggests that the Iron concentration on average is 100 times higher than Arsenic concentration. The question is, however, not the correlation, but if high Arsenic concentrations can be found at low levels of Iron.

From the Bangladesh dataset it can be seen that below 0.1 mg/l Iron we find only 19 samples out of 667 (= 2.8 %) samples to be above 10 µg/l Arsenic concentration. Similarly 6 samples (= 0.9 %) are above 50 µg/l. Hence if we can accept a mistake adopting the 10 µg/l guideline value on 2.8 % or adopting the 50 µg/l on 0.9 %, then we can measure Iron first. If the sample is below 0.1 mg/l, then continue to the next well, without measuring the arsenic level. The level of 0.1 mg/l Iron is chosen since the highest level found in Bangladesh from the DFID / BGS data had 1660 µg/l Arsenic and 0.188 mg/l Iron. If we set the value on 0,2 mg/l, we would not find this

very high Arsenic level. The six mistakes from the above example had: 337, 168, 81, 59, 54 and 52 $\mu\text{g/l}$ As. As discussed in connection with **¡Error! No se encuentra el origen de la referencia.**, page 70 the highest concentration of these would probably be found by other methods, since a single high level well on e.g. 337 $\mu\text{g/l}$ in a village, when all other wells shows below 50 or 10 $\mu\text{g/l}$, do not exist.

In Bangladesh 19 % of the 3533 samples lies below 0.1 mg/l Iron. Hence if all wells are to be measured in Nepal, and assuming that there is 300,000 wells in the Terai areas (Cf. chapter 4.3, page 23) we would save measuring 57,000 wells and as each cost at least 100 Nrps and takes 30 minutes to measure (See Table 4, page 41, below), this suggestion would save the measuring program for 5.7 mill Nrps and not the least 28,000 measuring hours.

The reason for this small analysis - based on 3533 dataset - is that Iron is much easier, quicker and much cheaper to measure accurately, as it is measured with an electrode and NEWAH therefore recommends to measure Iron simultaneously with Arsenic in order to get data from Nepal to verify the assumption that high As concentrations above 50 $\mu\text{g/l}$ only very seldom or never exist for Fe concentrations for example less than 0.1 mg/l.

The drawback of this suggestion is naturally, that we do not get Arsenic data from wells having an Iron level below 0.1 mg/l in Nepal. Others may evaluate whether we can live with that, given the above mentioned overview of the benefits.

10.2 A Village have Wells installed by a Variety of Stakeholders

In a typical village different agencies have installed different types of tube wells. Until now most of the organisations working in Nepal have been testing the wells supported by the agency itself. The challenge lies in testing all the tube wells, whether public or private.

NEWAH's policy is to test own wells first. If these show levels above 50 $\mu\text{g/l}$, then other neighbouring wells, private or installed by other agencies will be tested, and the information will be passed on.

The NGO's Informal Group for Arsenic Mitigation (NIGAM) has devised an organizational setup to initially test all the wells in Nawalparasi district, regardless of the installing agency. Such co-operation is necessary, but gives certain financial and organizational difficulties. There are around 35000 agency, public and private wells in Nawalparasi district, which is one of the worst affected in Nepal.

10.3 Available Field Measuring Kits on the World Marked

Table 8, below shows the field test kits available on the market today. As can be seen from this table the PeCo75 is the only one using a spectrophotometer, and that this kit furthermore can detect concentrations below 10 $\mu\text{g/l}$, which is necessary if a guideline value of 10 $\mu\text{g/l}$ is adopted. The table also shows that Nepal is today among the exclude members of the very few countries that produces their own Arsenator. Furthermore the Enpho kit is in certain ways better than some of the expensive European and American kits. [**Wateraid Bangladesh: An overview of the Arsenic Issue in Bangladesh, Draft Final report, Dec. 2000**], [**NASC: Nepal's Interim Arsenic Policy Preparation Report, May 2001**], [**Wateraid Bangladesh: Rapid Assessment of Household Level Arsenic Removal Techniques, Phase II Report, March 2001**]

Table 4: The Available Field Test Kits on the World Marked.

Field Kit Name	Country of Manufac.	Availabil. in Nepal	Detection Limit $\mu\text{g/l}$	Minutes for one test	Capital Cost US\$	Test Cost US\$	Remarks and Email-address
Asian As Network	Japan	No	20	30	?		No removal of Sulphide Not comparable with lab. test arthee@bdcom.com
AIPPH	India	Can be Ordered	50	30	?		Presence/absence only Needs good practise
E-Merck	Germany	No Agent	100	40	70	1.7	Used in Bangladesh. Visual Interpretation Cannot test Acidified Samples
Hack	America	Agent	10	50	160	1.7	Visual Interpretation worth@bangla.net Cannot test Acidified Samples
General Pharmaceutical Limited (GPL)	Bangladesh	?	30	35	50	1.0	Visual Interpretation Cannot test Acidified Samples
Nipsom	Bangladesh	No Agent	10	10	40		Used in Bangladesh iftikhar@bdonline.com
PeCo75	Austria	No Agent	5	20	770	1.5	Uses spectrophotometer and a Visual Interpretation Can test Acidified Samples peters.engineering@styria.com
Wagtech	England	Agent	5	?	6-800		Will be available in October 2002 Taken over agency of PeCo75 export@wagtech.co.uk Nick Price
Enpho Arsenic Testing Kit	Nepal	Produced in Nepal	10	10	30	0.5	Chemicals cheap available locally Cannot test Acidified Samples enpho@mos.com.np R. Roshan

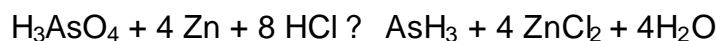
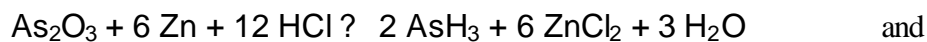
Some of the above test kits cannot measure acidified samples, used for conservation when samples are brought to a laboratory. Cf. Chapter 10.7, page 45. This is unfortunate, since it sometimes can be practical to test samples, conserved with acid and brought to a regional laboratory. The only equipment which can do this is the PeCo75. NEWAH will contribute to the development of the Enpho test kit to be able to do this.

10.4 The Gutzeit Method

The field techniques available today mentioned in paragraph 10.3, page 40, above all uses the Gutzeit method or modifications of this. [H.E. Taylor: U.S. Geological Survey, Considerations for the determination of trace concentration of Arsenic in Environmental Water samples, <http://www.brr.cr.usgs.gov/Arsenic/FinalAbsPDF/taylor.pdf>, 2001], [R.L. Chitrakar & A. Neku: The Scenario of Arsenic in Drinking Water and Arsenocosis in Nepal, <http://groups.yahoo.com/group/arsenic-source/files/Nepal-Chitrakar-Neku-Scen>, dec 2001.], [Dan Kroll: Improving Water quality in Bangladesh, Ground Water and Arsenic Monitoring, <http://www.wcp.net/ArchiveNewsView.cfm?pkArticleID=1328&AT=C>, January 2002], [Walter Kosmos: The Evaluation of the Arsenator, http://phys4.harvard.edu/~wilson/arsenic_project_paper2-3.html, 1999]

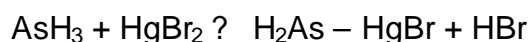
This test procedure is developed in 1920 and later described by A.E. Vogel in 1954. A modified procedure is today based on the following principles:

- 1) Arsenate (As(V), As_2O_3) is reduced to Arsenite (As(III), As_2O_5) by adding KI Potassium Iodine and SnCl_2 , Stannous chlorine, to an acidic environment.
- 2) Arsenite reacts with Hydrochloric acid (HCl) and Zinc (Zn) granules to form arsine gas (AsH_3) after the following reaction:



Sulphuric acid and zinc granulates can also be used to reduce the Arsenic compounds to produce arsine AsH_3 . See furthermore 7) below for PeCo 75.

- 3) The Arsine gas produced is passed through a cotton column moistened with lead acetate solution to avoid interference from the sulphide which is oxidized to sulphate. Also antimony interference is removed in this way.
- 4) The gas is passed through a filter paper impregnated with mercury bromide after the reaction:



Where the reaction products are widely unknown, however they produce a yellow brownish substance on the filter paper. The last reaction also implies that no hazardous gas is released under the measuring; however poisonous arsine gas is present in the column before the filter paper, and therefore the test should be done in a well ventilated room or preferably outside. Arsine has a garlic like odour.

- 5) The arsine gas can also be passed through a Silver Nitrate impregnated filter paper. This produces a grey colour, however today the Mercury Bromide is more often used. Similarly Mercury Chloride can be used to produce a reddish yellow spot on the filter paper. This chemical is used by the
- 6) The intensity of this colour is direct proportional to the amount of arsenic in the original water sample. This colour can either be valuated by a manual comparative judgement to a coloured scale or be measured in a spectrophotometer. The PeCo75 uses the last method, but Arsenator have also a manual colour scale.
- 7) The PeCo75 and the Enpho kit avoid the usage of conc. HCl, which is difficult and hazardous to transport to in the field. Instead Sulphamic acid and Sodium Borohydride is added in pills. These pills are toxic. The usage of liquid acid improves however performance. **[Wateraid Bangladesh: Rapid Assessment of Household Level Arsenic Removal Techniques, Phase II Report, March 2001]** The investigations done by NEWAH showed that the pills produced on the Enpho laboratory dissolves faster in the Arsenator apparatus. They are also smaller and do not break so easily.

10.5 NEWAH uses Three Methods of Measurement

In order to investigate the level of the Arsenic contamination in Nepal, NEWAH uses three practices of carrying out the tests for Arsenic compounds:

- 1) Usage of Atomic Absorption Spectrophotometer (AAS), which can only be done in a laboratory in Kathmandu. The AAS gives very reliable results and can furthermore test water samples below 10 $\mu\text{g/l}$. Water samples are collected in sampling bottles, conserved with conc. HCl, and sent to the laboratory in Kathmandu by the NEWAH field teams. The precision of this measurement is $\pm 10\%$ in the lab, however the conservation and subsequent transportation may hamper this, as discussed in Chapter

10.7, page 45. NEWAH is in the process of measuring the precision, by comparison to the field kits.

- 2) Usage of a field test spectrophotometer from Austria called PeCo 75 or the Arsenator, an Arsenic Field Testing Kit developed by Dr. Walter Kosmos, University of Graz [Walter Kosmos: The Evaluation of the Arsenator, http://phys4.harvard.edu/~wilson/arsenic_project_paper2-3.html, 1999] and Peters Engineering. NEWAH have bought 7 of these spectrophotometers. The PeCo 75 can measure reliable above 50 ppb and give good results between 10 and 50 µg/l. Samples are collected and analysed in the field. Lately the precision of this field kits have been compared to the Enpho kit and the variation between these two kits is judged to be $\pm 40\%$ by NEWAH staff. We are presently working on improving this accuracy. NEWAH have lately experienced some problems with the supply of chemicals from Austria. The former company's obligations have now been taken over by another company: Wagtech from England. This company is in the process of developing a new field test equipment. NEWAH have therefore done some successful experiments to use other chemicals in the PeCo 75, which can be produced locally in Nepal. In future we will have to use these chemicals due to the availability of the original. They are also are much cheaper.
- 3) Usage of the field test kit developed by Enpho. This kit is cheap and easy to use, however it can only measure reliably above 10 µg/l, and this measurement relies on a manual colour comparison. Two different people can judge this analysis differently. The precision is less than the PeCo 75. Furthermore it cannot measure acidified samples. But NEWAH highly recognizes the work done by Enpho, and will support and recommend this kit to other agencies. DWSS already uses the Enpho kit.

The reason for using all three methods are that measuring in the µg/l level of Arsenic contamination is difficult to do reliable using the field kits available on the world market today. It can, however, be done and NEWAH have bought the best available field kit, which uses a spectrophotometer, and is not dependant on personal judgements. The Arsenator can measured preserved samples.

10.6 The initiative by RONAST

In the spring 2002 Royal Nepal Academy of Science and Technology (RONAST) investigated the Kathmandu laboratories ability to measure a known artificial water sample of with an Arsenic concentration. The measurements were done using AAS, and showed that the different laboratories got very different results. This investigation only proved that measuring Arsenic concentrations in the microgram area is difficult, and only experienced persons are able to do this correctly. As NEWAH do not own an AAS, which is necessary to calibrate the field equipment, we also had the same intension prior to the RONAST investigation, but never did it, as NEWAH through the years have build up a constructive co-operation with ENPHO, giving us access to probably the best laboratory in Nepal.

a. Lab tests

Development of testing protocol

b. Field tests

Varieties of mushrooming kits and the range of results coming from them. They are not sensitive enough to obtain a fair estimation at lower concentrations. Human errors are also to be accounted for while using these field test kits.

The most reliable kit, Peters, case of unavailability of reagents
Wagtech
ENPHO's kit and the kit with support from the Asian Arsenic Network

Monitoring of ground waters at two weekly intervals at a number of sites, and at different depths, has shown some variation with time but there is as yet no convincing evidence for seasonal changes. Dramatic changes in contamination are not expected within a short timescale.

In a NEWAH investigation in a village in Nawalparasi (Not the same as the above) all wells showed from 150 µg/l and above. These wells all - according to the villagers - was from 60 to 75 feet deep. In one well 10 meters away from a contaminated well, which according to the owner was 25 feet deep, the concentration showed after a repeated measurement from 10 to 30 µg/l. Hence different underground aquifers have different arsenic concentration. However from a hydro geological point of view in a flat area of Nawalparasi, it seems strange that one well 10 meters away from another, pumps water up from different depths. Therefore the actual groundwater table in these wells should be precisely verified.

10.7 Conservation of samples from the field.

In order to be able to measure samples correctly taken from the Terai areas and brought to the laboratories in Kathmandu, the conservation methodology should be proved and done properly, when the water sample is brought from the field several hundreds kilometres away, often on very bumpy roads, and often up to a week prior to the measuring. I.e. measuring water samples accurately in the field should give the same result as measuring on sophisticated laboratory equipment in Kathmandu. This measuring methodology is simply very difficult, since many parameters affect the samples: Temperature, pH, time, level of contamination, other substances in the water, the amount of shaking from the well to the laboratory, sunlight. etc. **[Kim R. Adamsen & Anil Pokhrel: Procedure for Water Sampling, Internal NEWAH Report, 2002]**

10.8 The Measurements.

A total of approximately 17,000 Arsenic tests have been carried out so far in Nepal. These tests shows that above five percent of the water samples tested contain arsenic concentrations above the preliminary Nepali, the Indian, and the Bangladesh national guideline value of 50 µg/l (one millionth of a gram per liter). Furthermore more than twenty five percent of these samples exceed the WHO limit of 10 µg/l. Unfortunately these figures seems to be rising with increasing number of samples measured. Hence the actual number of Nepali people exposed to arsenic contamination is still unknown. For example in Nawalparasi district alone more than thirty percent of the samples measured exceed the 50 µg/l national interim guideline value. **[Kim R. Adamsen & Anil Pokhrel: The NEWAH arsenic Testing Protocol, Internal NEWAH Report, 2002.]**

10.9 MEASUREMENTS IN LABORATORY

Materials required

Sampling Bottle
Concentrated Hydrochloric Acid
Permanent Marker
Format for recording
Ball Point Pen

Box to keep samples clean

Collection of Water Samples

Pump the tube well or the deep tube well continuously for ten minutes.
Write the "Sample Number" with a marker pen at Three places on the sampling bottle.
Wash the sampling bottle with the water from the same tube well at least 2 times.
Fill the sampling bottle with water up to the neck of the bottle.
Add 8 drops of Concentrated Hydrochloric Acid to the sampling bottle.
Tighten the cap of the sampling bottle.
Shake it vigorously.
Store in collection box
Fill out form. This can also be done while pumping.

Precautions

Concentrated hydrochloric acid is very harmful. One should be very careful while using it. It should never be touched with bare hands or brought in contact with any part of the body. Wear rubber or plastic gloves, while using it. Acid even destroys your clothes. Especial attention is to be paid in the storage.

Keep it away from children.

Clearly write "Acid" in the container with some danger sign.

Check for any leakage from the sample bottle.

If by chance acid spills on any part of the body or clothes, use plenty of water to rinse it for several minutes.

[**Kim R. Adamsen & Anil Pokhrel:** Procedure for Water Sampling, Internal NEWAH Report, 2002]

10.10 MEASUREMENTS IN THE FIELD

Materials required

The PeCo 75 equipment

A copy of the manual for the PeCo 75

Sampling Bottle

Permanent Marker

Format for recording

Ball point pen

Collection of Water Samples

Pump the tube well or the deep tube well continuously for Ten minutes.
Wash the sampling bottle thoroughly two times with the water from the same well.
Fill the sampling bottle with water up to the neck or water sample could be directly collected with the Erlenmeyr flask provided with the PeCo75 Arsenic testing kits
If the water sample by the field kit is shown to be above 50 ppb, follow the procedure in Chapter 10.9. MEASUREMENTS IN LABORATORY ;**Error! No se encuentra el origen de la referencia..**

Precautions

The equipment PeCo 75 Arsenator is only to be operated by trained personnel, capable of observing the safety measures.

Because the method needs no liquid, but only solid chemicals the handling and notably the carrying in the field is much safer.

No concentrated acids are used for this.

The equipment being a digital electronic spectrophotometer, proper care and safe handling is to be carried out.

The handling of all the chemicals used for the testing is to be carried out using tweezers.

The manual provided with PeCo 75 Arsenic test kit is to be strictly followed.

[**Kim R. Adamsen & Anil Pokhrel:** Procedure for Water Sampling, Internal NEWAH Report, 2002]

10.11 RECONFIRMATORY TESTS

If the tests carried out in the sites does reveal contamination value above 50 ppb reconfirmatory test is to be carried out in the laboratory using Atomic Absorption Spectrum. See Chapter 10.9. MEASUREMENTS IN LABORATORY ;**Error! No se encuentra el origen de la referencia.**

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Please refer also to the NEWAH arsenic testing protocol for the Retesting, awareness raising, tube well painting, and closing down of contaminated tube wells above 50 ppb.

[**Kim R. Adamsen & Anil Pokhrel:** Procedure for Water Sampling, Internal NEWAH Report, 2002]

11 The Mitigation Plan

All sector agencies working in Nepal along with some INGOs and bilateral funded program currently try to devise a mitigation plan jointly. Lack of enough knowledge in this particular area, and the problems of limited funds have limited this initiative for long.

11.1 Mitigation options

Long term mitigation options include the following:

1. Tube wells that acquire water from deep aquifers.

The experiences from Bangladesh have shown that deep tube wells above 150 meters (see page **¡Error! Marcador no definido.** in Appendix 7:) would pass the international guideline value for Arsenic. In addition to this, manganese is also less prevalent at greater depths. NEWAH have shown that in Nepal the concentration lowers to a minimum below 75 meters. In Bangladesh the similar value is 150 meters. However further investigations concerning this has to be done in Nepal. The DFID / BGS investigation in Bangladesh states: "There have been persistent reports from West Bengal that deep wells often become contaminated within a few years. This has serious implications since the deep aquifers offer one of the viable long term options for water supply in some of the arsenic affected areas of Bangladesh".

2. Rain Water Harvesting.

Around 2000 mm of rainfall is reported to be received in Rohini, a border village lying close by the highway of the Rupandehi and Nawalparasi districts. This place lies close to the areas having high concentration of Arsenic in Nepal. Though the rainfall is concentrated within 4 months of the year, it could be a viable option for one third of the year. Proper low cost storage of this water could be used for a longer span of a year for cooking and drinking purposes.

3. Artesian and deep bore holes meant for irrigation purposes.

There are numerous deep tube wells constructed by Department of Irrigation for the purpose of irrigation in some of the districts facing problem with Arsenic problem. Water from some of these wells gush out automatically and are called artesian. These sources of water either directly irrigate the fields or are stored in elevated tanks. The water from these sources is found to be Arsenic free from studies carried out so far. The authority to use water from these sources rests upon the users themselves, and these sources could be utilized for drinking in addition to irrigation purposes.

4. Rehabilitation of hand dug wells and implementation of dug well projects.

Water from dug wells from a highly contaminated hot spot in northern Bangladesh was also found to normally comply with the WHO guideline value for arsenic and so could be a possible source of low arsenic water, given the appropriate sanitary precautions.

This result is in concordance with NEWAH's measurements in Nawalparasi. In one village no tube well was found to have less concentration than 300 µg/l. In an open dug well 5 meters away from a well which had concentrations of 800 µg/l, NEWAH measured repeatedly 0 µg/l. In another open dug well in the same village this measurement was again repeated. However the simultaneous microbiological investigation in the open dug wells showed very high numbers.

5. Exploration of safe springs and surface sources.

This could be one of the measures in the foothills of some districts. Though the cost of schemes to fetch water from far off located sources might prove relatively expensive, but if seen from a long- term effect this might prove economical and sustainable.

6. Sand filtrations of surface water.

This means in most cases in Terai: Electricity must be present.

7. Identification and use of safe private wells.

All the above mentioned long term solutions are possible if the water supply program is seen from an integrated water resource management principle for the whole Village Development Committee (VDC) (Cf. chapter 4.1, The administrative organization in Nepal, page 22) or watershed. Proper mapping of all the data will determine the safe areas or aquifers. This could help in designing further usage of water, especially for drinking purposes. This will save enormous human and financial resources poured into the implementation of new programs and the Arsenic mitigation.

The probing of pipes on the earth crust to get water from the underlying aquifers has to be regulated. It needs serious investigations prior to the driving. Nearby wells are to be tested for Arsenic and other contamination before drilling a well. A well found to contain Arsenic or other serious contamination after implementation would result on pouring another limited resource for mitigation.

However, this would present the problem of disposing of the arsenic loaded precipitate. Removing of the arsenic from the groundwater is not enough. We need to develop plans, for the precipitate also.

Most of the methods proposed for removal to date involve iron. For example, one approach involves using iron filings installed in tubes through which well water, which has been spiked with barium sulfate, is passed. Some of the iron is oxidized by air, creating an anerobic solution. The various arsenic species will then be reduced by the iron and in combination with sulfate, forming arsenopyrite precipitates, FeAsS . This method is reputed to lower the arsenic level to less than 1ppb.

A second method involves dipping alum or potassium aluminum sulfate, $\text{KAl}(\text{SO}_4)_2$, wrapped in cloth into the well water for a few seconds. An arsenic precipitate forms overnight, which is then filtered through the cloth. This method is simpler and alum is an inexpensive and readily available chemical, but only 70 to 80 % of the arsenic is removed. [Flynn: Arsenic and the law of Unintended Consequences: The Environmental Disaster in Bangladesh.

11.2 The Arsenic Filters

Only NRCS have actually worked in the field with Arsenic filters installed close to the individual tube well. Enpho are today leading in the investigation of the household filters, where water from the infected tube wells is filtered in each house for drinking and food preparing purposes. This household filtration can be done using a variety of methods, but the most promising in Nepal seems to be the so called Three Kushi System, where the tube well water is filtered through three local produced clay pots which contains, crushed bricks, old nails and charcoal. However further investigations are necessary, since the drinking water produced from these filters usually contains a higher number of bacteria. The awareness among the rural

population on hygienic methods needs to be significantly improved before the household filters can be used. Otherwise the Nepali population may revert the former microbiological problems present before the tube wells were installed.

The work done to mitigate the Arsenic problem in Nepal have only recently been initiated, and much more work is needed on the different levels. Both on the central water treatment plants in cities, the village level Arsenic removal methodologies, the necessary improved tube well installations and the removal filters on the household level. Cf. chapter 11, The Mitigation Plan.

12 The Microbiological problem in Nepal

Short explanation of this and that app. 30.000 people - children and other weak people -died every year from this problem. This number should be decreasing after the increase of the number of tube wells, but after the looking back study and my own, I would like to visit the statistical bureau in Nepal to verify this. Almost all wells we measured were microbiologically contaminated.

13 Conclusion

While arsenic and bacteriological contamination are the most prevalent water quality issues, other elements of concern from a health point view could be fluoride, manganese, boron, magnesium, nitrates and ammonia. There is therefore a need of a water quality test program to assure a safe source of drinking water in the bread basket of Nepal.

Various investigations in South East Asia indicates that there are no other groundwater quality problems on a comparable scale to the Arsenic contamination, although there are substances like Boron, Manganese and Uranium, which exceeds the guideline values of national or international (WHO) standards.

14 Recommendation and further work to be done

Bangladesh: A compensation for the population growth and the effect on the number of wells constructed per year have not been done.

The data could also be investigated for the surface distribution of the wells versus the construction year. If the new wells constructed after 1993 all lie in the low arsenic areas, since construction of new wells have been stopped in the high risk areas, this could also account for the shown downward trend. **¡Error! No se encuentra el origen de la referencia.** below shows a decreased number of new wells constructed the last two years of the Bangladesh data time period.

NEWAH recommends to measure Iron simultaneously with Arsenic in order to get more data to verify the assumption that high As concentrations above 50 µg/l do not exist at Fe concentrations for example less than 1 mg/l.

The problems goes deeper in Bangladesh, which is a slight indication of the theory that the Arsenic compounds originates from the Himalayan area, By statistical analysis it can be shown directly that the average depth of the problematic aquifers are direct proportional to the distance from the high mountains.

In order to be able to measure samples correctly taken from the Terai areas and brought to the laboratories in Kathmandu, the conservation methodology should be proved and done properly, when the water sample is brought from the field several hundreds kilometres away, often on very bumpy roads, and often up to a week prior to the measuring.

NEWAH therefore recommends to measure Iron simultaneously with Arsenic in order to get data from Nepal to verify the assumption that high As concentrations above 50 µg/l only very seldom exist for Fe concentrations for example less than 0.1 mg/l.

The Department of Water, Sanitation and Sewage (DWSS) are in the process of doing this, as a decision by The National Arsenic Steering Committee (NASC) of measuring two wells - randomly distributed - per km² was taken late in 2001.

The need of finding the smallest hot spot area. The Bangladesh data cannot be used for that, since they concentrate on measuring the whole country. In the report itself some villages have been measured throughout. The report must write about this. Find it and read. Make your own calculations on this hot spot size.

No direct data is available for the long term arsenic effects on the Nepali population to date. **[Kim R. Adamsen:** The Arsenic Concentration Impact on the Nepali Population, Internal NEWAH rapport, 2001.] NEWAH is working on this in a co-operation with the Tribuwan University, Kathmandu.

Some of the above test kits cannot measure acidified samples, used for conservation when samples are brought to a laboratory. Cf. Chapter 10.7, page 45. This is unfortunate, since it sometimes can be practical to test samples brought to a regional laboratory. The only equipment which can do this is the PeCo75. NEWAH will work on the Enpho test kit to be able to do this.

Lately the precision of these kits have been judged to be $\pm 40\%$ by NEWAH staff. We are presently working on improving this accuracy.

Appendix 1: Location of the Thermal Springs in Nepal.

Table 5: Location of the Thermal Springs in Nepal

Name	Latitude	Longitude	Comments
Nayargdi	28° 22' 10"	83° 30' 34"	
Kaligardali	28° 29' 50"	83° 39' 28"	
Sekeharku	28° 27' 25"	83° 37' 35"	
Seti Khola	28° 25' 10"	83° 59'	
Naya Gaon	28° 21' 35"	83° 57' 40"	
Chitepani 1	28° 14'	83° 57' 40"	
Chitepani 2	28° 13' 33"	84° 04' 18"	
Kodari	27° 56' 33"	85° 57'	
Tumman (Chi) inse)	28° 12' 41"	85° 18' 08"	
Lende Khola	28° 09' 49"	85° 19' 51"	
Parang	28° 13'	85° 17'	
Jumla	29° 12'	82° 03'	
Sirbari	29° 52'	80° 33'	
Sina	29° 53'	80° 41'	
Jeoligad	29° 37'	81° 05'	
Bauligad	29° 33'	81° 10'	
Chainphur	29° 32'	81° 14'	
Marsyangdi	28° 09'	84° 22' 24"	
Rior	27° 55'	82° 20'	
Janakphur	26° 43'	85° 56'	
Barpata	29° 44'	80° 47'	

Table 6: Temperature and Discharge of selected Thermal Springs in Nepal

Area	Number of Springs	Temperature °C	Discharge (Litre/sec.)	Chemical Composition
Jomosom	2	45	30	Alkaline - Chloride, Sulphate, Bicarbonate
Tatopani	7	36.6-42.2	0.33-0.1	Alkaline - H ₂ S - Chloride, Sulphate
Tarapani Lamas	1	24	0.6	Acidic Bicarbonate
Darchula+Bajang	5	57-73	0.26-0.85	Chloride Sulphate
Myangdi	1	40	2	Black Carbonaceous schist, silty phyllite
Kodari	>1	42	5	Black Carbonaceous slates, limestone
Rior	1	33	1.5	
Surai Khola	1	37	2	

Source: [United Nations : Geology and Mineral Resources of Nepal, New York 1993. page 75 ff.]

Appendix 2: List of Internet sites.

Table 7: Websites on Organizations Related to the Arsenic Problem in Nepal

Organization	Comment	Web-page
DWSS	No own Website	http://www.nepalnet.org.np/newera/drink.htm
R.L.Chitrakar pap.		http://www.irc.nl/products/documentation/ircdoc/title.php?titleno=25449
N. Tandukar paper		http://phys4.harvard.edu/~wilson/nepal.doc
DWSS paper		http://phys4.harvard.edu/~wilson/Nepal/Nepal1.htm
DFID		http://www.dfid.gov.uk/policieandpriorities/files/a_sia/ev_s549.htm
DoMG	Seismic Activities	http://www.seismonepal.org/default.htm
	Oil activities	http://www.petrolemnepal.com.np/
Enpho		http://enpho.org
Helvetas, Nepal		http://www.helvetasnepal.org.np/
JICA		http://www.jica.org.np/
JRCS	No own Website.	http://www.jrc.or.jp/english/home6.htm
MoH		http://www.moh.gov.np/
MoPE		http://www.mope.gov.np/
MWPP	No own Website	http://www.doi.gov.np/
NEWAH		http://www.newah.org.np
NPC		http://www.npc.gov.np/
NRCS		http://www.nrcc.org/
NWSC	No own Website	
RONAST		http://www.ronast.org.np/
RWSSFDB		http://www.rwss.org/
RWSSSP	No own Website	
WHO	Nepal site	http://www.who.int/water_sanitatio_health/arsenic/arsenicpois.htm http://www.un.org.np/other_info/tel_dir/who.html
UNICEF	Nepal site	http://www.unicef.org/arsenic http://www.unicef.org/programme/wes/news/nepal.htm
USEPA		http://www.epa.org http://www.epa.gov/safewater/arsenic.html

Table 8: Arsenic Papers and other Links

Organization	Web-page
British Geological Survey	http://www.bgs.ac.uk/arsenic/home.html

Dr. Wilsons homepage	http://phys4.harvard.edu/~wilson/FACTSHT8.html
R.L.Chitrakar paper	http://www.irc.nl/products/documentation/ircdoc/title.php?titleno=25449
Nirmal Tandukars paper	http://phys4.harvard.edu/~wilson/nepal.doc
DWSS paper	http://phys4.harvard.edu/~wilson/Nepal/Nepal1.htm
World Water Day	http://www.worldwaterday.org/2001/disease/arsenic.html
Arsenic in S.E. Asia	http://w3.whosea.org/rc54/54_8.htm

Table 9: General Links on Water and Sanitation

Organization	Web-page
Asian Development Bank	http://www.adb.org/
Wateraid	http://www.wateraid.org.uk http://www.wateraid.org.uk/aboutus/where/nepal.html
WEDC	http://www.lboro.ac.uk/wedc/index.htm
Martin Wegelins links	http://www.sodis.ch/Text2002/T-Links.htm
IRC, Dutch Water and Sanitation Center	http://www.irc.nl/

Table 10: The Nepali Government Institutions, etc.

Organization	Web-page
Government and NGO's	http://www.panasia.org.sg/nepalnet/mahilaweb/footer/org_profile.htm http://www.geocities.com/rnecairo/hmginfo.html
United Nations Nepal	http://www.undp.org.np/
Facts on Nepal	http://www.odci.gov/cia/publications/factbook/geos/np.html

Appendix 3: Pathological Picture of Acute effects of Arsenic Compounds

Acute Poisoning

Symptoms within 30 minutes, but delayed for hours if ingested with food. Absorbed usually through Gastro Intestinal Tract, but also inhaled or through the skin.

Dehydration, Intense thirst, burning lips, dysphagia, pain in extremities and muscles, weakness.

Blood pressure

Hypotensive from third spacing of fluids, diarrhoea, or blood loss into GI.

Pulse

Tachycardic secondary to pain, hypovolemia or cardiac effects. ³ Hypovolemia from capillary leaking.

Eyes

Conjunctivitis, photophobia, dimness of vision, diplopia, lacrimation, sometimes hyperdemia and chemosis. ^{4 5} Skin, eye and mucous membrane irritations.

Nose

Sense of burning, dryness and constriction of oral and nasal cavities may occur.

Throat

Garlic-like odour may be detected from breath, emesis and faeces. ⁶ Acute inhalation exposure have resulted in irritation of the upper respiratory tract. Throat constrictions.

Cardiovascular

Ventricular tachycardia and ventricular fibrillation. ^{7 8 9} QRS (?) morphology of ventricular arrhythmia. Bradycardia and asystole. ¹⁰ ECG abnormalities: QT prolongation, left axis deviations, peaked and deeply inverted T waves. ^{11 12} Hypotension from gastrointestinal fluid loss or myocardial depression. ^{13 14}

Respiratory

Pulmonary edema, either noncardiogenic from capillary leaking, or cardiogenic from myocardial depression. Inhalation exposure results in upper respiratory tract. ^{15 16}

³ Shum et al, 1995.

⁴ Grant, 1993.

⁵ Heyman et al, 1956

⁶ Lee et al, 1995.

⁷ Petersen and Rumack, 1997

⁸ Goldsmith, 1980.

⁹ St. Petery et al 1970.

¹⁰ Jolliffe et al, 1991.

¹¹ Gousios & Adelson, 1959.

¹² Heyman et al, 1956.

¹³ Schoolmeester & White, 1980.

¹⁴ Moore et al, 1994.

¹⁵ Hathaway et al, 1996.

¹⁶ ACGIH, 1996a

Neurologic

Encephalopathy: Toxic Delirium and permanent encephalopathy are complications of acute^{17 18} and chronic^{19 20} arsenic poisoning. Cortical atrophy.²¹

Neuropathy: Peripheral neuropathy²² after acute poisoning usually 3 weeks after intake.^{23 24 25}

Begins usually as parasthesia of the soles of the feet, then hands, and progressing proximally over the next few days.²⁶ Severe muscle weakness and wasting develops, causing severe disability.^{27 28} The paresthesias may be painful and are frequently described as severe burning

pain on hands and feet. Prominently decreased sensation to touch, pinprick, and temperature.²⁹

³⁰ Loss of vibration sense. Profound muscle weakness and wasting, distal more than proximal.³¹

³² Wrist drop, foot drop, and fasciculations may be seen.³³ Electrodiagnostics of arsenic neuropathy have shown a reduction of motor conduction velocity and marked abnormalities of sensory nerve action potentials.³⁴

Gastrointestinal

Excruciating abdominal pain, severe nausea, projectile vomiting, profuse bloody or “rice water-like” diarrhoea (Not always),^{35 36 37}

Hepatic

Hepatoocellular injury may occur, but not common.^{38 39} Mitotic activity of hepatocytes may be a postmortem finding.⁴⁰

Genitourinary

Anuria, hematuria, proteinuria,^{41 42} acute tubular necrosis, renal failure,^{43 44 45} and chronic renal insufficiency from cortical necrosis have been described.⁴⁶

¹⁷ Jenkins, 1966

¹⁸ Quatrehomme et al, 1992.

¹⁹ Freeman & Couch, 1978.

²⁰ Morton & Caron, 1989.

²¹ Fincher & Koerker, 1987.

²² Guha Mazmuder et al, 1992.

²³ Le Quesne & McLeod, 1977.

²⁴ Heyman et al, 1956.

²⁵ Goebel et al, 1990.

²⁶ Heyman et al, 1956.

²⁷ Le Quesne & McLeod, 1977.

²⁸ CFR, 1988.

²⁹ Heyman et al, 1956.

³⁰ Kelafant et al 1993.

³¹ Donofrio et al, 1987.

³² Heyman et al, 1956.

³³ Heyman et al, 1956.

³⁴ Le Quesne & McLeod, 1977.

³⁵ Gilman et al, 1985.

³⁶ Quatrehomme et al, 1992.

³⁷ Moore et al, 1994.

³⁸ Donofrio et al, 1987.

³⁹ ACGIH, 1991.

⁴⁰ Mackell et al, 1985.

⁴¹ Zaloga et al, 1970.

⁴² Schoolmeester & White, 1980.

⁴³ Giberson et al, 1976.

⁴⁴ Vaziri et al, 1980.

⁴⁵ Moore et al, 1994.

⁴⁶ Gerhardt et al, 1978.

Fluid-electrolyte

Death in acute As toxicity often due to loss of fluids and electrolyte disturbances. Rapid depletion from vomiting, diarrhea, dehydration, and third spacing of fluids is common. ⁴⁷

Hematologic

Hemolysis: Acute hemolysis may occur after acute poisoning. ⁴⁸ Probably not after chronic. Abnormalities of developing normoblasts are common. ⁴⁹

Pancytopenia: As can disturb erythropoiesis myelopoiesis, ⁵⁰ After acute or chronic As exposure pancytopenia may be seen. ^{51 52 53} Isolated leukopenia or anemia may also be seen. The anemia is usually normochromic, normocytic, but may be hypochromic, microcytic. ⁵⁴ Bone marrow aspirate may demonstrate pronounced erythroid hyperplasia similar to seen from pernicious anemia. ⁵⁵ Basophilic stippling and rouleau formation of red cells may also be observed. ⁵⁶

Dermatologic

After either acute or chronic As exposure findings may be flushing of skin, diaphoresis, palmar hyperkeratosis, peripheral edema, hyperpigmentation, brawny desquamation, ⁵⁷ and exfoliative dermatitis. ^{58 59 60 61}

Mee's line: Transverse white striae of nails (Mee's lines) may be seen after acute or chronic exposure. ⁶² Mee's lines takes 5 weeks to appear above the cuticle and advance 1 mm per week afterwards, allowing the approximation of acute exposure time. ⁶³

Musculoskeletal

On muscle biopsy disruption of the normal oxidative intermyofibrillar network (Type 1 fibers), perifascicular hypercontracted fibers, increased vacuolisation in approximately 30 % of fibers, abnormally enlarged mitochondria with loss of cristae, and abundant lipid vacuoles separating the myofibrils. ⁶⁴

Known Acute Effects on Specific Persons and Animal used for Experiments

Body Temperature

Loss of ability to regulate body temperature. ⁶⁵

⁴⁷ Hayes, 1982.

⁴⁸ Kyle & Pease, 1965.

⁴⁹ Ringenberg et al, 1988.

⁵⁰ CFR, 1988.

⁵¹ Rezuze et al, 1991.

⁵² Kyle & Pease, 1965.

⁵³ Kjeldsberg & Ward, 1972.

⁵⁴ Kyle & Pease, 1965.

⁵⁵ Selzer & Ancel, 1983.

⁵⁶ Kyle & Pease, 1965.

⁵⁷ Heyman, 1956.

⁵⁸ Zaloga et al, 1970.

⁵⁹ Schoolmeester & White, 1980.

⁶⁰ Hutton & Christians, 1983.

⁶¹ Huang et al, 1998.

⁶² Sass et al, 1993.

⁶³ Heyman et al, 1956.

⁶⁴ Fernandez-Sola, et al, 1991.

⁶⁵ Fincher & Koerker, 1987.

Cardiovascular

Myocardial congestion found at postmortem. ⁶⁶

Respiratory

Respiratory failure presumably from severe weakness of respiratory muscles in one patient. ⁶⁷
Breathlessness. ⁶⁸ Abrupt respiratory failure and asystole. ⁶⁹ Adult respiratory distress syndrome.
^{70 71 72}

Neurologic

Neuropathy: Sensory and mixed nerve conduction abnormal in 13 studied cases out of 13. 12 had absent sural nerve potentials. 11 had absent median and ulnar nerve potentials. 1 case no motor or sensory response in any of tested nerves. ⁷³ Negative correlation between estimated cumulative arsenic exposure and nerve conduction velocity. ⁷⁴ Nerve biopsy may demonstrate various stages of axonal degeneration without demyelination. ⁷⁵

Hematologic

Possibly decrease in hemoglobin and hematocrit values were the only sequelae associated with acute ingestion of 1.2 grams Sodium Arsenate in 44 year old woman. ⁷⁶

Dermatologic

Steven Johnson syndrome developed in 42 year woman 4 days after exposure from Arsenic trioxide for devitalization of a gangrenous tooth pulp. ⁷⁷

Musculoskeletal

Rhabdomyolysis: After ingestion of 20 g As₂O₃ a 23 year developed Rhabdomyolysis and multi organ failure and died 80 hours after ingestion. Autopsy demonstrated loss of striation and centralization of the nuclei in pectoral muscles. ⁷⁸ Mild Rhabdomyolysis (CPK 1200 U/liter) developed in a 21 year old man who ingested 4 grams of arsenic. ⁷⁹

Reproductive Hazards

Acute Ingestion of As in female with 30 a week pregnancy resulted in death of infant, born 4 days after poisoning. ⁸⁰ As (inorganic) is teratogenic in rodents at doses > 20 mg/kg ? 1,4 grams pr. 70 kg = person. In mice combination of maternal restraint stress and 20 mg/kg IP on day 9 of Sodium Arsenate produced roughly twice the incidence of exencephaly than either alone. Early chelation therapy is thought to have abrogated the toxic effects of an acute As ingestion in woman and her 20 week fetus. ⁸¹

⁶⁶ Jolliffe et al, 1991.

⁶⁷ Greenberg et al, 1979.

⁶⁸ Bansal et al, 1991.

⁶⁹ Moore et al, 1994.

⁵⁵ Zaloga et al, 1970.

⁵⁶ Schoolmeester & White, 1980.

⁵⁷ Bollinger et al, 1992.

⁷³ Oh, 1991.

⁷⁴ Lagerkvist & Zutterlund, 1994.

⁷⁵ Le Quesne & McLeod, 1977.

⁷⁶ Chan & Mathews, 1990.

⁷⁷ Vassileva et al, 1990.

⁷⁸ Sans et al, 1989.

⁷⁹ Moore et al, 1994.

⁸⁰ Lugo et al, 1969.

⁸¹ Daya et al, 1989.

Carcinoma

Epitheloid angiosarcoma of adrenal gland described in 59 year old vineyard cultivator, who was exposed to As insecticides for 20 years and in 60 year old man treated with potassium arsenate for psoriasis for 10 years.^{82 83}

Delayed Effects

Seizures, coma and death may follow within 24 hours of a severe acute exposure.

Multi-organ failure by inhibiting sulfhydryl containing enzymes within cells. Primary targets initially are the gastrointestinal tract, the heart, brain, and kidneys. Eventually the skin, bone marrow, and peripheral nervous system may be significantly damaged.

⁸² Livaditou et al, 1991.

⁸³ Duenas et al, 1988.

Appendix 4: Pathological Picture of Chronic effects of Arsenic

Chronic inhalation of inorganic arsenic compounds is the most common cause of industrial poisoning. The sequence of chronic poisoning involves weakness, anorexia, hepatomegaly, jaundice, and gastrointestinal complaints, followed by conjunctivitis, irritation of throat and respiratory tract, perforation of the nasal septum, hoarse voice, hyperkeratosis, hyperpigmentation, eczematoid and allergic dermatitis.

Numbness, burning, and tingling of the hands and feet, muscle fasciculations, gross tremors, ataxia, incoordination, and mental confusion have also been observed.

Final phase consists of peripheral sensory neuropathy of hands and feet. Motor paralysis. Certain arsenic compounds are known to be human carcinogenic. Chronic exposure either in occupational setting or through drinking contaminated groundwater carries increased risk of skin, lung, and bladder cancers.

Subnormal bodytemperature. ⁸⁴

Hypertension was found in a Taiwanese population. ⁸⁵

Nose

Perforation of the nasal septum. ^{86 87}

Neurologic

Encephalopathy: Toxic Delirium and permanent encephalopathy are complications of acute ^{88 89} and chronic ^{90 91} arsenic poisoning. Cortical atrophy. ⁹²

Neuropathy:

Peripheral neuropathy. ⁹³ Taiwan population chronically exposed to an arsenic pesticide showed peripheral neuropathy.

Cerebrovascular Disease (CD)

Chronic exposed population from drinking water in Taiwan increased prevalence of CD, particularly cerebral infarction. ⁹⁴

Interstitial myocarditis

Resulting in fatal ventricular arrhythmias. ⁹⁵

⁸⁴ Hayes, 1972.

⁸⁵ Chen et al, 1995.

⁸⁶ CFR, 1988.

⁸⁷ ACGIH, 1996a.

⁸⁸ Jenkins, 1966

⁸⁹ Quatrehomme et al, 1992.

⁹⁰ Freeman & Couch, 1978.

⁹¹ Morton & Caron, 1989.

⁹² Fincher & Koerker, 1987.

⁹³ Guha Mazmuder et al, 1992.

⁹⁴ Chiou et al, 1997.

⁹⁵ Hall & Haruff, 1989.

Hepatic

Hepatoocellular injury may be more common than after acute poisoning. Autopsy data from India of patients with liver disease showed higher hepatic arsenic levels than controls.⁹⁶ Liver biopsies from patients with hepatomegaly thought secondary to As contaminations of well water in India showed various degrees of fibrosis and expansion of the portal zone resembling non-cirrhotic portal fibrosis.^{97 98} Non-cirrhotic portal hypertension been associated with chronic As exposure.^{99 100 101 102}

Hematologic

After acute or chronic As exposure pancytopenia may be seen.¹⁰³ Aplastic anemia and acute myelogenous leukaemia have been described after chronic exposure.¹⁰⁴ Anemia reported after Chronic As exposure.¹⁰⁵ Patient suffered macrocytosis and peripheral neuropathy, but without anemia after chronic exposure to As pesticide.¹⁰⁶

Dermatologic

Dermatitis Exfoliative: After either acute or chronic As exposure findings may be flushing, diaphoresis, palmar hyperkeratosis, peripheral edema, hyperpigmentation, brawny desquamation,¹⁰⁷ and exfoliative dermatitis.^{108 109 110 111}

Skin carcinoma: Basal cell and squamous cell cancers of skin may be seen after years of exposure.^{112 113 114 115} Merkel cell carcinoma has been observed in a small number of patients after chronic arsenicism.¹¹⁶ The latency period is at least 10 years and carcinomas usually occur on unexposed areas of the body,¹¹⁷ and are usually multifocal and randomly distributed.¹¹⁸

Mee's line: Transverse white striae of nails (Mee's lines) may be seen after acute or chronic exposure.¹¹⁹

Sensitization: As₂O₃ and As₂O₅ are sensitizers and can cause contact dermatitis.¹²⁰

Airborne pesticides: The organic arsenical pesticide cacodylic acid has caused airborne contact dermatitis.¹²¹

⁹⁶ Narang, 1987a.

⁹⁷ Mazumder et al, 1988.

⁹⁸ Guha Mazumder et al, 1992.

⁹⁹ Guha Mazumder & Das Gupta, 1991.

¹⁰⁰ Nevens et al, 1990.

¹⁰¹ Guha Mazumder et al, 1988.

¹⁰² Duenas et al, 1998.

¹⁰³ Rezuze et al, 1991.

¹⁰⁴ Kjeldsberg & Ward, 1972.

¹⁰⁵ Guha Mazumder et al, 1992.

¹⁰⁶ Heaven et al, 1994.

¹⁰⁷ Heyman, 1956.

¹⁰⁸ Zaloga et al, 1970.

¹⁰⁹ Schoolmeester & White, 1980.

¹¹⁰ Hutton & Christians, 1983.

¹¹¹ Huang et al, 1998.

¹¹² Renwick et al, 1981.

¹¹³ Jackson & Grainge, 1975

¹¹⁴ Wagner et al, 1979.

¹¹⁵ Sass et al, 1993.

¹¹⁶ Lien et al, 1999.

¹¹⁷ Parish & Burnett, 1987.

¹¹⁸ Shannon & Strayer, 1989.

¹¹⁹ Sass et al, 1993.

¹²⁰ CFR, 1988.

Herpes Zoster: Shingles may be a complication of Arsenic poisoning.¹²²

Endocrine

Dose related increase in prevalence of diabetes mellitus have been seen in residents of areas where arsenicalism is hyperendemic and in workers exposed to arsenic in copper smelter.^{123 124}

¹²⁵ However there were no increased diabetes mellitus amongst Swedish art glass workers with chronic arsenic exposure.¹²⁶

Reproductive Hazards

Pregnancy: As can cross the placenta. In a study of women living near a copper smelter, placenta arsenic levels increased with increasing levels in environment.¹²⁷ Higher levels of As exposures were associated with lower percentage of reduced glutathione levels compared with total levels in maternal and cord blood, suggesting reduced antioxidant protection. Similar study did not find increased As body burdens in pregnant Swedish women.¹²⁸

Stillbirth and abortion: Correlation between As exposure in population living near working smelters and increased incidence of spontaneous abortions and stillbirths. These results are difficult to confirm due to several different chemical exposures.^{129 130} Increased incidence of stillbirths in Hispanic population in Central Texas, where As agricultural products have been produced for 60 years.¹³¹

Breastmilk: In population of women living in area of the Argentinian Andes, where drinking water contains about 200 µg/l As, the breast milk arsenic concentration was 2.3 µg/kg (Range: 0.83-7.6 µg/kg), indicating that inorganic As is not secreted to any significant extend in breast milk. Maternal blood and urine levels were 10 and 320 µg/l, respectively.¹³²

Carcinogenity

A chronic therapeutical, occupational, and environmental arsenic exposure have been associated with lung, bladder, skin and other cancers in humans. The Occupational Safety and Health Administration have linked Arsenic exposures to cancer furthermore in lymph glands, and bone marrow.¹³³ Study of population of Taiwan with high arsenic artesian well water found a dose-response relationship between amount of As in water and incidence of mortality rate from bladder, kidney, liver and lung cancer.^{134 135} This result was reproduced using the estimated cumulative As exposure and cancer incidents.¹³⁶ Patients with Blackfoot disease have increased risk of cancer.

¹²¹ Bourrain et al, 1998.

¹²² Jenkins, 1966.

¹²³ Lai et al, 1994

¹²⁴ Rahman et al, 1998.

¹²⁵ Rahman & Axelson, 1995.

¹²⁶ Rahman et al, 1998.

¹²⁷ Tabacova et al, 1989.

¹²⁸ Jakobson-Lagerkvist et al, 1993.

¹²⁹ Golub et al, 1998.

¹³⁰ Sholot et al, 1996.

¹³¹ Ihrig et al, 1998.

¹³² Concha et al, 1998.

¹³³ Anon, 1979.

¹³⁴ Chen et al, 1988.

¹³⁵ Chen et al, 1992.

¹³⁶ Chiou et al, 1995.

Appendix 5: Cures, Medical, and Industrial Usage of Arsenic

Cure

Dimercaprol does not seem to reverse arsenic neuropathy.^{137 138 139} Neuropathy may be prevented by administering Dimercaprol (BAL) within hours of ingestion¹⁴⁰ for acute poisoning. This is not the case all the time.¹⁴¹ A patient with arsenic neuropathy with asymmetric bilateral phrenic nerve involvement made significant recovery with D-penicillamine (250 mg three times a day).¹⁴²

In some cases arsenicosis is reversible if treated early enough. Fresh water, vitamins and drugs such as D-penicillin and Dimercaptosuccinic acid seems curative, but most of these remedies are often too expensive to be used by those affected. Once the cancer develops in internal organs after eight or ten years, the victims are beyond help. Poor nutrition also renders the populace more susceptible than they would otherwise be. To date the problem has seemed so massive, that it tends to overwhelm all attempts to find a solution.

Medical Usage of Arsenic Compounds

Arsenic compounds have been used as therapeutic agents since the fifth century BC, when the Greek physician Hippocrates recommended the use of arsenic sulfides for the treatment of ulcerated abscesses. Later physicians prescribed arsenic preparations for skin disorders, tuberculosis, asthma and leprosy. During the Middle Ages, inorganic arsenic compounds were widely used by physicians and professional poisoners.

Treatment of Leukaemia

In the late 19th century, a preparation known as "Fowler's solution", which contains water, 1% Potassium Arsenite As_2O_3 , $KHCO_3$, and alcohol was an accepted treatment for leukemia and dermatitis. However, based on accumulated evidence as to the toxicity of inorganic compounds of arsenic, most medical have since been curtailed. It is interesting that a recently reported trial study showed the effectiveness of As_2O_3 against a rare and fatal form of leukemia; this may spur a renewed interest in these inorganic compounds. [WHO: Environmental Health Criteria 224, Arsenic and Arsenic Compounds, <http://www.inchem.org/documents/ehc/ehc/ehc224.htm>, 2001]

Patients treated with As_2O_3 for elapsed acute promyelocytic leukaemia developed prolongation of the QTc after 1 – 3 treatments.¹⁴³ Complete atrial-ventricular heart block requiring a permanent pacemaker in one patient, who later died of idiopathic interstitial pneumonitis soon after first therapy.¹⁴⁴ Refractory ventricular tachycardia, which included torsades de pointes. Patient died within 24 hours after onset of dysrhythmias with a postmortem blood arsenic level

¹³⁷ Donofrio et al, 1987.

¹³⁸ Heyman et al, 1956.

¹³⁹ Le Quesne & McLeod, 1977.

¹⁴⁰ Jenkins, 1966.

¹⁴¹ Marcus, 1987.

¹⁴² Bansal et al, 1991.

¹⁴³ Huang et al, 1998.

¹⁴⁴ Huang et al, 1998.

of 69 ? g/l.¹⁴⁵ Pleural effusion in 5 out of 7 leukaemia patients.¹⁴⁶ Elevated serum transaminase levels from liver reported in 2/7 patients treated with As₂O₃ for promyelocytic leukaemia.¹⁴⁷

Treatment of Syphilis.

This have been done formerly before modern medicine was discovered. Well-known case: The writer Karen Blixen, who did not die directly from Arsenic poisoning, but had many of the mentioned symptoms like anorexia.

Organic arsenic compounds were first reported in the eighteenth century, but modern work on compounds with an arsenic-carbon bond began in 1905 when some of these compounds were reported to be effective against trypanosomiasis or sleeping sickness. This lead to a systematic study of the therapeutic properties of arsenicals, chiefly by Paul Ehrlich and co-workers; Ehrlich was already a prominent medical researcher, having jointly received the 1908 Nobel Prize for Physiology or Medicine. From this research came the compound known as Salvarsan or 606, as it was called, being the 606th in the series of compounds synthesized. This compound was shown in 1910 to be extraordinarily effective against syphilis, which is bacterial, and some other infectious diseases such as yaws and amoebic dysentery, which are caused by protozoa. These diseases are today treated by antibiotics.

Treatment of Psoriasis

Epitheloid angiosarcoma of adrenal gland described in 60 year old man treated with potassium arsenate for psoriasis for 10 years.

Usage in the Industry

The principal use of elemental arsenic is in alloys with lead in storage batteries, which contain trace amounts of arsenic to harden the lead. Arsenic is also used in lead shots, which is formed by allowing drops of the molten metal to fall through the air, and is made with from 0.5 to 2.0% arsenic, because the addition of arsenic makes the drops more spherical. Recently, arsenic is being increasingly used to make gallium arsenide (GaAs) semiconductors for use as light-emitting diodes (LEDs), solar cells and laser windows.

Sodium arsenite, NaAsO₂, is effective against locusts, As₂O₃ is a powerful rodent poison, while calcium arsenate, Ca(AsO₄)₂, is used as a pesticide against the cotton boll weevil and the potato beetle. In one notorious application, the organo-arsenic compounds known as Adamsite and Lewisite were used as poison gases during World War 1.

As₂O₃ is produced as a by-product of metal-smelting operations, especially those produced in copper smelting. Arsenic and As₂O₃ are used in the manufacturing of low-melting glasses. High-purity arsenic metal and gallium arsenide are furthermore used in semiconductor products. Worldwide usage in the early 1980s was estimated to be 16 000 tonnes As/year as a herbicide, 12 000 tonnes As/year as a cotton desiccant/defoliant and 16 000 tonnes As/year in wood preservative. By 1990, the estimated end-use of arsenic in the USA was 70% in wood preservatives, 22% in agricultural chemicals, 4% in glass, 2% in non-ferrous alloys and 2% in other uses including semiconductors. [WHO: Environmental Health Criteria 224, Arsenic and Arsenic Compounds, <http://www.inchem.org/documents/ehc/ehc/ehc224.htm>, 2001]

¹⁴⁵ Olmedo et al, 1999.

¹⁴⁶ Huang et al, 1998.

¹⁴⁷ Huang et al, 1998

Appendix 6: The Tube Wells installed by NEWAH in Terai

Table 11: The Regional / District Distribution and Number of Tube Wells Installed by NEWAH

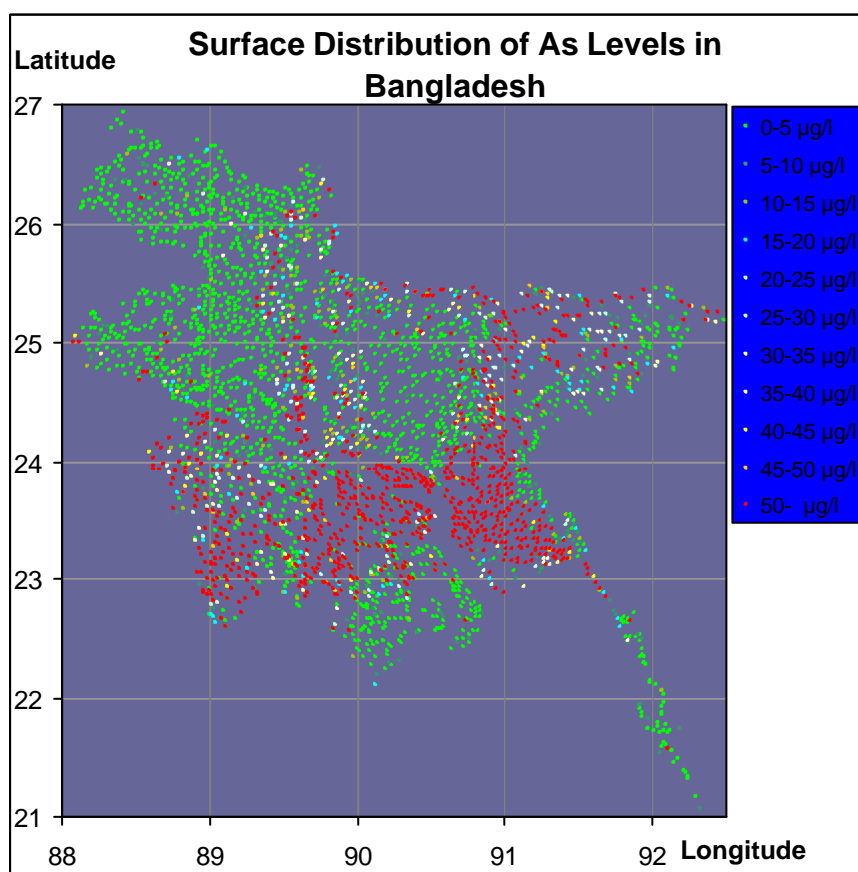
NEWAH TUBEWELLS		
INSTALLED FROM 1987- 2000		
Region: ERO		
S.N.	District	No. of TWs Installed
1	Jhapa	206
2	Morang	19
3	Saptari	1067
4	Siraha	1057
5	Udayapur	64
	Total :	2413
Region: CRO		
S.N.	District	No. of TWs Installed
1	Chitawan	92
2	Dhanusha	515
3	Mahottari	90
4	Parsa	107
5	Rautahat	387
6	Sarlahi	30
		1221
Region: WRO		
S.N.	District	No. of TWs Installed
1	Rupandehi	104
		104
Region: MWRO		
S.N.	District	No. of TWs Installed
1	Banke	198
2	Bardiya	598
3	Dang	11
		807
Region: FWRO		
S.N.	District	No. of TWs Installed
1	Kailali	500
		500
Total		5045

Appendix 7: The Arsenic Problem in Bangladesh

The DFID / BGS funded investigation in Bangladesh

In 1998-99 DFID / BGS funded a throughout investigation in Bangladesh and 3500 dataset was collected. A large number of water guidelines values was measured (As, Al, B, Ba, Ca, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Na, P, Si, SO₄, Sr, V, and Zn) and all names of well owner, GPS location, depth and building year was collected simultaneously. NEWAH have investigated these data and found no clear correlation between Arsenic concentration and any of the other substances measured. The correlation between Iron and Arsenic is discussed in chapter 10.1, page 39.

The surface distribution of arsenic concentrations above 50 µg/l in the BGS second phase survey showed large district variations. In Chandpur, Bangladesh 90 % of the samples was contaminated, whereas no samples were above 10 µg/l in the north-western districts in Bangladesh. See **¡Error! No se encuentra el origen de la referencia.,** below.



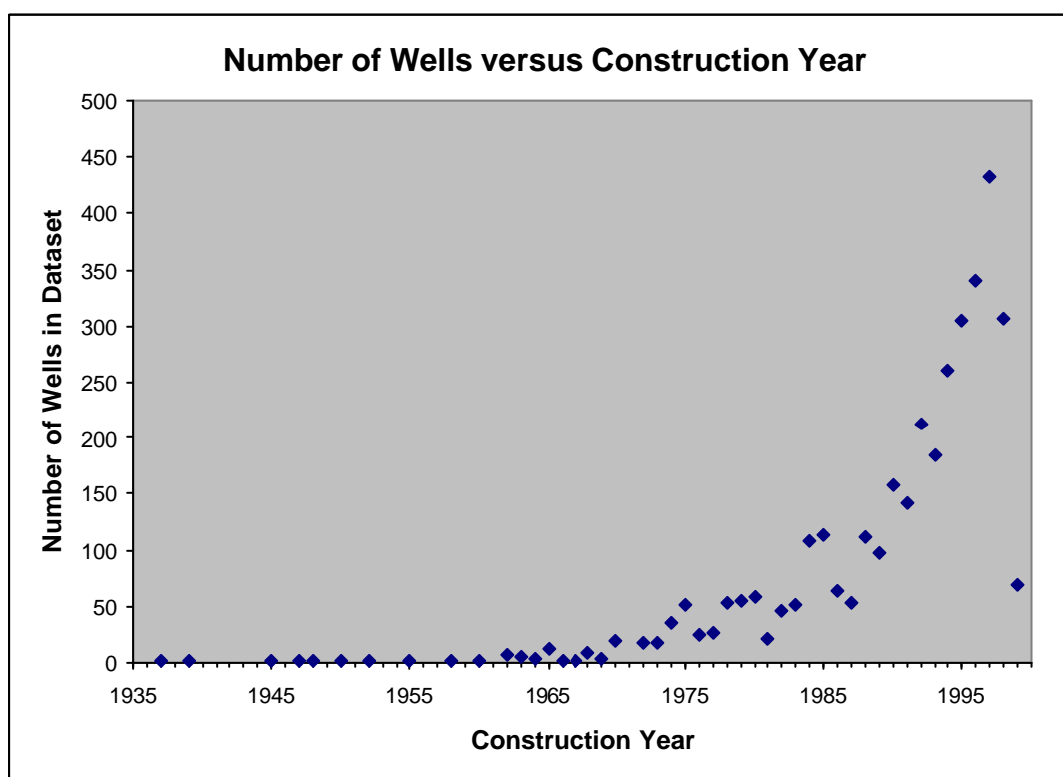
The surface distribution of Arsenic concentration using 3500 water samples in Bangladesh. Reddish dots > 50 µg/l. Greenish < 10 µg/l. The figure also shows that the sample points have been almost equally distributed over the surface and only areas in the South East of Bangladesh. The map also gives an indication of that the highest concentrations are found along the big rivers and in the southern part of the country. Data from BGS / DFID processed by NEWAH.

NEWAH have found that 25 % of the tube wells exceeded the 50 µg/l Bangladesh arsenic standard. Similarly the WHO guideline value (10 µg/l) was exceeded in 42 % of the tube wells.

Further Discussions of the Reason

The map below shows that the Arsenic problems in Bangladesh generally are present in the southern part of the country, in the deltaic formations of the large rivers and along the banks of these large rivers. This indicates that the Arsenic compounds have in geological time been transported by the rivers and hence, as these rise in Nepal there is basis for concern in the regions north of Bangladesh, inclusive Nepal. The map also shows the hypothesis D in chapter 3.1, page 19 that the arsenic concentrations should have connection to the seawaters influence need to explain the occurrence of the large areas near the sea, with concentrations well below the WHO guideline value. At least this hypothesis is again (See D, page 19) shown that it cannot be the prevailing explanation. Similar considerations gives clarification of that A, the theory which claims that the pumping should be responsible (See however **¡Error! No se encuentra el origen de la referencia.**, page 24) and C, which explains the phenomenon by the usage of fertilizers. This would mean that in the green areas on the map people pump less and use fewer fertilizers. This lack justification. NEWAH hence agrees to that the **major** reason for the Arsenic problem in South East Asia is natural, from geological times and due to the reductive conditions in the aquifers.

From **¡Error! No se encuentra el origen de la referencia.**, above it can be seen that the BGS / DFID investigation have concentrated on an even surface distribution in order to find the hot spots in Bangladesh, and to construct the above map.



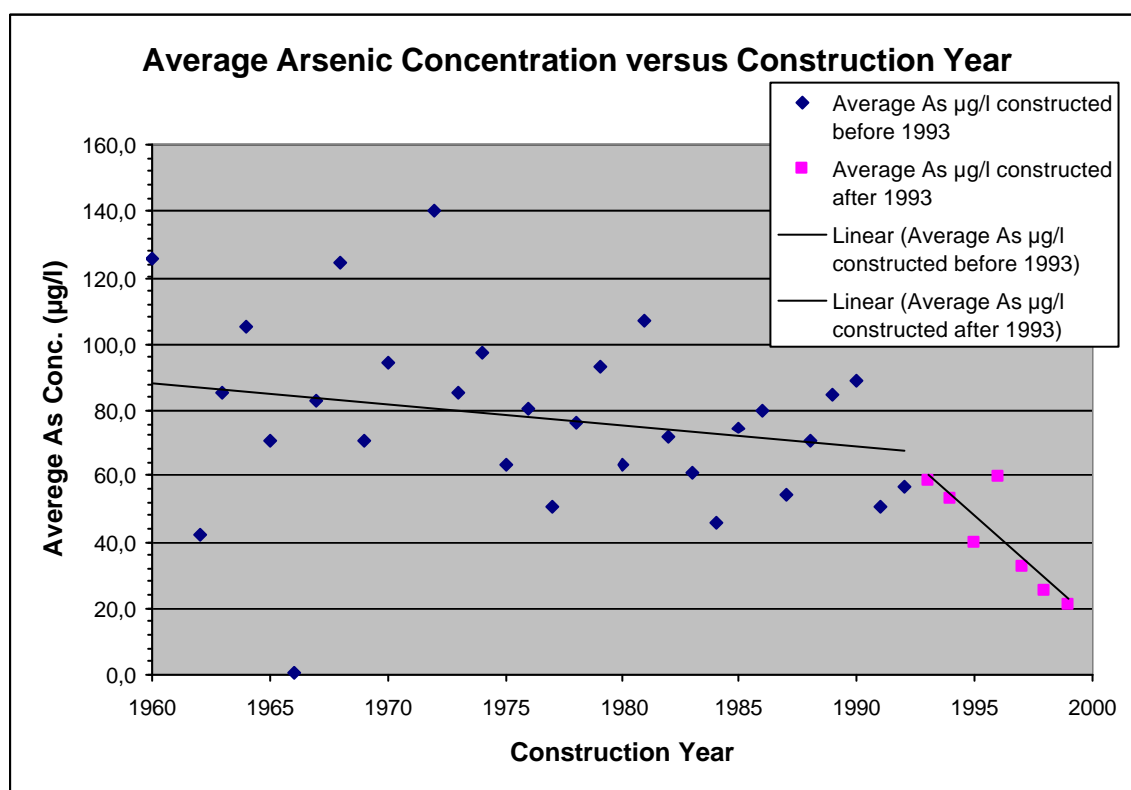
The Construction year versus the number of wells from the BGS /DFID dataset.

The Effect of the Arsenic Awareness campaign in Bangladesh

This focus on the surface distribution means that the building year data in the 3500 dataset are close to being random and the number of wells constructed in a special year in the dataset, therefore is an indication of the construction development over time of all wells in Bangladesh of the transfer from surface water to shallow and deep tube wells. These data are plotted in **¡Error! No se encuentra el origen de la referencia.** above, where it also is interesting to note that the development is close to being exponential. Only the last two years (1998 and 1999) the number of wells constructed in Bangladesh have been significantly lower. The reason for this rather sharp bend could be due to the increased awareness in the population concerning the poisoned drinking water. A "saturation effect" would probably first show a declining growth in the yearly number of wells constructed over some years, after which a stabilization should be seen related to the life time of a hand pump and the well. A compensation for the population growth and the effect on the number of wells constructed per year have not been done.

The Washing out of the Arsenic Concentration

It has in the literature been mentioned that the Arsenic compounds would be washed out after possibly many thousand years. Since the Bangladesh data contains wells over 60 years old, **¡Error! No se encuentra el origen de la referencia.** below, shows that this effect cannot be seen. On the contrary: The more water which has been pumped from the well the higher concentration.



Average As concentration in 5 meter intervals versus the construction year. The figure shows that no washing out effect can be observed from the data before 1993. The decreasing As conc. after 1993 might be the effect of increased awareness among all stakeholders. Newer wells have lower concentration than old.

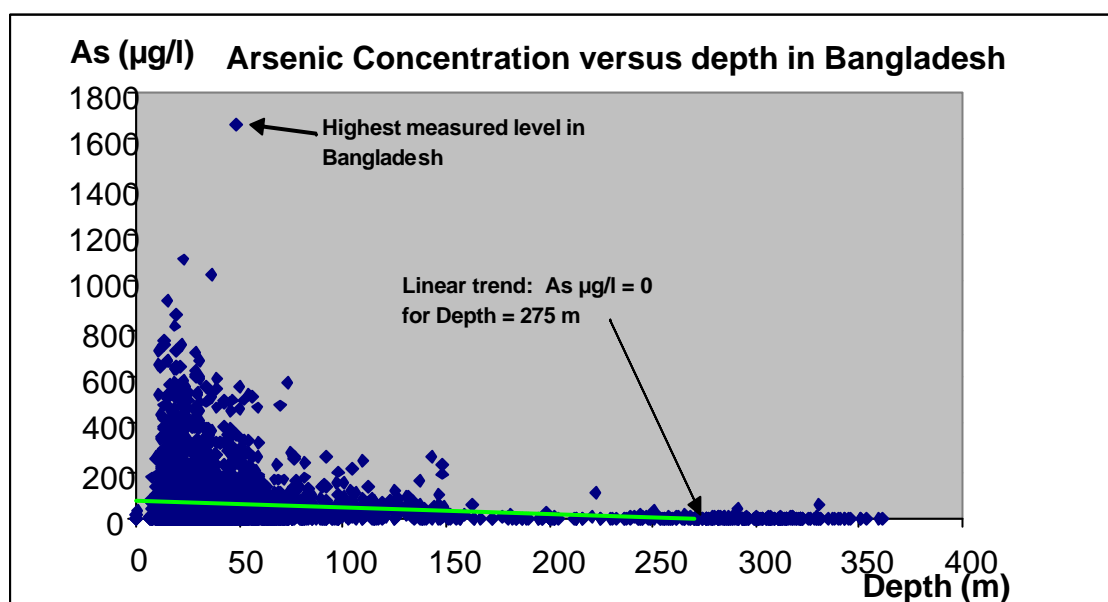
The data have been divided up in wells constructed before 1993 and those after, since the international awareness of the Bangladesh ground water problem increased around that year. Furthermore the newer wells have a steeper downward trend, which could indicate that new wells are measured before they are used. The data could also be investigated for the surface

distribution of the wells versus the construction year. If the new wells constructed after 1993 all lie in the low arsenic areas, since construction of new wells have been stopped in the high risk areas, this could also account for the shown downward trend. This figure can be compared to **¡Error! No se encuentra el origen de la referencia.** above, which shows a decreased number of new wells constructed the last two years of the Bangladesh data time period.

¡Error! No se encuentra el origen de la referencia. above shows, referring to the discussion in chapter 3.1: The Chemical Explanation, page 19, explanation A, that the concentration increases slightly with increased age of well. This can indicate that the problems to some extent are anthropologic, however this explanation cannot be the major reason for the ground water problem in Bangladesh as discussed above.

The Depth of the Arsenic bearing Aquifer in Bangladesh

From a simple linear trend and the same dataset on **¡Error! No se encuentra el origen de la referencia.**, below, it can be seen that the aquifers in Bangladesh contains hazardous Arsenic compounds down to 275 meters, which signifies that also Deep Tube Wells is a questionable option in Bangladesh. See however **¡Error! No se encuentra el origen de la referencia.**, below for a more accurate estimation of this depth.

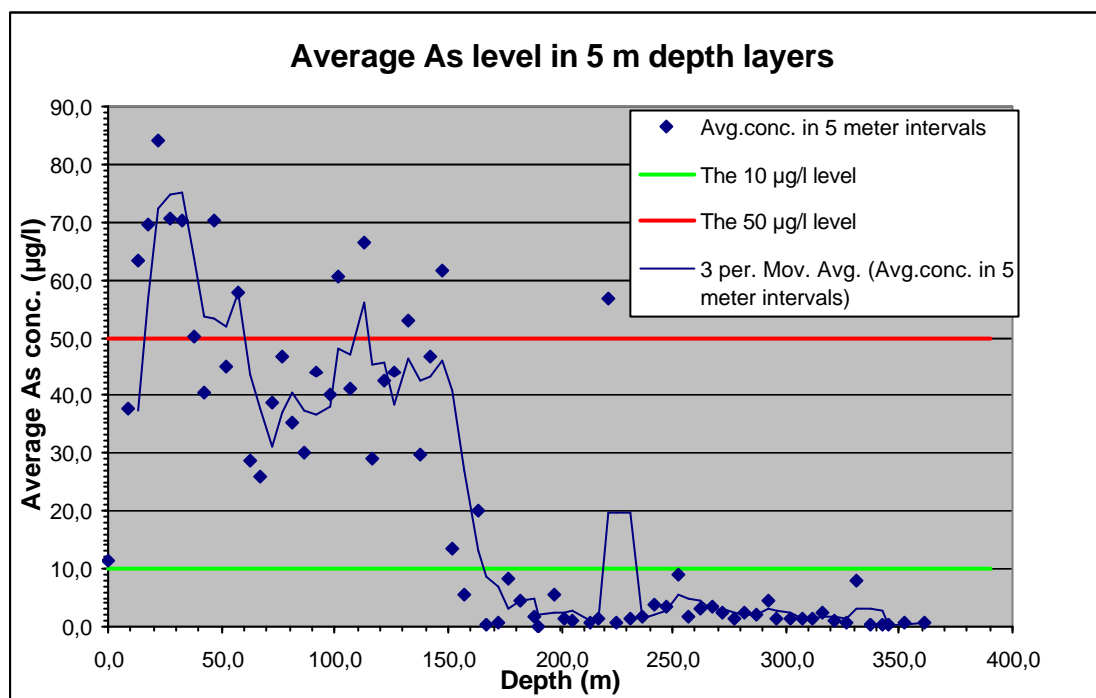


3500 dataset from Bangladesh showing the As problem exists in aquifers down to 275 meters.

Averaging the As Concentration in Depth of 5 meter Intervals

The data from Bangladesh are not equally distributed over the different depths as is approximately the case for the surface distribution. Much more data has been collected from wells below 50 meters. Dividing the 3500 data up into 5 meter intervals and calculating the average Arsenic level, gives a similar, but a slight different conclusion, shown in **¡Error! No se encuentra el origen de la referencia.** **¡Error! No se encuentra el origen de la referencia.** above indicates also that shallow tube wells below 5 meters have 0 or less concentration. This observance could be due to the oxidation effect in very shallow wells, and a dilution consequence from Arsenic free surface water seeping fast into the borehole. This last effect is the main reason for bacterial contamination of tube wells.

Below 175 meters 3.5 % of the samples lies above 10 $\mu\text{g/l}$. Only 0,6 % (relative to those above 175 m depth) are above 50 $\mu\text{g/l}$ according to these Bangladesh data. The bulge on the blue curve in 223 meters depth is due one (1) level on 108 $\mu\text{g/l}$ in Satkhira (22°41'06" N, 89°07'19"). Furthermore it can be seen from the curve below that the highest Arsenic contamination is between 15 and 50 meters below the surface. The low arsenic level near the surface is based on only 5 measurements of which 4 is noted to have been taken in 0 meters depth. Hence one should be precautious to conclude low levels of Arsenic in very shallow tube wells (below 5 meters depth) from the DFID / BGS data alone.



Averaging the Arsenic levels in 5 meter aquifer layers shows that the concentrations are below 10 $\mu\text{g/l}$ or 50 $\mu\text{g/l}$, when the borehole is deeper than 175 meters. Below this depth the concentration drops rapidly below 10 $\mu\text{g/l}$. The bulge at 223 meter is due to a single As level of 108 $\mu\text{g/l}$.

If a policy is adopted not to measure wells deeper than 175 meters in Bangladesh, only 2 wells (= 0.6 %) deeper than this level have As concentration (on 54 and 108 $\mu\text{g/l}$ respectively) above the 50 $\mu\text{g/l}$. 11 wells (= 3.5 %) deeper than 175 meters have levels above 10 $\mu\text{g/l}$.

In order to investigate this depth more throughout where the error is negligible, if a policy was adopted in Bangladesh not to measure deep tube wells below a certain level **¡Error! No se encuentra el origen de la referencia., ¡Error! No se encuentra el origen de la referencia.** have been constructed from the 3533 dataset. This figure shows a bend on both the 10 and 50 $\mu\text{g/l}$ curves on 150 meter. This means that no significant error improvement will be experienced by measuring wells deeper than 150 meters. Hence it is this reports recommendation that if a level should be introduced in Bangladesh, it should be at 150 meters. The figure also shows that the Arsenic rich aquifers lies from 0 to 150 meters in Bangladesh.

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page

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