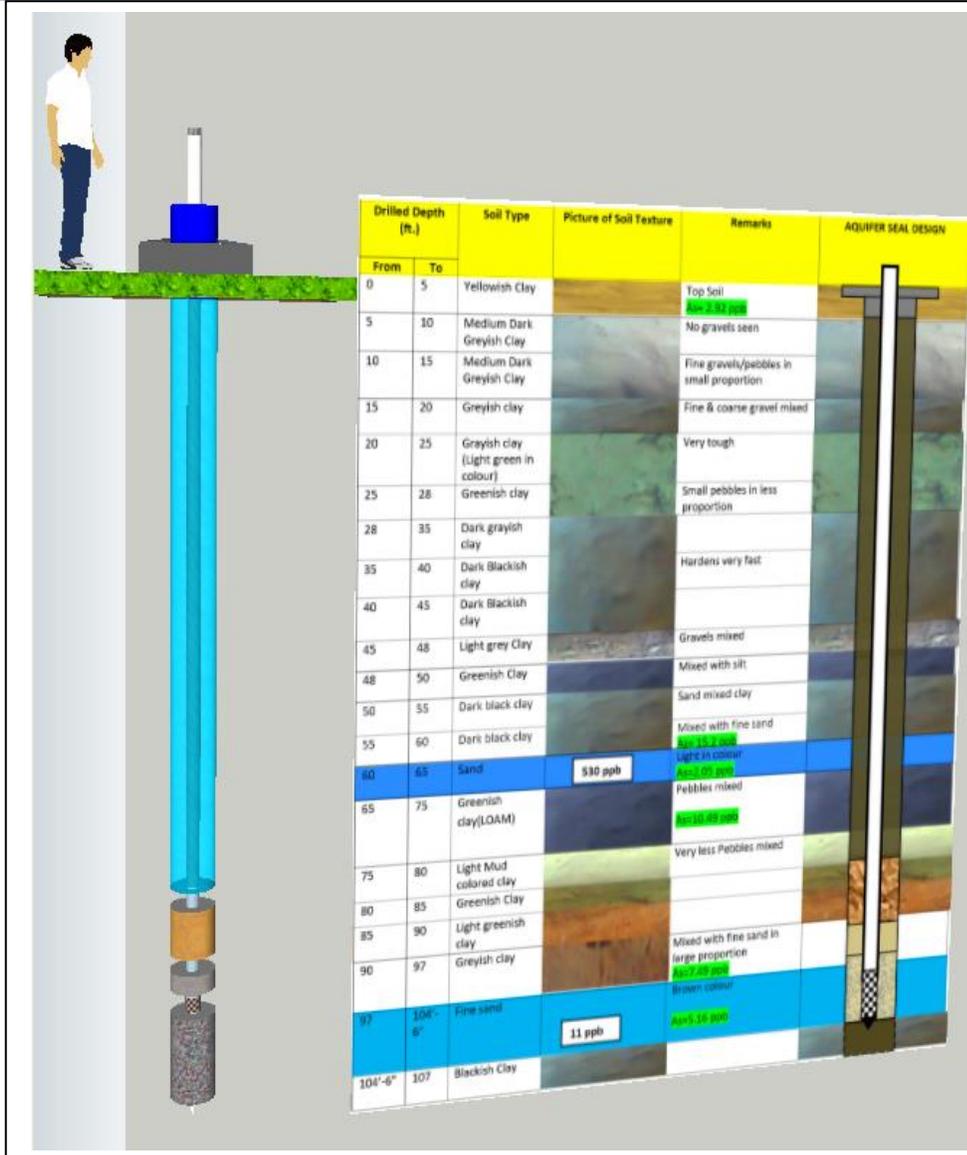


A Final Report on Arsenic Aquifer Sealing

2012



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ACRONYMS

AAS	Atomic Absorption Spectrometer
ANSI	American National Standard Institute
As(III)	Arsenite
As(V)	Arsenate
As ₂ S ₃	Orpiment
AsS	Realgar
Conc.	Concentration
COD	Chemical Oxygen Demand
DoI	Department of Irrigation
DWSS	Department of Water Supply and Sewerage
EC	Electrical Conductivity
ENPHO	Environment and Public Health Organization
Fe	Ferric (Iron)
FeAs ₂	Lollingite
FeAsS	Arsenopyrite
GFH	Granular Ferric Hydroxide
GWRDP	Ground Water Resources Development Project
IEC	Information, Education and Communication
JICA	Japan International Cooperation Agency
KAF	Kanchan Arsenic Filter
l	Liter
m	Meter
mg	Milligram
MIT	Massachusetts of Technology
NASC	National Arsenic Steering Committee
NAST	Nepal Academy of Science and Technology
N.P.	Nagar Palika
NEWAH	Nepal Water for Health
NRCS	Nepal Red Cross Society
NTU	Normal Turbidity Unit
pH	Potential of Hydrogen
ppb	Parts per billion
PVC	Poly Vinyl Chloride
RWSSP-WN	Rural Water Supply & Sanitation Project-Western Nepal
SDDC	Silver Diethyl Dithio Carbamate Spectrophotometric Method
USGS	United States Geological Survey
UNICEF	United Nations Children's Education Fund
VDC	Village Development Committee
WHO	World Health Organization
µg	Microgram
µS/cm	Microseimen per centimeter

ABSTRACT

The project has been conducted to explore the viability of developing an Arsenic mitigation measure by promoting *Arsenic Aquifer Sealing* technology in the Terai region of Nepal. It includes the study of groundwater aquifer quality and conditions Ward No. 12 & 13 of Ramgram NP and Pratappur VDC, Nawalparasi District and to recommend the appropriate solutions for improving the water quality of the water for domestic purpose.

6 pilot (monitoring) tubewells were drilled (3 promoted by RWSSP & 3 by UNICEF) and their hydrogeological data were recorded. Up to date 4 of them have been completed with sealing. The samples were analysed by different methods. Field testing of the sample was done by using Arsenator and also the samples were tested in the Laboratory in Kathmandu. High Arsenic concentration was observed in the shallow aquifer and was found to be decreasing with the depth; for which Sealing of the contaminated aquifer zone of the well can prevent the further contamination of other uncontaminated aquifers. Also, higher concentrations of Iron were observed which show some interrelation with the presence of high Arsenic in the shallow aquifers.

On the current circumstances, where Bio-sand filters also aren't functioning in satisfactory conditions, this sealing technology has been tested on developing itself as a mitigating measure in solving Arsenic contamination issue in drinking water in terai region of Nepal.

Secondary data from different agencies were also used to draw up the pictures of Arsenic concentration and their fluctuations in the working zone. On a health camp conducted, it was observed that villagers were suffering from Arsenic and other skin diseases due to drinking of poor quality water. People should be made aware of Arsenicosis and its prevention and precautions to be adopted.

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About the Project

This is a report of the project Arsenic Aquifer Sealing; a research project which was supported by Rural Water Supply and Sanitation Project-Western Nepal (RWSSP-WN), Pokhara and partly by UNICEF, Country Office, Nepal from 30th Nov, 2010- 30th June, 2011. The project time period was added later due to the several sudden uncertained constraints during the research work at village level. The project is all about conducting research on behalf of promoting a very pioneering sealing technology as a sustainable Arsenic mitigating measure for the Arsenic contaminated Terai region of Nepal; currently in Nawalparasi District and develop a cheap , socially acceptable and easily replicable local sealing technology.

The report contains a detail descriptions of works carried out during the construction of 6 sealed pilot tubewells at different places,tapped in safe aquifer zones. 4 of them were located at Kunuwar and Siwangadh Village and rest of two were located at Pratappur VDC of Nawalparasi District.

1. INTRODUCTION

1.1 Background

Arsenic contamination of groundwater is a natural occurring high concentration of arsenic in deeper levels of groundwater, which became a high-profile problem in recent years due to the use of deep tubewells for water supply in the Ganges Delta, causing serious arsenic poisoning to large numbers of people. A 2007 study found that over 137 million people in more than 70 countries are probably affected by arsenic poisoning of drinking water. Arsenic contamination of ground water is found in many countries throughout the world, including the USA.

Nepal, being a resourceful country in context of water resource is still suffering from As-safe drinking water problems. Almost 90% of the people who are the inhabitant of Terai region mainly rely on ground water. Groundwater contains many compounds such as ammonia, arsenic, iron, and bacteriological elements, etc.; which makes the water unsafe if they are present in excess amount in drinking water. So those health hazardous compounds contained in ground water are to be mitigated for safe drinking purpose.

Nevertheless few researches have been done in Nepal by various researchers and study teams (DOI, USGS, UNICEF, Sharma, 1999;; ENPHO/RWSSP, 2002-2003 and Shah, 2003), on addressing this arsenic poisoning in drinking water issues. As a step towards further research , this is our endeavour towards developing some innovative ways of As-mitigation technology that can give a sustainable solution for challenges in accessing quality drinking water in the affected belts of Terai region of Nepal.

The concept of aquifer sealing has been introduced with a view to seal the shallow As contaminated aquifer zone and tap the water from As-free zone in tubewells and thus prevent the possible aquifer cross contamination issues and its long term aquifer pollution problems. In context of Nepal, where sealing works hasn't been practiced wide yet, the current project signifies its need as one of the pilot testing of sealing technology in Nepal. Also, the prior concern of this research project was to study the vulnerability of aquifer pollution caused by the unscientific ways of handpumps installations in most of the villages in Terai regions of Nepal. The preferences of local people of extracting water for their household purposes from the deeper aquifers, crossing beyond the shallow or overlying aquifers, precisely triggers the vulnerability of leakage of water from the upper aquifers through seepage across the periphery of vertical water conduits; consequently leading to the mixing of water among all the intercepted aquifers along the bore hole of the well.

1.2 Objective of the Study

The main objective of the study is to determine the possibility of sealing groundwater aquifer so as to prevent arsenic pollution of groundwater. The specific objectives are:

- To construct all together 3 monitoring wells in Ward No. 12 & 13 of Ramgram Municipality and Pratappur VDC and study the fluctuation of Arsenic Level in the installed sealed wells throughout a longer period afterwards.
- To do a research on determining the role of sealing technology in addressing aquifer contaminations by preventing seepage contamination (*Minerological + Microbiological*) inbetween multi-aquifers.
- To study groundwater quality and correspondent lithology relationship.
- To study the ways of improving the water quality and recommend the appropriate sustainable As-mitigation measures.
- To promote sealing technology as a supportive reference to the ongoing deep bore hole drilling of mini-overhead water supply system under RWSSP-WIN.

1.3 Scope of the Study

It is evident that arsenic in water may pose a serious problem in many areas where primary source of drinking water is groundwater. Many technologies have been developed for the removal of arsenic. Several attempts have been made so as to develop low-cost, easily operable and socially replicable treatment methods for As-removal. Arsenic aquifer sealing technology is emerging as an appropriate local technology because of ease of installing and replicating capability giving a sustainable solution to the arsenic contamination in domestic water supply. The present study was undertaken to assess the viability of sealing technology for the prevention of arsenic contamination in the uncontaminated aquifers in the Terai region of Nepal. The project was assigned with task of constructing 3 pilot sealed tube wells and were located within Ramgram N.P. Ward 12 & 13 and Pratappur VDC of Nawalparasi District.

1.4 Limitations of the Study

The limitations of the study are as follows:

- The research project and overall testing was meant for aquifer stratas lying above 200 ft. from the ground level. The research has been confined to installation of monitoring of three wells only.
- It's not a wide research and only 3 sealed wells were installed and monitored performance.
- Pratappur VDC required a different drilling as well as sealing mechanism; which varies from the developed sealing guidelines.
- Lack of appropriate drilling technology has modified the simple ways of sealing into complicated procedures.
- Most of the time of project was spend in developing/finding an appropriate drilling technology apart from the task of sealing mechanism.
- Majority of the wells have been constructed in easy drilling locations (i.e.) Parasi Region and minority of wells in challenging Pratappur Region.

Contamination specific nations and regions:



2. LITERATURE REVIEW

Arsenic was the poison of choice in Renaissance Italy, with members of the Borgia and Medici families being highly skilled practitioners of the art. Because of its favoured use as a murder weapon among royal families, Arsenic has been called “the poison of kings and the king of poisons”. [Robbins & Cotral, "Pathological Basis of Diseases"] Arsenic is found naturally in soils and water and is used in products such as wood preservers, as well as herbicides and other agricultural products. Arsenic is present in some Chinese and Indian herbal medicines as well. Large concentrations of inorganic Arsenic are present in groundwater used for drinking in countries such as Argentina, Chile, China, Bangladesh, America, India and Nepal as well.

Groundwater Arsenic contamination has exponentially endangered the human life and complicated the efforts for obtaining and maintaining drinking water quality standards. **Prior to the 1970s, Bangladesh had one of the highest infant mortality rates in the world. Ineffective water purification and sewage systems as well as periodic monsoons and flooding exacerbated these problems. As a solution, UNICEF and the World Bank advocated the use of wells to tap into deeper groundwater for a quick and inexpensive solution. Millions of wells were constructed as a result. Because of this action, infant mortality and diarrheal illness were reduced by fifty percent. However, with over 8 million wells constructed, it has been found over the last two decades that approximately one in five of these wells is now contaminated with arsenic above the government's drinking water standard.**

Consequently, the contamination issues of those deep tube wells left a strong doubt among the stakeholders about the possibility of ground water aquifer contamination, which suspects to be the only causative agent behind the scene, and eversince ideas of sanitary sealing are emerging.

Drilling a hole through an impermeable layer is a little like taking the ‘plug out of the sink’ or in technical terms a connection, (a short cut) is created between the first and the second aquifer; so enabling contaminants to flow down from the polluted layer to the clean, second aquifer and enter the well-screen. Thus, the mineralogical (chemical) & microbiological (pathogens) impurities/ components get a permanent access inbetween multi-aquifers. And this is all how aquifer contamination begins. And once entered in the groundwater, the pathogens and chemicals not only spread horizontally (left-right), but also vertically (up-down), deeper into the aquifer.

Apart from this, the social preferences of local people in accessing better quality water from deeper aquifers, crossing beyond the shallow and contaminated aquifers, with unscientific local well construction methods has also enhanced these deeper aquifer contaminations to a greater extent.

2.1 Hydrogeology

Groundwater: is fed by the infiltration of rain through the soil and it eventually flows to lower areas and rivers. The groundwater level can drop dramatically during the dry season, because at that time the groundwater that flows out of the pores of the formation to lower areas is not replaced by infiltrating water from rainfall. Only when the rains start the groundwater level will rise again.

Aquifers: The word ‘aquifer’ simply means ‘a water bearing layer’. A good aquifer for the installation of a well-screen is a permeable layer below the groundwater table (par. 1.3). During drilling you may come across different aquifers at different depths, separated by impermeable layers.

Phreatic aquifer: The upper aquifer is called the ‘phreatic’ aquifer. Rainwater directly infiltrates the soil. The water moves down and when it reaches the water level it is added to this aquifer. The water can take contamination (such as bacteria or pesticides) down into the groundwater. Therefore a phreatic aquifer is prone to pollution from activities taking place on surface. Phreatic groundwater exists in a permeable layer above an impermeable layer (see fig.1a). If this phreatic groundwater layer is just a few meters thick, it may run dry during the dry season, leaving the well empty.

Second aquifer: The next aquifer, covered by an impermeable layer on top (for example, a clay layer) is called the ‘second’ aquifer (see fig 1a). The impermeable layer above this water bearing layer forms a barrier for bacteria and pollution and prevents them from traveling down to the second aquifer.

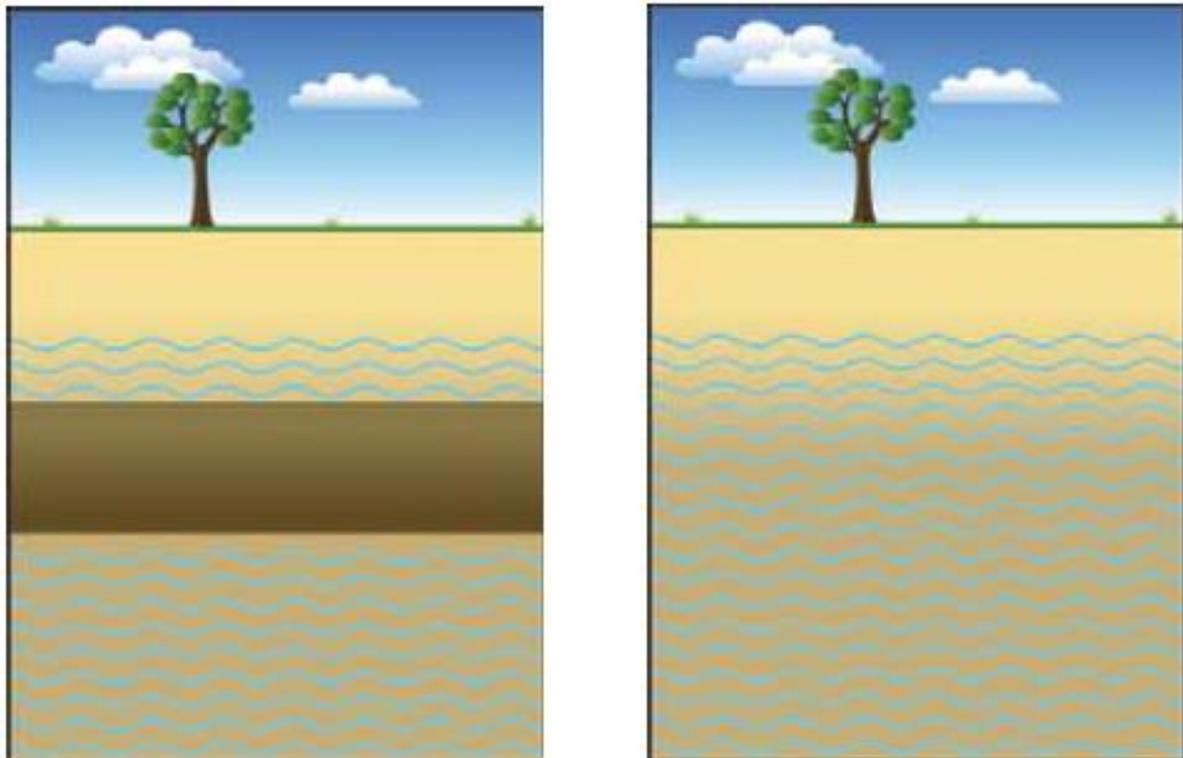


Fig 1: (Left) Multi Aquifers ; (right) one aquifer

2.2 Mineralogical Contaminations in Aquifers

2.2.1. Arsenic Contamination:

a) Arsenic:

Arsenic, the ubiquitous element lies in the fifth group in the periodic table. It is found in atmosphere, soil and rock, natural waters and organisms. The abundance of arsenic in the earth's crust is 2 mg/Kg. Trace concentrations are found in all environmental media, including air, water soils/sediments and biota. It is mobilized in the environment through natural processes as well as anthropogenic activities. Arsenic is perhaps unique among the heavy metalloids and oxyanion forming elements (e.g. arsenic, selenium, antimony, molybdenum, vanadium, chromium, uranium, and rhenium) in its sensitivity to mobilization at the pH values typically found in groundwater (pH 6.5—8.5) and under both oxidizing and reducing conditions. Arsenic can occur in the environment in several oxidation states (-3, 0, +3 and +5) but in natural waters it is mostly found in inorganic form as oxy-anions of trivalent arsenite (As (III)) or pentavalent arsenate (As(V)).

b) Sources of Arsenic

i. Natural Processes

Arsenic is found in the nature in various forms such as arsenopyrites (FeAsS), orpiment (As₂S₃) and realgar (As₄S₄). Arsenic present in combination with minerals is mobilized in the environment through natural processes such as weathering reactions, biological activity and volcanic emissions.

ii. Anthropogenic Activities

Mining activity, combustion of fossil fuels, the use of arsenical pesticides, herbicides and crop desiccants and the use of arsenic as an additive to livestock feed, particularly for poultry are the major anthropogenic activities through which the arsenic is mobilized in the environment. Besides these, mobilization of naturally present arsenic takes place as a result of changing redox conditions occurring from groundwater exploitation. Although the use of arsenical products such as pesticides and herbicides has decreased significantly in the last few decades, their use for wood preservation is still common. The impact on the environment of the use of arsenical compounds, at least locally, will remain for some years of the Arsenic Contamination of Groundwater in Ramgram NP, Nawalparasi, Nepal.

c) Mobility of Arsenic in Ground Water

The most prevalent natural cause of high concentration is releases from iron oxides and sulphide mineral oxidation. Many debates are ongoing so as to what exactly the sources of Arsenic are and which transfer mechanism is involved. It has been generally accepted that the sources of Arsenic that contaminates groundwater in the Terai is natural in origin, originally present in the soil, and is closely

associated with iron sulphides. Evidences have been given to support both oxy hydroxide reduction and pyrite oxidation theories, which are given here;

i) Pyrite Oxidation Theory:

High abstraction of ground water and the subsequent lowering of the water table results in the penetration of the pores by air or water with dissolved oxygen as result sulphide minerals containing Arsenic which are present in the soil decompose and release Arsenic leading to the Arsenic rich shallow ground water (BGS-MML,1998) as illustrated below;



The best correlation between the concentration of Arsenic in sediments and other elements is with iron. This is also the basis for the use of iron, aluminium and manganese salts in water treatment, including Arsenic removal (Edward, 1994).

ii) Oxy-hydrides Reduction Theory:

Arsenic is naturally transported and adsorbed onto iron or manganese oxy-hydroxides, which slowly breakdown in anaerobic condition of groundwater. Most of the groundwater contaminated with Arsenic is rich in Ferrous ion. Very low sulphate concentration in Arsenic contaminated groundwater indicates that the contamination is not due to oxidation of pyrites rather the anaerobic condition leading to the reduction of Ferric iron (I) the most possible mechanism (Bhattacharya, 1998). The studies concluded that the Arsenic adsorbed on the Ferrogenious coating of sediments is the most likely source of Arsenic in Bangladesh Aquifer; the condition is likely to be the same in case of Nepal, too.

d) Chemistry of Arsenic

Arsenic, As, is a metallic main group element found in group V (b) of the periodic table with atomic number 33 and relative atomic mass 74.92. Arsenic is found in the minerals as oxides, sulphides and arsenides. The various forms of arsenic are as follows:

- | | | |
|---|--|---|
| 1. Arsenolite, As ₄ O ₆ | 2. Realgar, As ₄ S ₂ | 3. Orpiment, As ₂ S ₂ |
| 4. Mispickel or Arsenical pyrite, Fe AsS | 5. Cobaltite or Cobalt Glance, CoAsS | |
| 6. Tm white cobalt, CoAs ₂ | 7. Arsenical Iron, As Fe and As ₄ Fe ₃ | |
| 8. Nickel Glance, NiAsS | 9. Kupfer nickel, Ni As etc. | |

Arsenic is similar to calcium in its chemical properties. Arsenic in its elemental form exhibits allotropy and three forms are known:

- **Gamma:** Arsenic which is also known as grey-arsenic is the ordinary form and it is a steel-grey metallic substance with a bright luster.
- **Beta:** Arsenic is formed when the gamma Arsenic is heated in a stream of hydrogen and black crystals of beta Arsenic are deposited nearest the hot end of the tube.
- **Alpha:** Arsenic is formed when the gamma Arsenic is heated in a stream of hydrogen and a yellow powder of alpha Arsenic is deposited in the cooler part of the tube. Alpha Arsenic is very sensitive to light and reverts to gamma-Arsenic.

e) Metabolism of Arsenic

Arsenic is radio-opaque and is seen on x-ray of the abdomen. It is also detected on hair and nails for months following exposure. Arsenic is absorbed through the skin, lungs, and gastrointestinal tract. Inorganic (trivalent) compounds are absorbed more readily than organic (pentavalent) forms, with greater than 80% of an ingested dose absorbed by the gastrointestinal tract. Arsenic is distributed from blood to liver, kidney, lungs, spleen and intestines within 24 hours of ingestion and to skin, hair, and bones within two weeks. Inorganic arsenic does not cross the blood brain barrier but does cross the placenta. Between 5 to 10% of arsenic is excreted in faeces and 90 to 95% is excreted in urine. Arsenic residue in skin, hair, and nails lasts for a very long time. Arsenic levels in blood, hair, nails and urine have all been used as bio-indicators of exposure. Blood arsenic is used in poisoning cases and an indicator of acute high-level exposure. Poor correlation has been reported between arsenic concentrations in drinking water and blood arsenic levels because arsenic is cleared rapidly from the blood. Arsenic in nails and hair is considered a reliable indicator of exposure that occurred 1 to 10 months earlier, assuming that external contamination of the samples has been eliminated. Total urinary arsenic is used as an indicator of more recent arsenic exposure. However, studies that quantitatively co-related past level of arsenic exposure with arsenic in hair and nails are lacking and further epidemiological studies are needed. Acute condition may be seen only after six months to two years or more depending on the amount of arsenic intake.

f) Specific Characteristics of Arsenic

The specific characteristics are as follows:

- It is a virulent poison on acute ingestion, as 6mg As (III) is considered to be lethal to adult. • It is extremely toxic on long-term exposure to very low concentrations.
- It has not any taste or is not even visible in water and food. Even heavily contaminated water may be clear, colorless and having pleasant smell. It has no smell even at deadly concentrations.

g) Guidelines of Arsenic in Drinking Water

The first version of International standards for drinking water included arsenic in the category of toxic substances and established 200 ppb as the allowable concentration in drinking water (WHO, 1958). In updated standards of 1963, WHO lowered the allowable concentration to 50 ppb (WHO, 1963). The WHO continued its review work to lower the guideline value for arsenic in drinking water by establishing a guideline value (provisional) of 10 ppb in 1993 (WHO 1993). This provisional Guideline Value (GV) of 10 ppb has been adopted as the national standards for drinking water by a number of countries. However many developing countries have retained the previous WHO GV of 50 ppb as their national standards.

The currently accepted national standards for arsenic in drinking water in various countries are presented below:

Table 2.1 Currently accepted national standards of arsenic concentration in drinking water in different countries (Yamamura, 2003)

<i>Countries</i>	<i>Standard</i>
Australia (1996)	7 ppb
European Union (1998), Japan (1993), Jordan (1991), Laos (1999), Laos, Mongolia (1998), Namibia, Syria (1994)	10 ppb
Canada 1999	25 ppb
United States (1986), Mexico (1994)	Countries considering to lower the standard from 50 ppb
Bahrain, Bangladesh (unknown), Bolivia (1997), China 50 ppb 4known), Egypt (1995), India (unknown), Indonesia (1990), Philippines (1978), Saudi Arabia, Sri Lanka (1983), Vietnam (1989), Zimbabwe, Nepal (2002)	50 ppb

2.2.2. Arsenic Contamination in Groundwater of Nepal

The Siwalik range consists of fluvial river sediment which were deposited under conditions similar to those at the present time in Terai. Although these Siwalik sediments were also derived from the same Himalayan rock assemblage where Arsenic bearing Sulphide minerals are known to occur, the aquifers resulting from the second cycle erosion of these Siwalik sediments have higher Arsenic content. Previous studies carried out in Bangladesh have indicated that Arsenic bearing sulphide mineralization in the Himalayas are the ultimate source of Arsenic release into the groundwater.

Evidence of arsenic contamination in groundwater, which is detected in neighboring Bangladesh and west Bengal state of India in the past decade, has also been found in the southern plains of Nepal, causing health hazards to those drinking well water contaminated with arsenic.

From the derived blanket testing data and NASC Report-2007, among the 338,949 tube wells tested, approximately 2.8% show values above the Nepal Drinking Water Standard of 50 ppb, while approximately 10.15% of tube wells contain 11-50 ppb of arsenic concentration. Thus, in total, approximately 13% of tube wells are above the WHO Guideline (10 ppb). Earlier studies suggested that over 26,000 households best on a ratio of one well for every 1.8 households will need to treat their drinking water or avoid contaminated sources. The percentage of all tube wells exceeding 50 ppb varies from 0.9% of the wells in Saptari to 11.7% in Nawalparasi. Similarly, the percentage of tube wells exceeding the WHO Guideline ranges from 5.4% in Saptari to 23.8% in Nawalparasi. Out of 652 tested VDCs/municipalities, the majority (approximately 72%) are moderate vulnerable and 39 (approximately 6%) are highly vulnerable to arsenic contamination in groundwater.

The study conducted by Royal Institute of Technology of Sweden in Nawalparasi district found that Prevalence of dermatological manifestations were 11.3% (56 out of 495 tested). Melanosis was observed in 95.6% of the patients, while keratosis was found in 57.8% of the patients.

2.2.3 Theories of Aquifer Contamination

A community drinking-water supply is a tapped from a lower (deep) drinking-water aquifer which is separated from an upper (shallow) unconfined aquifer by a low-permeability aquitard. Shallow aquifers can cross-contaminate deeper aquifers through penetration of an intervening aquitard, via sandy intervals in the aquitard, along well casings, across long well screens, or around aquitard pinchouts. Distinguishing among these potential pathways requires the use of evaluation tools that may support or eliminate certain pathways. When the drinking-water aquifer is covered to be contaminated, the chemical pathway is usually via a discontinuity in the aquitard, which allows communication with a contaminated upper aquifer. These discontinuities typically fall into three categories: natural breaks or “holes” in the aquitard, man-made “holes” through the aquitard (e.g., from a well bore), or complete pinchout of the aquitard.

a) Potential cross-contamination paths

When groundwater contamination of the lower aquifer in a multi-aquifer system occurs, three mechanisms for cross-contamination are generally proposed. These mechanisms are shown schematically on Fig. 2:

1. Penetration of an aquitard: in this case, contaminants have traveled through the aquitard separating the two units. Specific chemicals may alter the hydraulic properties of an aquitard to accelerate this process.
2. Discontinuous aquitard: minor discontinuities in aquitards, such as gradational sandy zones or coarse channel deposits, can create significant avenues for contaminant migration.
3. Seepage along well casings: seepage along well casings, or also seals may be imperfect.
4. Aquitard pinchout and flow reversal: in this case, natural aquitard pinchout allows mingling of contaminated upper aquifer groundwater with clean lower aquifer groundwater. **Pumping from lower aquifers for water supply accelerates or reverses natural groundwater gradients, which exacerbates cross-contamination and causes contaminant plume migration into areas that may not have been anticipated.**

Mechanism 4 is described in Bethune et al. (1996), who analyzed contamination of a water supply lake induced by reversal of groundwater flow through heavy pumping.

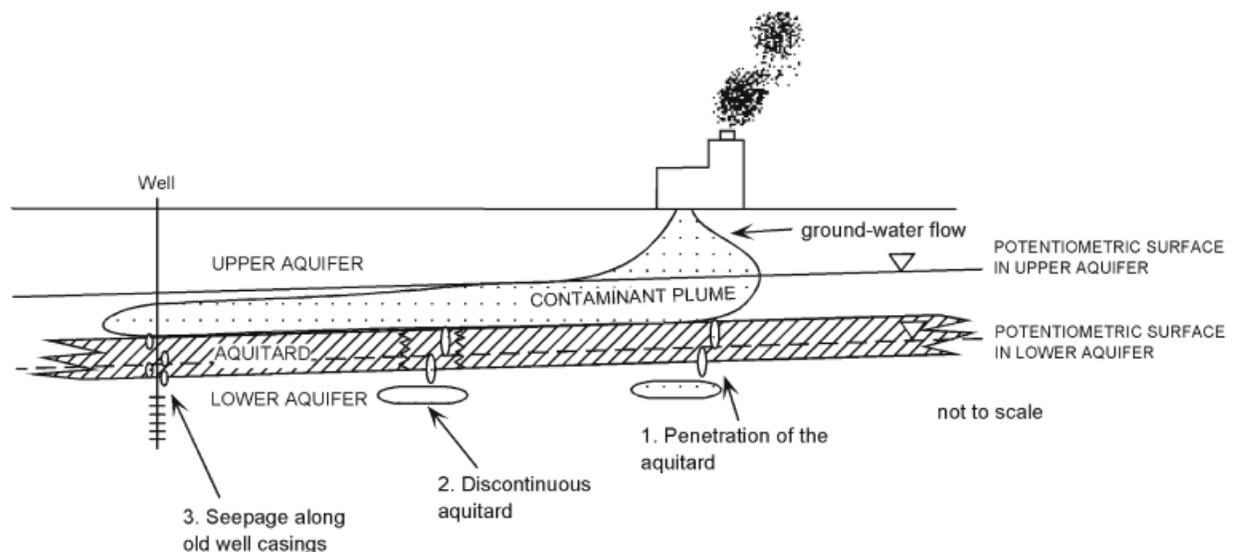


Fig 2: Aquifer cross- contamination pathways through an intervening aquitard with downward gradient.

(Source: Investigating cross-contamination of aquifers: Paul M. Santi et al, 2004)

b) Groundwater gradients and aquitard penetration

One of the strongest arguments against contamination of a lower aquifer from an upper aquifer would be demonstration of an upward vertical groundwater gradient. Several factors such as direction of flow of ground water, piezometric heads of different aquifers, capillary rise in soil, density of contaminants and cohesion factor of soil strata govern the entire flow directions and concentrations of contaminant mixing mechanism.

The effects of the equivalent head are shown in Fig. 2.

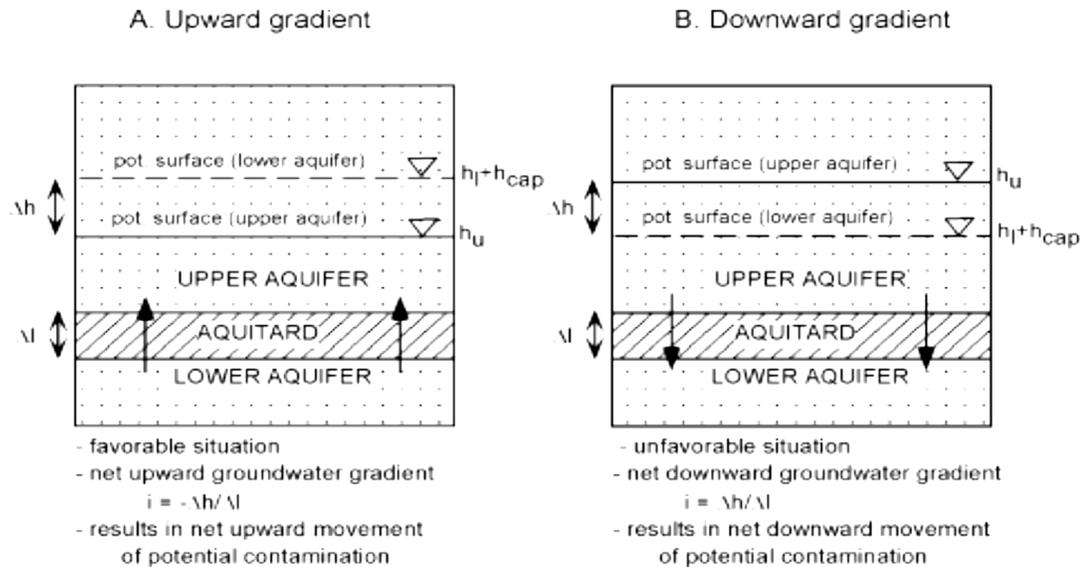


Fig 3: Diagram showing the effects of vertical ground-water gradients and flow direction of contaminations in between aquifers.

In Fig. 2A, the head in the lower aquifer, $h_l + h_{cap}$, is greater than the head in the upper aquifer, h_u . The resultant upward gradient between the two aquifers inhibits downward migration of contaminants. In Fig. 2B, the head in the lower aquifer is now less than that in the upper aquifer, resulting in a downward groundwater gradient and potential downward migration of contaminants. On penetrating through the aquitard, the travel time of the contaminants depends on the hydraulic conductivity of the aquitard, which may be very slow.

c) Changes in concentration of contaminants during pumping

A pumping-concentration test may also be used to distinguish between possible contaminant sources. Such a test is performed by sampling aquifer water and testing chemical concentrations before pumping, and then sampling and testing at specified intervals after pumping begins.

Locke (1994) notes the importance of stratification of concentrations of ion species within an aquifer, and evaluates the changes in concentrations with pumping for both the pumping well and an observation well. He concludes that the greatest concentration changes occurred in or directly adjacent to the screened interval, and the smallest changes occurred at the base of the aquifer. Some ion species increased with pumping, some decreased, and some did not show a trend in either direction.

d) Evaluation of leaky wells

(Source: John E. McCray · Paul M. Santi · Jamie L. Martens, Colorado School of Mines, USA)

Old wells or wells for which installation information is incomplete are common scapegoats for aquifer cross contamination because of improper backfill or screening across multiple water-bearing zones. Lacombe et al. (1995) present fluid flow and solute transport algorithms, as well as groundwater modeling results for leaky boreholes in the same idealized as: an upper unconfined aquifer, a middle aquitard, and a lower confined aquifer.

Improper backfill and screened intervals of wells may be identified with logs or completion diagrams or by using video logs of wells.

Evaluation of open-hole sections can be done by video or by using Borehole Image Processing (BIPS). The Acoustic Borehole Televier has similar capabilities, and is effective through muddy water, since it relies on sonic waves rather than light waves (Welenco 1995).

Casing leakage and upward or downward water flow may be detected using temperature, flowmeter or hydrophysical (conductivity) logs.

A geophysical Cement Bond Log (CBL) may be used to gauge the quality of the bonding of cement grout to the outside of a steel or PVC well casing (Welenco 1995). The CBL relies on the difference in sonic velocities between cement and void space or unconsolidated formation materials and it will also detect casing perforations as a low amplitude signal (Welenco 1995).

Tracer tests can be used to evaluate leakage through annular backfill at the ground surface or interconnection between aquifers via unknown screened intervals. For instance, Meiri (1989) describes the use of a sodium bromide tracer to confirm leakage from an upper unconfined aquifer through a clay aquitard, and into a lower confined aquifer via a poorly constructed well completed in the lower aquifer. If the appropriate wells are available, pumping tests can evaluate the “leaky” condition induced by leakage along the well casing or through multiple screened intervals. The ideal arrangement would be to have at least one shallow aquifer well and one deep aquifer well flanking the suspect well.

If leakage is detected, then the magnitude and rapidity with which it becomes apparent may be used to distinguish between the three possible cases: *(1) natural leakage through the aquitard (low leakage rates, delayed occurrence), (2) leakage along the well annulus (moderate leakage rates, moderately rapid occurrence), or (3) leakage through a well screen that extends through both aquifers (high leakage rates, rapid occurrence).*

2.3 Microbiological Contaminations in Aquifers

2.3.1 Pathogens Contamination:

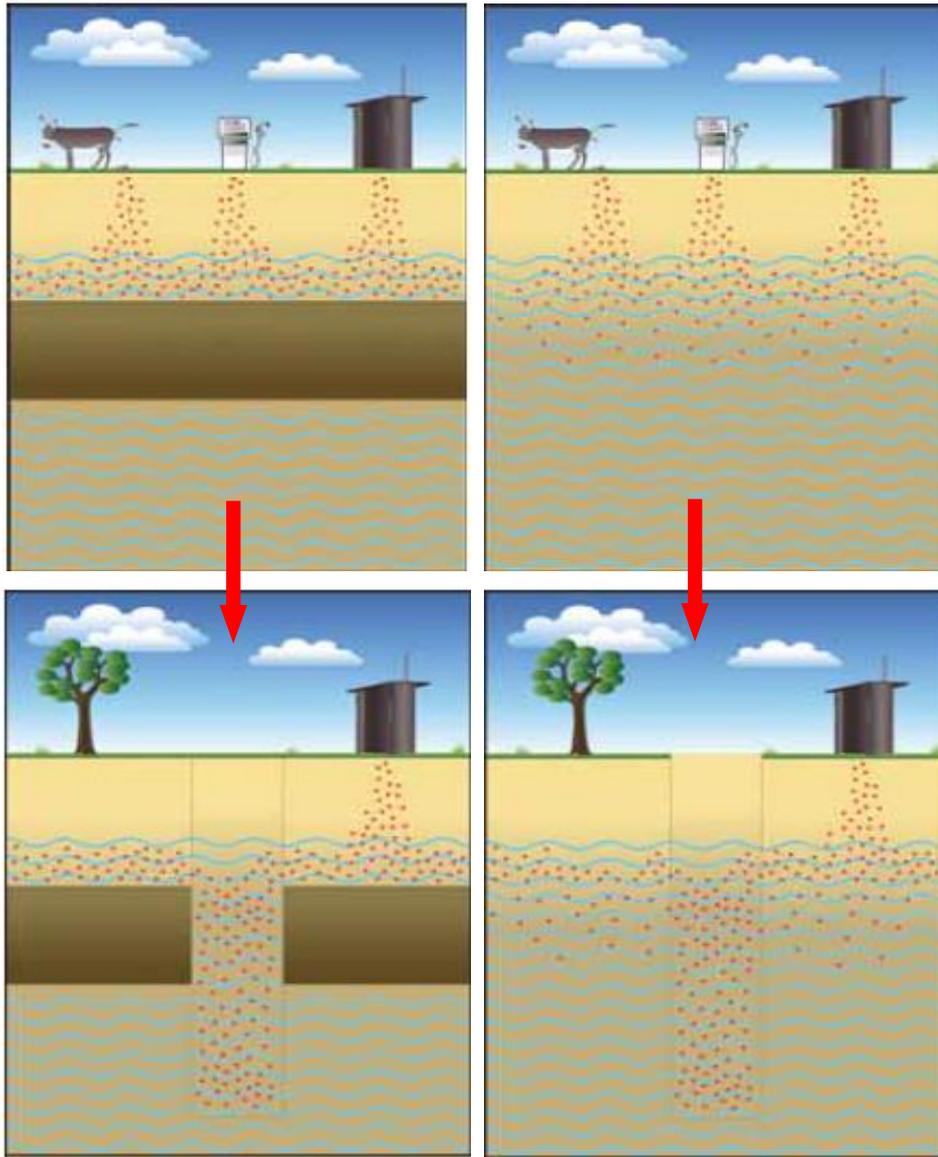


Fig 4: Microbial contamination transfer mechanism inside tubewell (red dot= bacteria).

Toilets, cattle sheds or any waste wastewater collecting ditches when constructed around tubewell/water source, the source could be contaminated with (micro) organisms such as bacteria, viruses and parasites. Some of these organisms can cause disease (like diarrhea) when the water is used for drinking and are called pathogens. The pathogens from the human waste in the latrines move downwards through permeable layers, and so locally contaminate the groundwater (see figure 4). Although pathogens will not survive long outside the human body, it will take a while before they die off completely. Therefore groundwater close to latrines can contain living and harmful pathogens.

2.3.2 Microbial Contamination Mechanism;

Water with pathogens retained in shallow phreatic aquifers does not easily flow/penetrate through the confined impermeable clay layers in case of multi-aquifers zone. Due to their fine texture (very fine particles), impermeable layers prevent/blocks pathogens from further vertical migration down into the underlying aquifer. Whereas, in case of single aquifer zone, although there is no impermeable layer, further down into the sand layer the number of living pathogens will decrease gradually (every meter down, fewer pathogens will be present). It takes time for the pathogens to travel down and while doing so they die off over time. (Source: *Understanding groundwater & Wells, 2010; PRACTICA F., USAID, UNICEF*).

However, these pathogens remain no longer trapped as soon as they find any short circuiting routes inbetween two aquifers through the annular gap of water extracting conduits/handpumps which works as a connecting link for pathogens and soon the deeper aquifers get contaminated(see fig 4).

2.4 Health Effect of Arsenic

Arsenic is found in nature in different concentrations. WHO has set the threshold value in drinking water as 10 ppb. However, concentration exceeding the guideline value by 10 to 200 fold has been reported in many parts of the world. The term Arsenicosis is being used these days to denote arsenic poisoning.

According to WHO, six out of 10,000 people use drinking water containing more than 10 ppb of arsenic over a long period run the risk of getting cancer. In comparison with this figure, the Nepal Interim Standard of 50 ppb means the risk rises to 30 out of 10,000 people. A published report in India indicates that with 50 ppb of arsenic in the water, the maximum permissible limit would be reached by a water consumption of two liters per day (Chaudhary et al, 2001) Water consumption in the Terai during the warm months is typically 4-6 liters per person, per day.

2.4.1 Acute Effects

The acute poisoning of arsenic involves effects on 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 etc. 20-30 ppb of arsenic gas inhaled for 30 minutes is lethal. Inorganic arsenic compounds are also extremely toxic. United States Environmental Protection Agency (USEPA) has established a reference dose of 0.3µg/kg/d for inorganic arsenic compounds. Acute effects due to arsenic poisoning are:

In the initial stage of chronic exposure of arsenic for more than five years, skin colour becomes black (melanosis), rough and tough (keratosis), eyes become red (conjunctivitis). Also in some cases there will be pain in inhaling (Bronchitis) and Vomiting and Diarrhea (Gastroenteritis). The manifestations of arsenicosis are clearer in the second stage with black and white spots on the skin (leukomelanosis), palms and soles are affected by hard nodules (Hyperkeratosis), swelling of legs, Peripheral Neuropathy and complications of kidney and liver. Finally it also turns to cancer in skin, lungs, kidneys, liver and other organs.

Following are some photographs of Arsenic infected victims during a 3 day camp lead by Dr. Akhtar; a JICA field As-diagnosis program held in 24,25, 26th August, 2011 in Nawalparasi District of Nepal.



2.5 Theories of Arsenic Removal and Mitigation Measures

2.5.1) Small Scale:

A simpler and less expensive form of arsenic removal is known as the **Sono arsenic filter**, using three pitchers containing cast iron turnings and sand in the first pitcher and wood activated carbon and sand in the second. Plastic buckets can also be used as filter containers. It is claimed that thousands of these systems are in use and can last for years while avoiding the toxic waste disposal problem inherent to conventional arsenic removal plants. Although novel, this filter has not been certified by any sanitary standards such as NSF, ANSI, WQA and does not avoid toxic waste disposal similar to any other iron removal process.

In the United States small "**under the sink**" units have been used to remove arsenic from drinking water. This option is called "point of use" treatment. The most common types of domestic treatment use the technologies of adsorption (using media such as Bayoxide E33, GFH, or titanium dioxide) or reverse osmosis. Ion exchange and activated alumina have been considered but not commonly used.

2.5.2) Large-scale:

In some places, such as the United States, all the water supplied to residences by water utilities must meet primary (health-based) drinking water standards. This may necessitate large-scale treatment systems to remove arsenic from the water supply. The effectiveness of any method depends on the chemical makeup of a particular water supply. The aqueous chemistry of arsenic is complex, and may affect the removal rate that can be achieved by a particular process.

Some large utilities with multiple water supply wells could shut down those wells with high arsenic concentrations, and produce only from wells or surface water sources that meet the arsenic standard. Other utilities, however, especially small utilities with only a few wells, may have no available water supply that meets the arsenic standard.

Coagulation/filtration (also known as flocculation) removes arsenic by co-precipitation and adsorption using iron coagulants. Coagulation/filtration using alum is already used by some utilities to remove suspended solids and may be adjusted to remove arsenic. But the problem of this type of filtration system is that it gets clogged very easily, mostly within two to three months. The toxic arsenic sludge are disposed of by concrete stabilization, but there is no guarantee that they won't leach out in future.

Iron oxide adsorption filters the water through a granular medium containing ferric oxide. Ferric oxide has a high affinity for adsorbing dissolved metals such as arsenic. The iron oxide medium eventually becomes saturated, and must be replaced. The sludge disposal is a problem here too.

Activated alumina is an adsorbent that effectively removes arsenic. Activated alumina columns connected to shallow tube wells in India and Bangladesh have successfully removed both As(III) and As(V) from groundwater for decades. Long-term column performance has been possible through the efforts of community-elected water committees that collect a local water tax for funding operations and maintenance. It has also been used to remove undesirably high concentrations of fluoride.

Ion Exchange has long been used as a water-softening process, although usually on a single-home basis. Traditional anion exchange is effective in removing As(V), but not As (III), or arsenic trioxide, which doesn't have a net charge. Effective long-term ion exchange removal of arsenic requires a trained operator to maintain the column.

Both **Reverse osmosis** and **electrodialysis** (also called **electrodialysis reversal**) can remove arsenic with a net ionic charge. (Note that arsenic oxide, As_2O_3 , is a common form of arsenic in groundwater that is soluble, but has no net charge.) Some utilities presently use one of these methods to reduce total dissolved solids and therefore improve taste. A problem with both methods is the production of high-salinity waste water, called brine, or concentrate, which then must be disposed of.

2.6 Testing and Investigation

“The Interim Nepal Guidelines and Policies for Arsenic in Drinking Water” has recommended the use of lab testing with specific preference for the Atomic Absorption Spectrophotometer (AAS) method as it is the most reliable. However, Arsenic Contamination in ground drinking water can be detected in the field or in the laboratory with a choice of testing methods depending on the nature and purpose of the analysis. The majority of tests undertaken in Nepal use field test methods because of low cost, and mobility in the field. However, we had undertaken test of samples in several laboratories as any one of those lab at a time couldn't be considered reliable enough with their manipulated data.

2.6.1 Reliability of Field Testing:

The reliability of arsenic test results is critical, and therefore checks have to be made to test the reliability of test kits in use. Arsenator was used for field test whereas lab test (AAS) was also carried on during the project. However, certain variations were observed in the test results. Neither, the field test data or nor lab data were reliable enough to be dependent alone.

2.7. Geomorphology and Hydrogeology of Nepal

2.7.1. Geology: The problem of As contamination of the groundwater of Nepal is mainly confined to the alluvial Terai plains along the southern border of the country. The Terai forms a more or less continuous belt from east to west covering 23% & the total country area with a width ranging from 10 to 50 km. Most of the Terai lies south of the Churia hills and represents the northern edge of the Indo-Gangetic alluvial plain. Some of the Terai plains occurring in tectonic strike valleys north of the low Churia foothills are not substantially affected by arsenic contamination. The Terai is subdivided into the Bhavar Zone, and the main Terai Zone. The Northern Bhavar Zone at the foot hills of the Chure Hills extends southwards with a maximum width of approx. 12km. This zone consists of boulders, cobbles, pebbles, gravel, sand and clay of varying size. It is a principal recharge area for the ground water reservoir of the Terai. The Bhavar deposit is derived principally from erosion of the Siwalik formation in the Siwalik Hills. Hence, it consists mostly of reworked sediment from the Siwalik rocks. Streams cut through the hills and dump their sediments as alluvial fans, and the alluvial and colluvial fans in the Bhavar coalesce into piedmont slopes and merge with the main Terai in the south (DOI, 2004). The main Terai Zone in the south consists of interlayers of clay, silt, sand and gravel deposits of varying thickness from braided rivers which frequently change their courses. In general the grain size decreases to the south but there are some exceptions. The sediment of the main Terai extends to the Nepal - India border and beyond.

The various physiographic zones of Nepal with arsenic concentration of different districts of Terai is shown in figure 2.5 below:

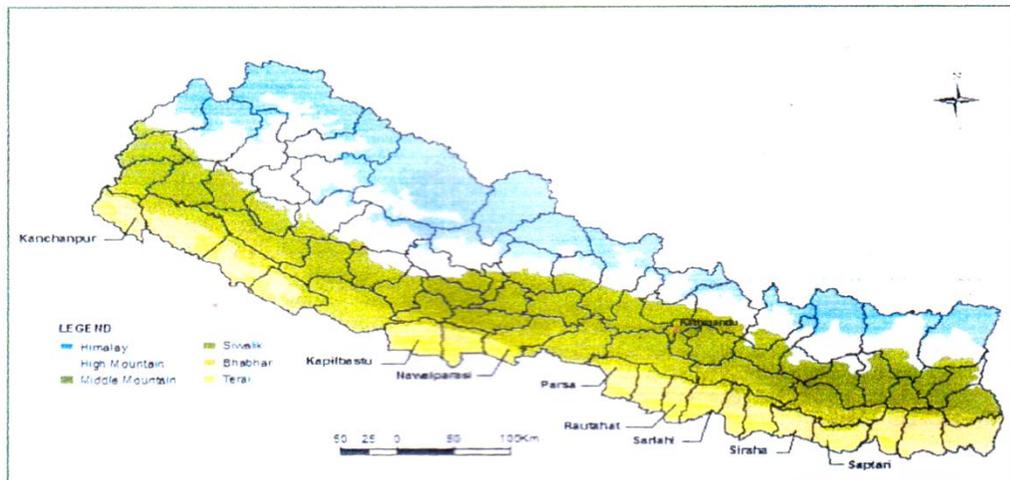


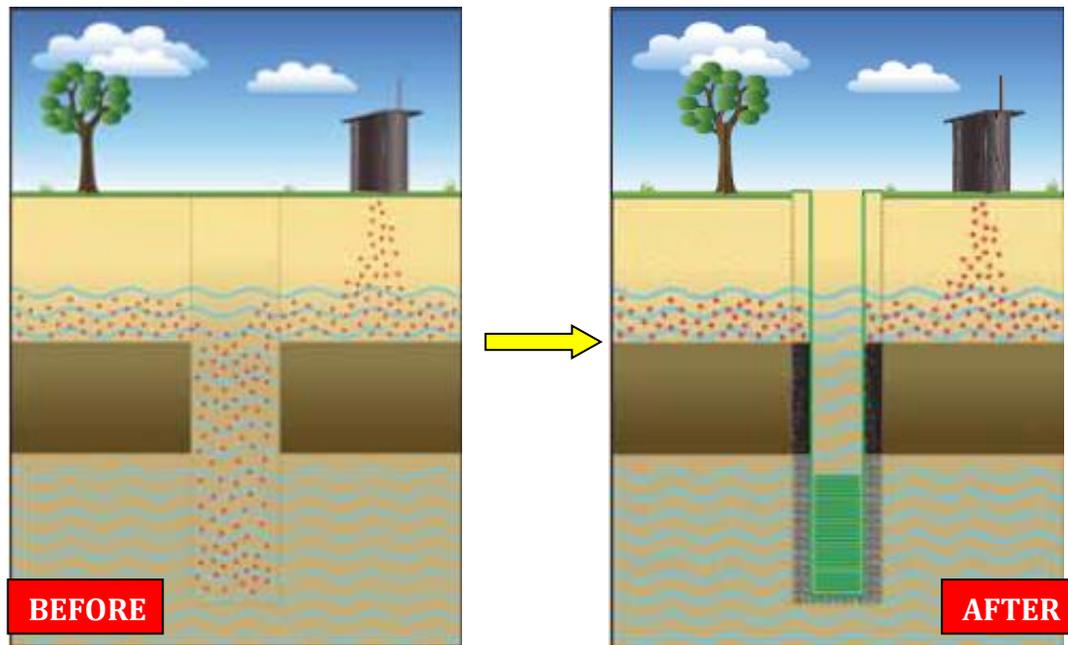
Fig 5 Physiographic zones of Nepal

2.7.2 Aquifer System: In the Terai subsurface, a multiple aquifer system consists of both unconfined and semi-confined shallow aquifers and confined deep aquifers. Perched aquifers are also common. The

upper 50-60m of sediment provides good productive shallow zones, and most groundwater production occurs in the upper 250m. Between 20-50% of screenable sand layers are unconfined to a depth of 46m. Generally transmissivity is high and well discharge is good (Kansakar 1996), although areas of low transmissivity occur where high proportions of clay are present. The piezometric head in some confined aquifers is above the land surface in some parts of the southern Terai, so free-flowing wells occur. Permeable material of interest occurs up to 250m below ground surface.

2.7.3 Local River Effect: Drainage systems in the Terai districts seem to have influenced local geology in terms of grain size distribution and the composition of sediments. Constant shifting of the rivers has resulted in flood plain deposits being spread over a wide area. This has influenced arsenic concentration in the region. Some earlier studies carried out suggest a direct relationship between arsenic contaminated groundwater regions and the source area of the sediments that comprises the aquifer.

2.8 Sealing Technology



The sealing technology is a recently emerging Arsenic mitigation technology. The concept is of sealing the contaminated aquifer zone, so that water could be extracted from the underlying uncontaminated aquifer safely without letting any mineralogical or microbiological contaminations derived from upper aquifers. Nevertheless, the technology hasn't been yet globally accepted as the appropriate sustainable solution of Arsenic mitigation due to its limited research and development. The very first research trial was attempted in the Indo-Gangetic plain of Bangladesh, under the collaboration of some national and international universities. This technology has been practiced very well in case of deep tube wells, with a great investment. And the challenge here is concerned with the down scaling of the investment making it applicable for the shallow aquifer zone, so that the technology could be easily socially accepted as local technology with easy installation and regeneration features. So, it's obvious that the technology is being tested here for the shallow aquifers with multiple aquifers comprising lithology. Meanwhile, this project is concerned with the execution and practical observation of the sealing technology in two of the terai villages of Nepal, i.e the Kunuwar Village of Ramgram Municipality & Pratappur VDC of Nawalparasi District.

This project mainly concerns about promoting the aquifer sealing technology as a mitigating approach to Arsenic contaminated hand pumps for household purposes. Technology is not a new one in itself, nevertheless most of the facts are still incomplete and confusing. Here, we are carrying out the project on a complete research basis under the technical guidance of research papers and works published from western countries and expertise from relevant sectors as well.

When a borehole is drilled, a well-screen will be installed and a gravel pack placed. Then the impermeable layer has to be sealed (closed), to prevent contaminants from traveling down into the second aquifer. This is done by a sanitary seal. The sanitary seal is made of cement or bentonite (natural clay which swells to many times its dry volume when wetted) which will seal (close) again the impermeable layer.

2.8.1 Smooth Grout Details

SMOOTH GROUT 30 bentonite-grouting composition is easy to use and contains high-swelling, sodium montmorillonite clay. It is designed for use in water wells and monitoring wells, for sealing the annular space around the well casing, and for plugging drilled holes and abandoned wells. SMOOTH GROUT 30 bentonite-grouting composition contains no organic additives or polymers.

A one-sack formulation of SMOOTH GROUT 30 bentonite-grouting composition mixes with freshwater to yield a 30% pumpable grouting slurry with an extended working time. When it sets up, the SMOOTH GROUT 30 bentonite-grouting composition develops a satisfactory seal with adequate structural strength and low-hydraulic conductivity. When properly placed, the SMOOTH GROUT 30 bentonite-grouting composition remains flexible, rehydratable, and unstratified through heating and cooling cycles.

Typical Physical Properties

Physical appearance.....	Beige-to-tan powder
Moisture content.....	8%
Specific gravity	2.5
pH (8% slurry)	7.0
Slurry density	10 lb/gal (1.2 kg/L) for 30% solids
Dry bulk density.....	64 lb/ft ³ (1,025.2 kg/m ³)
Screen analysis.....	75% min. passing through 200-mesh

Applications

- Sealing and grouting casing
- Sanitary sealing in water-well construction
- Sealing in monitoring wells
- Plugging and abandoning exploration boreholes

Advantages

- Inorganic, non-fermenting, and non-toxic
- Develops lower-solids slurries up to 30% activity
- Easily mixed with most conventional rig equipment
- Permanent, flexible seal prevents entry of contaminants from the surface
- Extended working time controlled by the grout solids content
- Firm texture providing structural stability after grout set

Addition Method

A measured quantity of clean water is added into the mixing tub/barrel first and pumping and circulation starts. Then the cement is gradually added to the water and mixed thoroughly. At this stage the mix is like gray water. Next, bentonite powder is slowly added into the jetting area of the barrel, slowly enough so clumps of bentonite do not form. This should be constantly checked by scraping the bottom with a shovel. When clumps form, slow down and do not add any more powder until they are dissolved. Keep adding bentonite until the watery mix transitions to an oily/slimy consistency. Observe the consistency while mixing and let the grout thicken for another five to ten minutes. Generally, the mix thickens some more with added mixing time. Add more bentonite as required. When it is smooth and like thick cream or pan- cake batter, it is as heavy as is it feasible to pump. Drips of the grout should then barely come off a dipped finger and form “craters” in the fluid surface. That is the correct consistency for pumping the grout batch down the tremie-pipe. When possible, withdraw the tremie after each batch an amount corresponding to the grout level in the boring to keep the pumping pressures as low as possible.

Table 10. Recommended (achievable) filter pack characteristics for common screen slot sizes (after ASTM D-5092)

Size of screen opening (mm (in.))	Slot no.	Sand pack mesh size name(s)	1% passing size (D-1) (mm)	Effective size (D-10) (mm)	30% passing size (D-30) (mm)	Range of uniformity coefficient	Roundness scale
0.125 (0.005)	5 ^a	100	0.09 to 0.12	0.14 to 0.17	0.17 to 0.21	1.3 to 2.0	2 to 5
0.250 (0.010)	10	20 to 40	0.25 to 0.35	0.40 to 0.50	0.50 to 0.60	1.1 to 1.6	3 to 5
0.500 (0.020)	20	10 to 20	0.70 to 0.90	1.00 to 1.20	1.20 to 1.50	1.1 to 1.6	3 to 6
0.750 (0.030)	30	10 to 20	0.70 to 0.90	1.00 to 1.20	1.20 to 1.50	1.1 to 1.6	3 to 6
1.000 (0.040)	40	8 to 12	1.20 to 1.40	1.60 to 1.80	1.70 to 2.00	1.1 to 1.6	4 to 6
1.500 (0.060)	60	6 to 9	1.50 to 1.80	2.30 to 2.80	2.50 to 3.00	1.1 to 1.7	4 to 6
2.000 (0.080)	80	4 to 8	2.00 to 2.40	2.40 to 3.00	2.60 to 3.10	1.1 to 1.7	4 to 6

Different ratios of Bentonite:Cement: Water adjusted for testing in lab

Cu be	Adjusted B:C:W				Remarks
	Proportions	Bent onit e	Ceme nt	Wate r	
1 st	2p:94p:6gal	1.28 %	60.88 %	37.8 %	
2 nd	2p:94p:7gal	1.35 %	64.36 %	34.28 %	This proportion showed optimum workability.
3 rd	3p:93.38p:6.95gal	1.92 %	60.48 %	37.59 %	
4 th	2.82p:90.8p:6.7gal	1.88 %	60.51 %	37.61 %	

These tests have been carried out in different ratios by keeping the net weight of the composition as constant (700 gram during lab tests.)

3. METHODOLOGY

The project is meant to assess the groundwater quality of Ramgram Municipality and Pratappur VDC of Nawalparasi District, Lumbini Zone and develop the appropriate arsenic mitigation alternatives and ultimately promote the Sealing Technology on behalf of those alternatives. Several researches and mitigation technologies have been implemented by different researchers but no long-term solutions have been found. Hence, for this purpose entirely new technology which has not been implemented yet in context of Nepal i.e. Sealing Technology should be executed precisely, carefully and regular monitoring the well after installation.

The project site for the case-study was selected to be Kunuwar & Siwangandh village of Ramgram N.P. and Pratappur VDC of Nawalparasi district.

3.1. General Description

To assess the quality of the groundwater of several multi-aquifers and find out the site specific arsenic removal alternatives, the following steps were considered;

1. Review of literatures regarding the scenario of arsenic contamination in Nepal and research and development updates.
2. Conduct pre-mobilization meeting with PSU (Inception meeting).
3. Conduct pre-mobilization meeting with DWASH Unit of Nawalparasi (Inception meeting)
4. Prototype testing of sealing design and adjust grout proportions.
5. Field visit to the project site and making arrangements of local technicians and identification of drilling technology and drilling equipments.
6. Specific site selection by making several trial wells up to the depth of 150-200 feet.
7. Select the sites for sealing.
8. Collect the construction materials and local labors.
9. Drilling and study of soil and water samples & field as well as lab testing of samples.
10. Preparation of sealing design according to the hydrogeology of site.
11. Installation of wells & sealing activities.
12. Monitoring of As-fluctuation in sealed well.

3.2 Study Area

Nawalparasi district is located in between 83035' east to 84025' east longitude and 27020' north to 27055' north latitude. It is bounded by Chitwan district and India in the east, Tanahu and Palpa district in the north, Rupandehi district in the west and India in the south (Figure below). Physiographically, it lies in Terai region and is elevated from 91 m in the south to 1,933.4 m in the north with a total area of about 2,162 square kilometers consisting of 73 VDCS and 1 Municipality. The location of the study area is shown in figure 6.

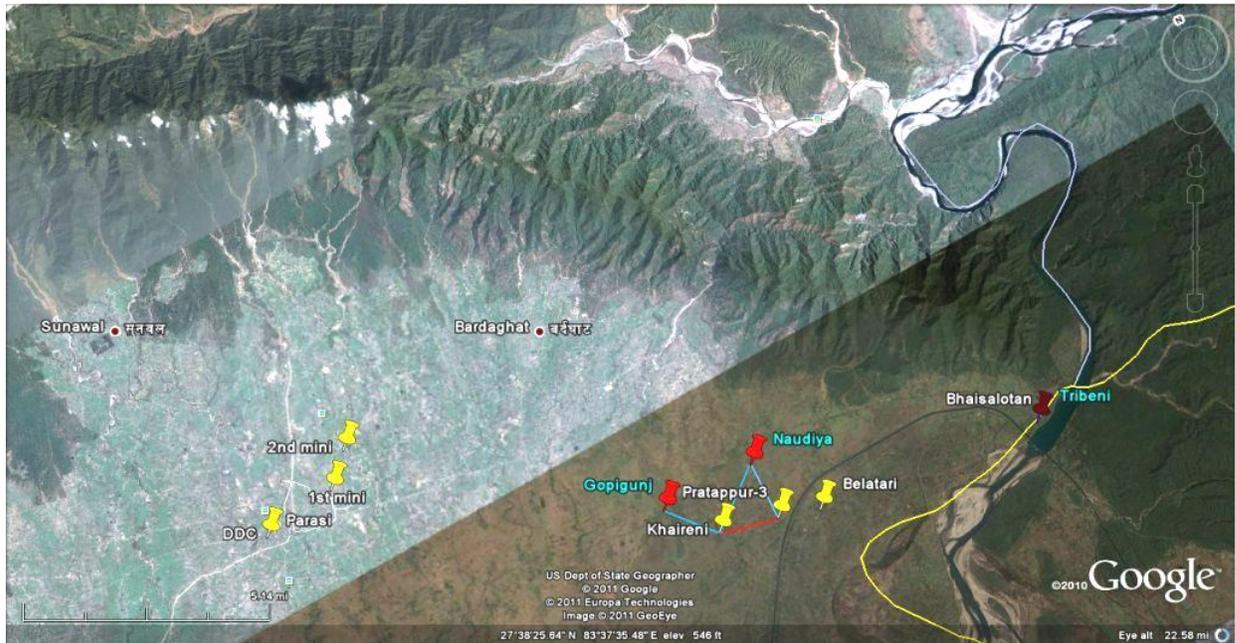


Figure 6. Location of the study area (i.e. Ramgram N.P. & Pratappur VDC=yellow dots)

The Kunuwar Village of Nawalparasi District lies around 4-5 km North East of Parasi Bazaar whereas Pratappur VDC lies 24-25 km east.

The climate in Nawalparasi district as well as in the whole Terai is characterized by monsoon rainfall that occurs between June and September and delivers average of 80% of the total annual rainfall.

The elevation of the test site Kunuwar and Pratappur village ranges from 110 m to 115 m from mean sea level. The groundwater of Ramgram municipality in Nawalparasi district contains a large amount of arsenic. The arsenic distribution in highly affected wards of Ramgram municipality in Nawalparasi district is shown in figure 7.

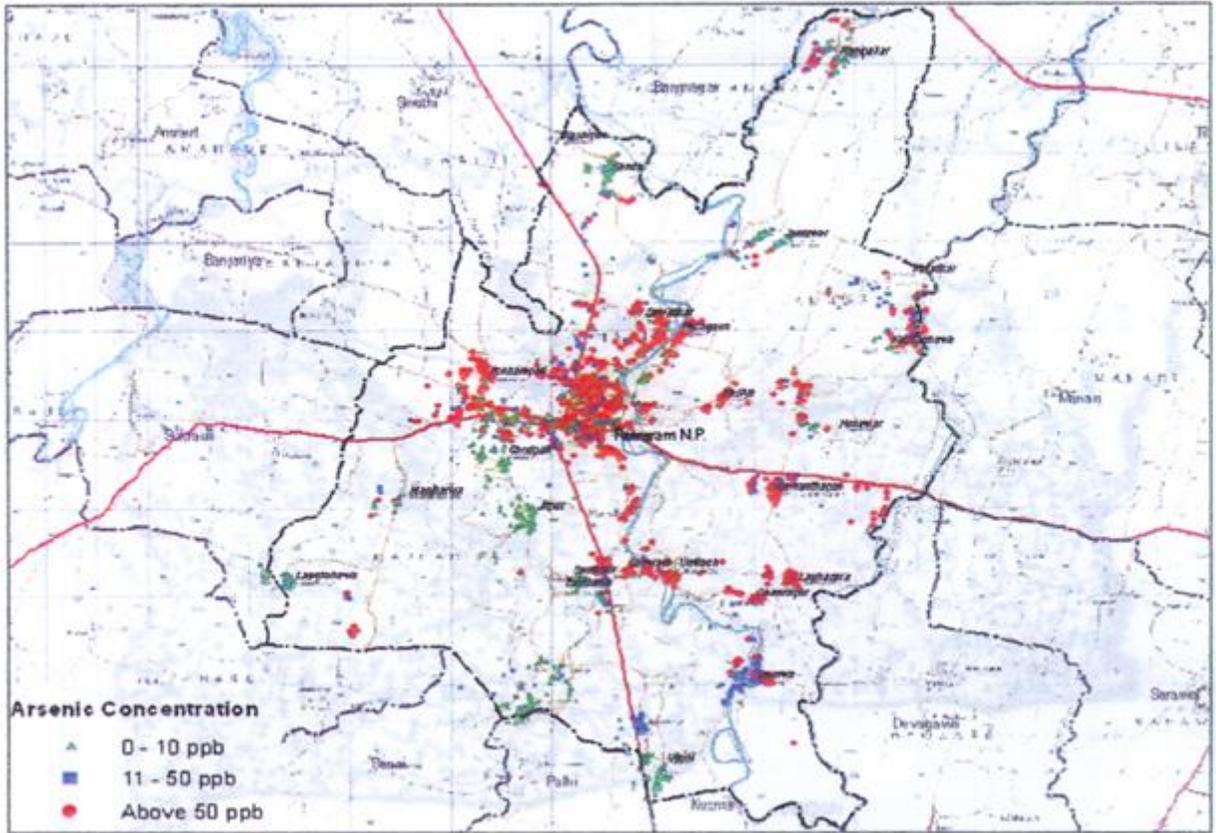


Fig 7: Arsenic Distribution in Ramgram N. P. of Nawalparasi District.

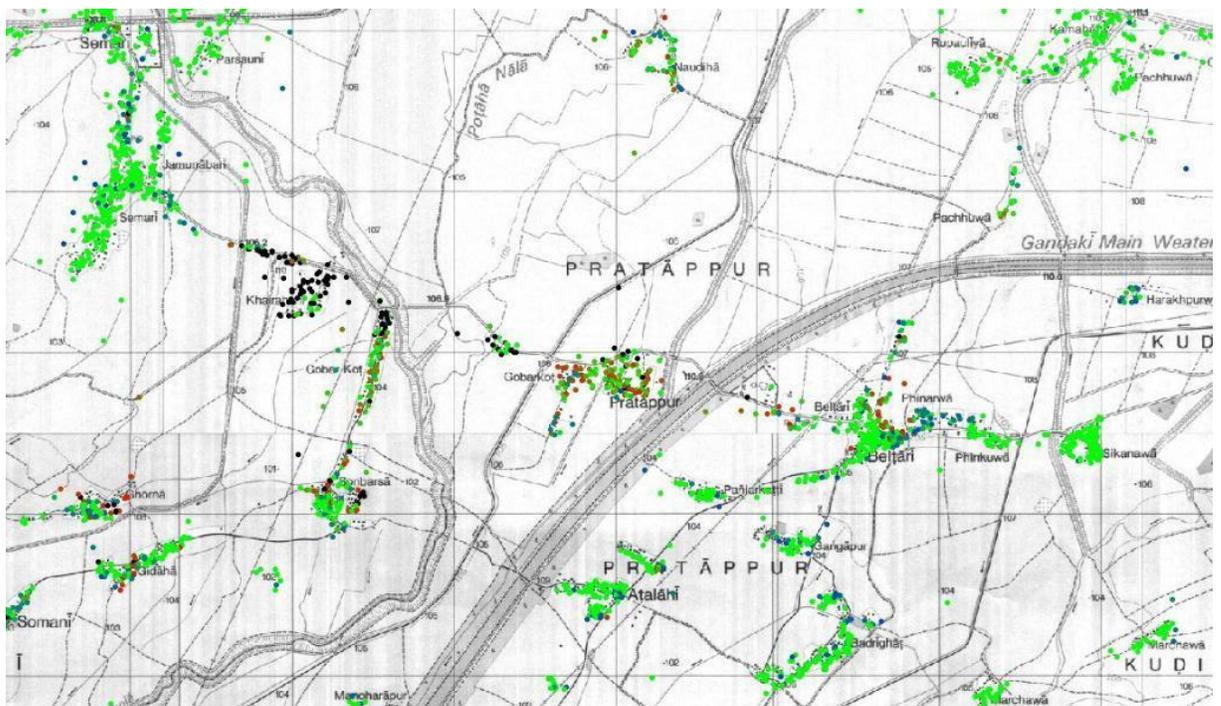


Fig 8: Arsenic Distribution in Pratappur VDC of Nawalparasi District.

3.3 Criteria for Site Selection

The selection of exact site for the execution of the project was based on the following criteria.

- i. Area where the arsenic contamination is observed the highest within the Ramgram N.P. and Pratappur VDC. The secondary data of blanket testing record of Kunuwar & Pratappur village was taken as the reference for these criteria.
- ii. Area where multi-aquifers were present and comprising of intercepted large aquifer having arsenic concentration less than 50 ppb within 150-200 feet from ground level.
- iii. Area where the number of handpumps giving As-free water were less and families were unable to install handpumps individually due to lack of money.
- iv. This criteria was fixed so that the final constructed handpump can be used as a public source of water in the village.

3.4 Determination of Arsenic

There are several numbers of analytical methods available for the determination of trace amount of arsenic in groundwater. They are;

- a) Arsenic Generation followed by Atomic Absorption Spectrometry (AAS)
- b) Spectrophotometric Method
 - i. Molybdenum Blue
 - ii. Arsenic Gas Generation followed by complexation with Silver Diethyl Dithio Carbamate (SDDC)
- c) Total Reflection X-ray Fluorescence (TRXF) Spectroscopy
- d) Revolving Electrode Method

However, nowadays AAS method is mostly practiced for arsenic test in the laboratories. It is the most sensitive technique among the methods mentioned above.

Analytical Method – Atomic Absorption Spectrometry (AAS) Method

The concentration of arsenic in a groundwater sample is determined by using Atomic Absorption Spectrometry (AAS) technique. Basic principle of the technique is that AAS is dependent on the fact that metallic elements, in the ground state will absorb light of the same wavelength as they emit when excited. When radiation from a given excited element is passed through a flame containing ground state atoms of that element, the intensity of the transmitted radiation will decrease in ratio to the amount of the ground state element in the flame. A hollow cathode lamp or an electrode less discharge lamp provides the radiation.



Figure 9. Atomic Absorption Spectrophotometer

The metal atoms that have to be measured are placed in the beam of the radiation by aspirating the specimen into an oxidant fuel flame (FAAS), or by pipetting a few μL of the solution in an electrothermally heated graphite furnace (ET-AAS). From a number of elements (As, Sb, Bi, Te, Sn, Pb) the hydrides can be formed and is introduced in a quartz tube in gaseous form. The characteristic radiation is isolated by a monochromator. The method excels by its specificity. The proportionality between the concentration of the element and the absorption of the characteristic wavelength (Linearity of the calibration line) is only valid over a limited concentration range.

An AAS measurement can be conducted in 3 steps. First, a series of standards of target ions have to be prepared and then it is used to calibrate the spectrometer. Second, absorbance of those standards is measured and a calibration curve is plotted for the target ions to ensure that the standards are prepared correctly. At last, the absorbances of both blank-water sample and of an unknown solution are measured in order to determine the concentrations of the target ions. In each range of samples, a reference standard solution is also measured for the control charts. AAS is a mono-element technique; so many laboratories are using nowadays the multi-elemental techniques inductively coupled plasma atomic emission spectrometry (ICP-AES) or even mass spectrometry (ICP-MS). Lowest detection limits can be obtained by use of ICP-MS.

3.5 Sampling and Sample Preparation

Representative samples of groundwater were taken from different aquifer of the drilled wells. Field test of water quality was done using Arsenator and ENPHO Kit. However, for lab test two water samples per one aquifer, one acidified with 2ml conc. HCl, and next one non-acidified were collected and labeled in 200 ml PVC sampling bottles; whereas 3 soil samples; one aquifer particle and the rest two of adjacent upper and lower soil strata were preserved in polythene bags. Samples were later sent to laboratory in Kathmandu for further test of EC, .

3.6 Water Quality

The water samples extracted and collected in PVC bottles from the site were brought for the test in the laboratory in Kathmandu. Those samples were then analyzed in the laboratory for the determination of groundwater quality of drilled wells. The samples were tested in the site for the determination of arsenic concentration by ENPHO arsenic test kit. To detect the amount of arsenic concentration Arsenic Test Strip was used.

The different parameters analyzed and instruments/methods used to test those parameters were turbidity by Turbidity Meter, Conductivity by Conductivity Meter, pH by pH Meter, Manganese, Iron and Arsenic by Atomic Absorption Spectrophotometer, Nitrite and Nitrate. The laboratory analysis report, thus, gives the groundwater quality of Kunuwar and Pratappur sites. The appropriate technology, then, can be adopted for arsenic mitigation and other parameters for use of groundwater in domestic purposes.

Parameters tested in water quality analysis:

pH, EC, Turbidity, Iron, Manganese, Arsenic, NO_3^- , NO_2^-

Parameters tested in soil analysis:

Texture, (Silt:Clay:Sand), Arsenic

3.7 PROCEDURES OF SEALING IN SAND, SILT, CLAY AND SOFT ROCKY ZONE

3.7.1. Drilling of bore hole

With very sincerity and taking serious precautions at each and every step, a borehole drilling was carried out in the periphery of the earlier collapsed @Kunuwar borehole such that the hydrogeology of the new borehole remains same with the earlier abandoned one so that earlier soil & water lab test data can be referred. The next drill log was also prepared which resembled same at most of the portions, besides a deeper (i.e. 8 ft.) aquifer was found at the depth of 58 ft. to 66 ft. whereas; there was just 5 ft. deep aquifer in the earlier abandoned borehole at the same layer.



Fig 10: Drilling(1.5"-dia) at new site by sludging method(soil samples being collected on mesh)

3.7.2. Making of drill bit

As the earlier drill bit got broken inside the borehole, so a new drill bit was made by collecting heavy metals and mild steel parts of bearings of automobile from local workshops.



Fig 11: Collecting usable heavy metal spare parts.



Fig 7: Locally making of stronger drill bit in workshop.



Fig 13: Carefully fixing of (5"-dia)drill bit (made up of bearing metal & heavy duty pipe)



Fig 14: Pouring bentonite slurry (1:22) in borehole (5.5"-dia) for preventing borehole collapsing.

Overdrilling of Borehole:

It may be necessary to overdrill the borehole if it is anticipated that material from the drill bit during removal or the bottom plug will remain in the borehole. Normally, 3 to 5 feet is sufficient. If the borehole is drilled deeper than desired, it can be backfilled to the design depth with bentonite pellets, bentonite chips, or filter pack sand. Overdrilling may also be used to create a sump area for the placement of a catch basin or storage area of additional well casing attached below the well screen, designed to "catch" the sediment that drops out of suspension in aquifers that are naturally turbid and will not yield clear sediment-free water after extensive development.

3.7.3 Preparation of Bentonite Chips

The Bentonite Powder (which is very fine even than cement) was taken on a wide plate and spreaded in a thin layer. Water was sprinkled in small amount with pressure over filter-mesh(0.5 mm) which was held above the plate. Water was allowed to get sprayed frequently over the moving/shaking) plate. Because of this, tiny water droplets used to fall and come in contact with powdered Bentonite and due to high cohesive nature of Bentonite, the bentonite powder get stucked in tiny water droplets and form granules of different size. Later, the granules are sieved through calibrated sieves to get the granules of desired size and left to get dried for 48 hours. Ultimately, tough B-chips were formed at last. The development of this local idea of making granular bentonite can address the problem of Bentonite pellets in the project.



Fig 15: Making of Bentonite Chips by spraying water through 0.5 mm PVC-mesh.

Fig 16: Sieving for screening of large size B-Chips which are mainly required during sealing.

Fig 17: Drying of fresh prepared B-chips under sun for a duration of 48 hours

3.7.4 Preparation of Well Graded Aggregates or “Filter Pack”

The annular space between the well screen and the bore-hole wall is often filled with uniform gravel/sand media to serve as a filter pack. Filter pack sand (materials) should be clean, well-sorted, hard, of uniform size and, insoluble siliceous composition. Particle sizes should be based on sieve analysis and a grain-size distribution and should minimize head loss and prevent sediment migration into the well.

The filter pack is of washed aggregates and clean material, without shale or iron pellets. It's ensured that all well-construction materials, including gravel pack, are clean and sanitary prior to placement. Monitoring well filter pack materials must be of higher quality than this baseline, however, to ensure accurate water quality samples. Monitoring well filter pack must be chemically inert and composed primarily of clean quartz sand or glass beads and be free of claystone and carbonaceous debris. The individual grains should be well rounded.



Fig 18: Hips of washed aggregates at Tinau River



Fig 19: Sieving aggregates through a series of (12,10,8,6,4,3,2,1,0.5 mm) mesh



Fig 20: Sieved aggregates of different sizes(left) & mixed in same proportion(right) (FILTER PACK)

3.7.5 Well Screening and Casing Placement

A minimum of 6 inches of the filter pack material should be placed in the bottom of the borehole under the well screen to provide a firm footing and an unrestricted flow of water under the well screen. The filter pack sand should be emplaced through the augers or tremie to the target depth around the well screen. The filter pack should extend at least 2 feet, but not more than 3 feet, above the well screen, to allow for settling and to isolate the screened interval. If using hollow stem augers, the augers should be withdrawn slowly during placement of the filter pack to avoid bridging and to insure that the annular space is filled properly. During withdrawal of the augers or tremie, a weighted tag line should be used to insure proper placement of the filter pack.

Screen length should be selected based on the formation to be monitored. For formations less than 50 feet thick, a maximum 10-foot screen length is appropriate. Screen lengths exceeding 10 feet may result in diluted water samples. Appropriate slot sizes should be selected based on formation materials and the screens/slot opening should retain 90 percent of the filter pack material. Screens within naturally developed filter packs must be sized to retain 50 percent of the aquifer material.

Well Screening for monitoring wells:

Monitoring well screen length is a variable worthy of some consideration in well design. Most monitoring wells function as both fluid-sampling points and as a piezometer. Monitoring well intakes are normally from 2 to 10 feet long. Shorter intakes provide more specific and precise information about vertically distributed water quality, hydraulic head, and flow. If the objective of the well is to monitor for the gross presence of contaminants in an aquifer, a longer intake may be appropriate. However, long intakes may cause a dilution of depth-specific contaminants during sampling, and thereby provide inaccurate data on the nature of aquifer contamination. One instance in which wells with long intakes may provide discrete data is in geochemical wireline

bore hole logging. Geochemical probes are slowly lowered into small diameter wells fully penetrating the aquifer. The resultant log provides a geochemical profile through the aquifer of such parameters as pH, Eh, conductivity, dissolved oxygen, and temperature. Screen placement may be at the bottom, within, at the top, and even extend above the top of the saturated part of an aquifer to satisfy the design purpose. Monitoring wells installed in unconfined aquifers for the purpose of monitoring light non-aqueous phase liquids (LNAPLs) must extend above the top of the water table. Water table fluctuations should be considered when designing wells to intersect the top of water table aquifers.



Fig 21: Screen being wrapped up by 0.5 mm mesh filter

3.7.6 Quantity Estimation of sealing construction materials[Grout & Filter Pack]

The chart below may be used to estimate the total volume of grout slurry required to fill the annular space between the permanent well casing and the borehole. The bags of grout required can be determined by dividing volume listed in the table below by the grout manufacturers suggested yield per bag. Be sure the yield per bag is in cubic feet (ft) for this calculation. If not, recall that 1 cubic foot of water = 7.48 gallons.

An amount equal to 20 percent of the calculated volume may have to be added to allow for borehole irregularities.

CALCULATIONS

The minimum sealing grout volume necessary to grout a well can be calculated using:

$$\text{Grout Volume (ft}^3\text{)} = \text{Volume of Bore hole (ft}^3\text{)} - \text{Volume of Casing (ft}^3\text{)}$$

$$V = L [\pi(r_B^2 - r_C^2)]$$

where ;

$\pi = 3.14$ (approx)

r_B = radius of borehole (ft)

r_C = radius of casing (ft)

L = length of bore hole to be sealed (ft)

Table No.1; BOREHOLE VOLUME REQUIREMENTS:

ANNUAL SPACE VOLUME (Cubic Feet)												
DIAMETER IN INCHES												
WEL CASING DEPTH IN FT.	CASING	2	2	4	4	5	5	6	6	6	8	8
	HOLE	4	6	6	8	8	10	8	10	12	10	12
	25	1.4	4.1	2.1	6.0	4.5	9.4	2.7	7.6	12.6	3.5	9.5
	50	2.8	8.3	4.3	11.9	9.0	18.8	5.5	15.3	27.3	7.0	19.0
	75	4.2	12.4	6.4	17.9	13.5	28.2	8.2	22.9	40.9	10.5	28.5
	100	5.6	16.5	8.6	23.8	18.0	37.6	11.0	30.6	54.6	14.0	37.9
	125	7.2	20.7	10.8	29.8	22.5	47.1	13.7	38.3	68.2	17.5	47.4
	150	8.5	24.8	12.9	35.8	27.0	56.5	16.4	45.9	81.8	20.9	56.9
	175	9.9	29.0	15.1	41.8	31.5	65.9	19.2	53.6	95.5	24.4	66.4
	200	11.3	33.1	17.2	47.7	36.0	75.3	21.9	61.2	109.1	27.9	75.9



Fig 22: Quantity estimation of bentonite chips & graded aggregates for the borehole sealing.

GROUTING WELLS - NEAT CEMENT-BENTONITE VOLUME REQUIREMENTS

The chart below may be used for estimating the number of bags of cement required for grouting the annular space between the permanent well casing and the borehole. These figures are based on a mixture of one bag (94 lbs.) of cement to 6.0 gallons of clean water, which yields a volume of 1.28 cubic feet. The quantity of cement is calculated for a clean borehole. It is a common practice to add an amount equal to 20 percent of the calculated volume to allow for borehole irregularities and severely fractured formations.

Table No.2: SEALING GROUT VOLUME REQUIREMENTS

CASING	2	2	2	4	4	4	5	5	5	6	6	6	8	8	8
HOLE	4	5	6	6	7	8	7	8	9	8	9	10	10	11	12
25	1.1	2.1	3.3	1.7	3.1	4.7	2.0	3.5	5.4	2.2	4.0	6.0	2.7	5.0	7.5
30	1.3	2.5	3.9	2.0	3.6	5.6	2.4	4.2	6.5	2.6	4.8	7.2	3.3	6.0	9.0
40	1.8	3.2	5.2	2.7	4.9	7.5	3.2	5.6	8.7	3.5	6.4	9.6	4.4	8.0	12.0
50	2.2	4.1	6.5	3.4	6.2	9.4	4.0	7.0	10.9	4.3	8.0	12.0	5.5	10.0	14.9
60	2.7	5.0	7.8	4.1	7.4	11.3	4.8	8.4	13.1	5.2	9.6	14.5	6.6	12.0	17.9
70	3.1	5.8	9.1	4.7	8.6	13.2	5.6	9.9	15.3	6.0	11.2	16.9	7.7	14.0	20.9
80	3.6	6.6	10.4	5.4	9.9	15.0	6.4	11.3	17.4	6.9	12.3	19.3	8.8	16.0	23.9
90	4.0	7.5	11.7	6.1	11.1	16.9	7.2	12.7	19.6	7.8	14.3	21.7	9.9	18.0	26.9
100	4.4	8.3	13.0	6.8	12.3	18.8	8.1	14.1	21.8	8.6	15.9	24.1	11.0	20.0	29.9
ft. 120	5.4	10.0	15.6	8.1	14.8	22.5	9.7	16.9	26.2	10.4	19.1	28.9	13.2	24.0	35.9
140	6.3	11.6	18.3	9.5	17.3	26.3	11.3	19.7	30.5	12.1	22.3	33.7	15.4	28.0	41.9
160	7.1	13.3	20.9	10.8	19.8	30.1	12.9	22.5	34.9	13.8	25.5	38.6	17.6	32.0	47.8
180	8.0	15.0	23.5	12.2	22.2	33.8	14.5	25.3	39.2	15.5	28.7	44.4	19.8	36.0	53.8
200	8.9	16.6	26.1	13.5	24.7	37.6	16.1	28.1	43.6	17.3	31.9	48.2	22.0	40.0	59.8
220	9.8	18.3	28.7	14.9	27.2	41.3	17.7	31.0	48.0	19.0	35.1	53.0	24.2	44.0	65.8
240	10.7	20.0	31.3	16.2	29.6	45.1	19.3	33.8	52.3	20.7	38.3	57.8	26.4	48.0	71.7
260	11.5	21.6	33.9	17.6	32.1	48.9	20.9	36.6	56.7	22.5	41.4	62.7	28.6	52.0	77.7
280	12.4	23.3	36.5	18.9	34.6	52.6	22.5	39.4	61.0	24.2	44.6	67.5	30.8	56.1	83.7
300	13.3	25.0	39.1	20.3	37.0	56.4	24.2	42.2	65.4	25.9	47.8	72.3	33.0	60.1	89.7



Fig 23: Field test of liquid (grout/water) blocking property of bentonite chips.
 [Left: water held in annular gap @ top / Right: Impermeable Bentonite Chips layer @ bottom]

3.7.7 Filter Pack Placement

The filter pack is properly mixed and well graded and is emplaced through tremie to the target depth around the well screen. The annular space of the well along the entire screened interval must be filled to at least 1 to 3 feet above the top of the screen as well as filling of the overdrilled portion of the bore hole is also considered (minimum 6 inches). The depth to the top of the filter pack is probed using the tremie pipe, verifying the thickness of the sand pack. Additional filter pack is sometimes required to compensate for additional settling of the filter pack after emplacement. Under no circumstances should the filter pack extend into any aquifer other than the one to be monitored. In most cases, the well design can be modified to allow for a sufficient filter pack without threat of cross flow between producing zones through the filter pack.



Fig 24: Filter Pack placement



Fig 25: 8 ft. long slot

3.7.8 Bentonite Seal Plug:

The bentonite seal should be placed directly on top of the filter pack to an un-hydrated thickness of 2 feet using a tremie pipe. The pellet seal should be hydrated with potable water for 24 hours.



Fig 26: Pouring of dried B- chips (left) through tremie pipe(right)

3.7.9 Making of Bentonite Cement Grout

A homogenous mixture of dry Cement and Bentonite in the ratio of 6% Bentonite by weight is prepared and thus grout is formed.



Fig 27: Preparing of Bentonite Cement Grout

3.7.10 Grouting Method

Grout Pipe Method (Gravity)- The grout is placed in the annular space by gravity through a funnel attached to a grout pipe (or tremie) that is suspended in the annular space. A 1 inch or 1¼ inch rigid pipe is used as the grout pipe. The borehole diameter must be large enough to accommodate the grout pipe. A two inch or larger annular space will usually be sufficient, which requires a borehole that is 4-5 inches larger than nominal size of the casing. The grout pipe is extended down between the permanent casing and conductor casing. The grout is placed through the funnel & tremie in one continuous operation, beginning at the bottom of the zone being sealed. The bottom end of the grout pipe should be kept full of grout and remain submerged in grout during the operation. The grout pipe is gradually withdrawn as the grout fills the annular space. This is accomplished by disjuncting it in typically 10 foot sections. The conductor pipe should be removed as the grout is being placed in the annulus. Grout should be added until it appears at ground surface. Where a surface pad is to be installed, grout may be terminated a few feet below surface.

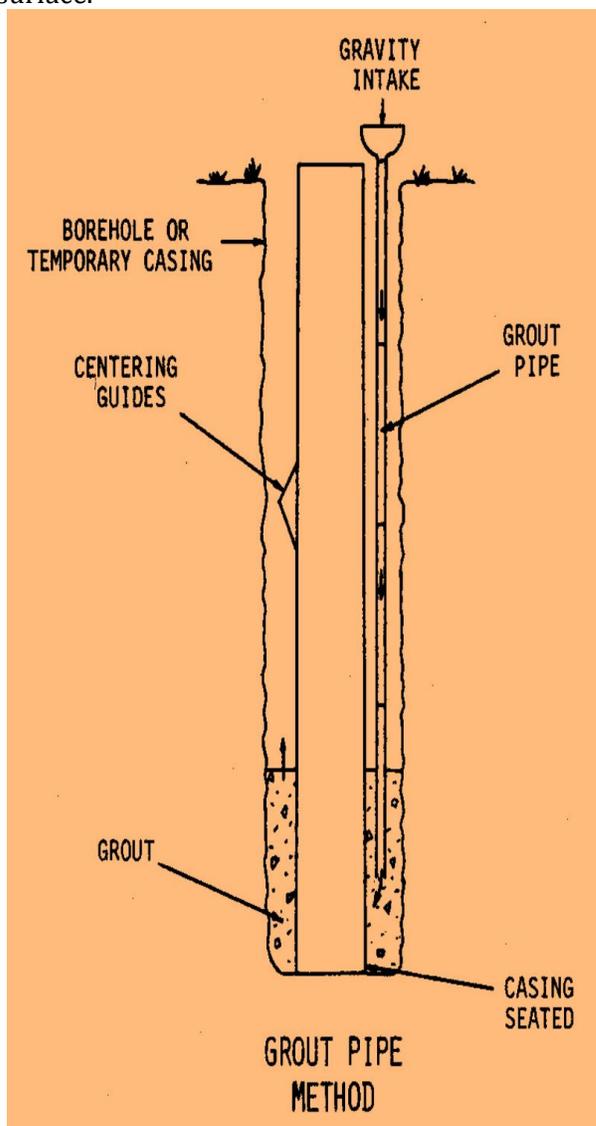


Fig 28: Pouring sealing grout in the borehole through funnel connected to tremie pipe.

Grout should be placed from the top of the bentonite seal to within 2-feet of the ground surface. Grouting should not disturb the bentonite seal or filter pack. Grout should be allowed to cure for 24-48 hours or per the manufacturer's specifications before the concrete surface pad and protective casing is installed.



Fig 29: Rising of the grout inside the borehole (left: checking the quality of top layer grout)

3.7.11) Well- Development

Wells should not be developed within 24 hours of completion of the surface pad and protective casing to allow sufficient time for the well materials to cure. Regardless of drilling methods, all wells must be developed to remove the residual materials and to re-establish the natural hydraulic flow conditions of the formation which were disturbed by well construction. A new monitoring well should be developed until the column of water is free of visible sediment and the temperature, pH, turbidity, and specific conductivity measurements have stabilized. In some cases water may remain turbid after all parameters have stabilized. In this is the case, the well may need continuous flushing over a period of several days. To insure that the formation has re-stabilized to pre-well conditions, at least 24 hours should be allowed to elapse prior to sampling a new well or a newly developed well. Wells developed with more stressful measures may require longer intervals between development and sampling.

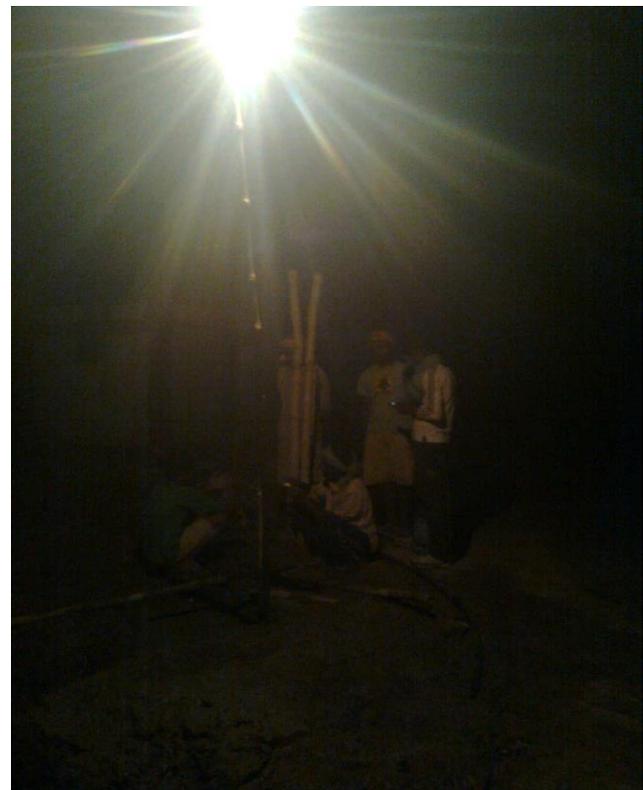


Fig 30: Continuous Well development task being carried on (29/03/2011; 12 am; midnite)

3.7.12 Surface Pad and Protective Casing

The surface pad should be constructed of concrete or aggregate reinforced cement of sufficient strength and durability appropriate to the setting and location should be installed. At a minimum, for a 2" I.D. well, the well pad should be 3'x3'x 4" and for a 4" I.D. well, the well pad should be 4'x4'x6". The finished pad should be slightly sloped to allow water drainage away from the protective casing and off the pad. In non-traffic areas, above-ground completion is preferred. A protective outer casing of corrosion-resistant material with a locking cap and weep holes should be installed to a height of at least 3 feet and painted with highly visible enamel paint.



Fig 31: Construction of surface pad for monitoring sealed well @ Sano Kunuwar.

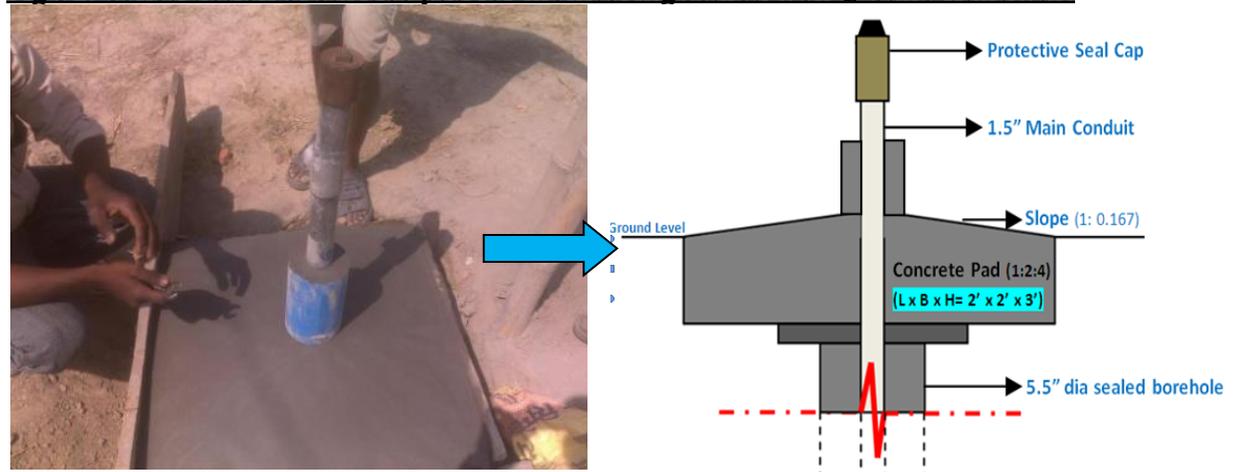


Fig 32: Design of Surface Pad

3.8 PROCEDURES OF SEALING IN SAND, SILT AND BOULDER ZONE.

Apart from the procedures of drilling and sealing technology like in soft sand and clay zone of Parasi Bazaar of Nawalparasi District, there is change in both mechanisms in case of boulder zone mixed sites like of Pratappur. The hydrogeology of Pratappur explains the presence of Arsenic contaminated shallow aquifers up to the depth of 30ft. -35ft. which comprises of soft soil mass. Underneath, there lies a rocky and boulder mixed strata with abundant good quality aquifer which is comparatively hard to penetrate. A better idea can be taken from ANNEX-I [i.e. the drill logs of nearby Mini O/h tank sites of Pratappur(ward no: 3) and Gopigunj]. Local people use sludging method for installing domestic handpumps and they haven't gone beyond this hard rocky bed-layer as it is costly to drill by hammering for individual household purpose. So, here we found ourselves a space to make an endeavor to drill with the help of local hammering method beyond this hard strata layer as much as possible in order to access that virgin aquifer layer which has very potable water.

On behalf of this secondary objective, apart from pilot testing of sealing technology, we explored the possibilities of installing a deeper 4" tubewell with the mixed sludging & hammering method of drilling.

Steps Of Drilling & Sealing Mechanism:

Drilling Mechanism:

STEP A) = Sludging Method 1 (initial sludging is done with 1.5" GI Pipe until the boulder zone is reached)

STEP B) = Stone Hammer Method (hammering is done on 4" Pipe until the As-free aquifer is reached)

STEP C) = Sludging Method 2: (sludging is done for 5-6 times around 4" pipe for creating enough annular gap for lowering tremie pipe & lastly with enlarged concentric drill bit before sealing is done)

Sealing Mechanism:

Initially, a mixture of sand, bentonite and clay(0.5:2:1) is made and poured for filling 2' plug inside the borehole. Afterwards, the prepared grout is batched down continuously until the grout reaches at the top. Appropriate calculations are done prior to batching down of sealing chemicals/grout. A better idea could be taken from the video attached at the end of the report.

On the following day, a slab of (4'x4'x0.5') is constructed with certain drain off gradient at the top and the pipe is kept closed with lead for 24-48 hours so that the system gets enough time to set. Afterthen, well development is started with continuous pumping of water at a mild rate for few hours until a steady turbidity is observed in the pumped water. The construction of a sealed pump is thus completed.

4. RESULTS AND DISCUSSIONS

4.1 Description of the 6 bore hole sites:

Table 4.1 Description of the 6 bore hole sites of sealed tubewells

S. No.	Boring ID	Location	Drilled Depth (ft.)	No. of multiaquifer	Upper Aquifer As-conc (ppb)	Lower Aquifer As-conc (ppb)	Status
1	R1	Kunuwar	70	2	0	120	Completed
2	R2	Pratappur	57	2*	90	40	Completed
3	R3	Pratappur	57	2*	150	40	Completed
4	U1	Siwangadh	125	3	300	96	N-C
5	U2	Paratikat	95	2	100	5	Completed
6	U3	Kunuwar	107	2	530	11	N-C
7	R1'	Kunuwar	200	3	Collapsed 1 st borehole near R1		

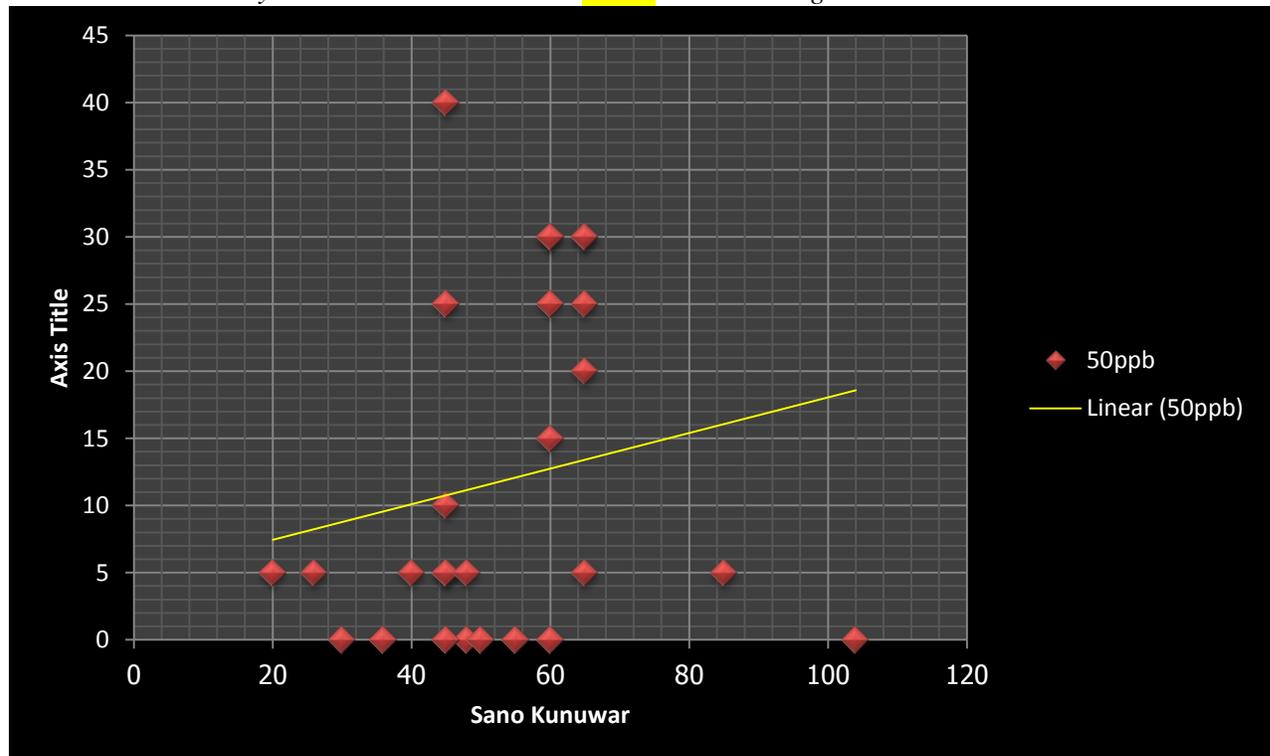
R = RWSSP_WN Funded Sealed Well & U = UNICEF Funded Sealed Well

* = Not distinguished yet

N-C = Not completed

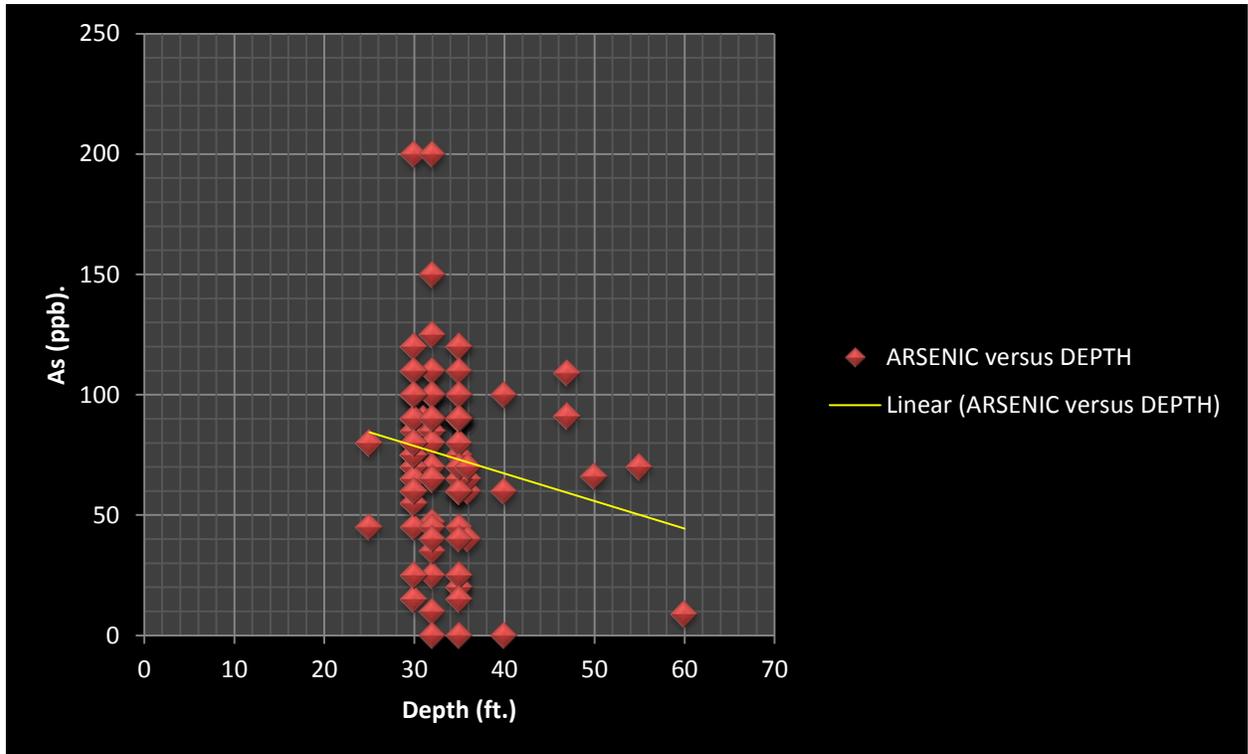
Row No. 5 = Currently in abused state.

40/70 = Fluctuating in between



Graph 1: Existing tubewells & their As- concentration at R1 site (Sano Kunuwar Village)

Graph 1 is derived on the basis of Blanket testing data of Sano Kunuwar Village. It shows a general trend of hydrogeology at Sano Kunuwar Village where R1 sealed tube well is located which clarifies that there is increase in As concentration in the aquifers lying in shallow depth. And accordingly it satisfies the aquifer positioning and As- concentration of R1 sealed tube well which has 0 ppb aquifer at 20 ft. depth and 120 ppb aquifer at 65 ft depth from ground level.



Graph 2: Existing tubewells & their As- concentration at R2 & R3 site (Pratappur Village)

Graph 2 has been derived from the blanket testing data of Ward No. 3, Pratappur Village of Pratappur VDC. R2 & R3 sealed tube wells are located in this region. According to the graph, hydrogeology of Pratappur explains the presence of Arsenic contaminated shallow aquifers up to the depth of 30ft. -35ft. which comprises of soft soil mass. Underneath, there lies a rocky and boulder mixed strata with abundant good quality aquifer which is comparatively hard to penetrate.

And majority of villagers are extracting water from aquifers located above the boulder zone which is highly As- contaminated.

PROJECT : ARSENIC AQUIFER SEALING

LAB REPORT ANALYSIS:

Name of Sender: UNICEF / RWSSP

Sampled by: Client / SUDET Co. P. Ltd.

Sample (R1): Kunuwar: 65 Feet

Parameters	Units	WHO GV	NDWQS	LAB	WATER TRAINING	NESS	SOIL TEST				
				Analyzed Date	28/01/2011 - 14/02/2011	07/03/2011 - 22/03/2011	27/03/2011	25/04/2011	08/05/2011	07/06/2011	19/08/2011
				Test Methods							
Conductivity	uS/cm	-	1500	Conductivity Meter	774.0	906.0	810	801.0	-	-	-
Turbidity	NTU	5	5(10)	Nephelometer	-	-	260	300.0	-	3.4	-
pH	-	6.5 -	6.5-8.5*	pH Meter	7.3	7.4	8.0	7.9	-	-	-
Nitrite	mg/l	3	-	NEDA / Colorimetry	0.09	3.6	<0.003	0.039	-	-	-
Nitrate	mg/l	50	50	UV Screening	1.4	25.0	1.0	1.0	-	-	-
Iron	mg/l	0.3	0.3 (3)	AAS	38.2	1.5	20	18	-	1.6	-
Manganese	mg/l				-	-	0.8	0.75	-	<0.05	-
Arsenic	mg/l	0.01	0.05		<0.005	0.12	0.12	0.05	0.13	0.11	0.06

Sample (R2 & R3): Pratappur: 57 Feet

					R2				R3				
Parameters	Units	WHO	NDWQS	LAB	SOIL TEST	ARSENATOR TEST			SOIL TEST	ARSENATOR TEST			SOIL TEST
				Analyzed Date	01/07/2011	15/06/2011 - 01/07/2011			01/07/2011	01/07/2011 - 16/07/2011			19/08/2011
				Test Methods									
Conductivity	uS/cm	-	1500	Conductivity Meter	1245.0	Day	RunTim	As	931	Day	RunTim	As	1140
Turbidity	NTU	5	5(10)	Nephelometer	25	15/06/2011	1 hrs	38 ppb	10.2	01/07/2011	1 hrs	18 ppb	-
pH	-	6.5 -	6.5-8.5*	pH Meter	7.4		3 hrs	80 ppb	7.3		2 hrs	49 ppb	7.1
Nitrite	mg/l	3	-	Colorimetry	0.5	01/07/2011	0 hrs	19 ppb	<0.02		3 hrs	39 ppb	<0.01
Nitrate	mg/l	50	50	UV Screening	1.0		1 hrs	93 ppb	2		4 hrs	100 +	4
Iron	mg/l	0.3	0.3 (3)	AAS	<0.1		2 hrs	77 ppb	<0.1		5 hrs	100 +	9.0
Manganese	mg/l	-	1500	Conductivity Meter	<0.005			<0.05	5.5	-	0.3		
Arsenic	mg/l	5	5(10)	Nephelometer	0.08	←	2.5 hrs		0.04	16/07/2011	0 hrs	0 ppb	0.08

4.2 Water Quality Monitoring of Sealed Wells of RWSSP-WN.

Table 4.1: Multi-aquifer positioning at different sealed well sites.

S.No	Well ID	Depth (ft.)	Location	Upper Aquifer		Lower Aquifer	
				Depth (ft.)	As-conc (ppb)	Depth (ft.)	As-conc. (ppb)
1.	R1	65	Sano Kunuwar, Nawalparasi	20	0	65	120
2.	R2	57	Pratappur-3, Nawalparasi	35	80-200	57	26
3.	R3	57	Pratappur-3, Nawalparasi	35	100-150	57	30

Table 4.2: Arsenic (As) fluctuation monitoring before & after sealing @ R1 sealed well.

S.No.	Well ID	Date of Testing	As. Concentration (ppb)	Remarks	
1.	R1	March, 2011	120	AAS	Before Sealing
2.		April, 2011	120		
3.		April, 2011	50		
4.		May, 2011	130		
5.		June, 2011	110	ICP-MS	After Sealing
6.		August, 2011	60		
7.		November, 2011	118		
8.			122		
9.			109		
10.		January, 2012	160		

Table 4.3: Arsenic (As) fluctuation monitoring before & after sealing @ R2 sealed well.

S.No.	Well ID	Date of Testing	As. Concentration (ppb)	Remarks	
1.	R2	July, 2011	80	AAS	Before Sealing
2.		September, 2011	70		
3.		September, 2011	40		
4.		January, 2012	10	0 min.	After Sealing (AAS)
5.			35	5 min.	
6.			47	15 min.	
7.			26	60 min.	

Table 4.4: Arsenic (As) fluctuation monitoring before & after sealing @ R3 sealed well.

S.No.	Well ID	Date of Testing	As Concentration (ppb)	Remarks	
1.	R3	July, 2011	40	AAS	Before Sealing
2.		August, 2011	80		
3.		January, 2012	17	0 min.	After Sealing (AAS)
4.			8	5 min.	
5.			44	15 min.	
6.			47	30 min.	
7.			30	60 min.	

Table 4.5: Iron (Fe), Managnese (Mn), Nitrate (NO₃⁻), Nitrite (NO₂⁻), Conductivity, pH, turbidity fluctuation monitoring in sealed well R1.

S.No.	Well ID	Date of Testing	Fe (mg/l)	Mn (mg/l)	NO ₃ ⁻ (mg/l)	NO ₂ ⁻ (mg/l)	pH	Conductivity (µs/cm)	Turbidity (NTU)	Remarks
1.	R1	February, 2011	38.2	-	1.4	0.09		774	-	High turbid sample acidified
2.		March, 2011	1.5	-	25	3.6	7.4	906	-	
3.		April, 2011	20	0.8	1.0	<0.003	8.0	810	-	High turbid sample acidified
4.		April, 2011	18	0.75	1.0	0.039	7.9	801	-	High turbid sample acidified
5.		May, 2011	1.6	<0.05	-	-	-	-	3.4	
6.		June, 2011	1.6	<0.05	-	-	-	-	-	
7.		November, 2011	7.2	0.55						ICP-MS Testing
8.		"	9.5	0.61						
9.		"	7.8	0.58						
10.			January, 2012	40	2.35	-	-	-	-	-

Table 4.6: Iron (Fe), Managnese (Mn), Nitrate (NO₃⁻), Nitrite (NO₂⁻), Conductivity, pH, turbidity fluctuation monitoring in sealed well R2.

S.No.	Well ID	Date of Testing	Fe (mg/l)	Mn (mg/l)	NO ₃ ⁻ (mg/l)	NO ₂ ⁻ (mg/l)	pH	Conductivity (µs/cm)	Turbidity (NTU)	Remarks
1.	R2	July, 2011	<0.1	<0.05	1.0	0.5	7.4	1245	25.0	Before Sealing
2.		September, 2011	4.6							
3.		September, 2011	4.2					1052		
4.		January, 2012	0 min.	7.2	<0.05					Continuous testing in single 1 hour pump test after 4 months of sealing.
5.			5 min.	20	0.25					
6.			15 min.	4.4	0.1					
7.			60 min.	4.2	0.15					

Table 4.7: Iron (Fe), Managnese (Mn), Nitrate (NO₃⁻), Nitrite (NO₂⁻), Conductivity, pH, turbidity fluctuation monitoring in sealed well R3.

S.No.	Well ID	Date of Testing	Fe (mg/l)	Mn (mg/l)	NO ₃ ⁻ (mg/l)	NO ₂ ⁻ (mg/l)	pH	Conductivity (µs/cm)	Turbidity (NTU)	Remarks
1.	R3	July, 2011	<0.1	<0.05	2	<0.02	7.3	931	10.2	Before Sealing
2.		August, 2011	9.0	0.3	4	<0.01	7.1	1140		
3.		January, 2012	0 min.	20	0.25					Continuous testing in single 1 hour pump test after 4 months of sealing.
4.			5 min.	9	<0.05					
5.			15 min.	4.4	<0.05					
6.			30 min.	3.6	<0.05					
7.			60 min.	3.6	<0.05					

Table 4.8: Cross checking inbetween three laboratories of Kathmandu, Nepal

S.No.	Date	Sampling Well	Parameter	Unit	Laboratories		
					Soil Test P. Ltd.	NESS P. Ltd.	DWSS-Lab
1.	19/9/2011	R2	Arsenic	ppb	70	40	-
2.	3/1/2012	R1 _{initial}			10	<0.005	15.415
3.		R1 _{final}			160	200	182.33
4.		R2			26	100	49.907
5.		R3			30*	<0.005	35.944
6.	19/9/2011	R2	Iron	mg/l	4.2	4.6	-
7.	3/1/2012	R1 _{initial}			8	8.7	10.169
8.		R1 _{final}			40	45.7	
9.		R2			4.2	4.6	5.1596
10.		R3			3.6	3.9	4.714
11.	3/1/2012	R1 _{initial}	Manganese	mg/l	0.25	-	0.2615
12.		R1 _{final}			2.35	-	2.3484
13.		R2			0.15	0.2	0.1663
14.		R3			<0.05	0.06	0.0235

*= 30 ppb is the As concentration observed after requesting for rechecking. Initial the lab had reported As concentration of 70 ppb for the sample of well R3.

4.2 Findings

- a) **Table 4.1:** The table shows that in case of sealed well R1 located at Sano-Kunuwar Village, shallow aquifer (As = 0 ppb) is intercepted at 20 ft. depth from ground level and deeper aquifer (As = 120 ppb) is intercepted at 65 ft. depth from ground level. This well thus holds good for working as a sample of study for reverse hypothesis of sealing Technology in shallow tubewells.

In case of sealed wells R2 and R3 located at Pratapur village of Pratappur VDC, Ward No. 3, shallow aquifer (As>50 ppb) is intercepted at 35 ft. from ground level and deeper aquifer (As<50 ppb) is intercepted at 65 ft. depth.

Sealed Well R2 has upper aquifer having As of (80-200ppb) and the lower aquifer having As of 26 ppb(as per latest data of monitoring).

Sealed Well R3 has upper aquifer having As of (100-150ppb) and the lower aquifer having As of 30ppb(as per latest data of monitoring).

- b) **Table 4.2:** The table shows the monitoring of As-fluctuation at R1 sealed well in between May, 2011 to December, 2012. The trend of data shows some outliers as As=50 ppb, As=60 ppb of April and August, 2011, respectively. As concentration in January 2012 is recorded to be high up to 160 ppb which has been determined due to high turbidity in the acidified sample, because of additional dilution of As content in sediment particles. The ICP-MS analysis of water samples showed average As concentration of R1 sealed well around 120 ppb.

- c) **Table 4.3:** The table shows As-concentration fluctuation at R2 sealed well before and after sealing. Sealing in R2 well was done in the month of September, 2011. Initial As concentration in the tube well is determined to be greater than that observed after sealing. The data of continuous single 1 hour pumping of water from R2 sealed well shows a general trend of increasing As concentration with increase in time of pumping up to 15th to 30th min, and then decrease in 60th min. which might have been due to stabilization or out coming of fresh water directly from aquifer.

- d) **Table 4-4:** The table shows As-concentration fluctuation at R3 sealed well before and after sealing. Sealing in R3 well was done in the month of September, 2011. Initial As concentration in the tube well is determined to be greater than that observed after sealing. The data of continuous single 1 hour pumping of water from R3 sealed well shows a general trend of increasing As concentration with increase in time of pumping up to 30th min and then decrease in 60th min. which might have been due to stabilization or out coming of fresh water directly from aquifer.
- e) **Table 4.5:** The table shows fluctuation of different parameters as Fe, Mn, NO₃⁻, NO₂⁻, EC, pH, turbidity at R1 sealed well during the project. Certain outliers in the data such as Fe= 38.2 mg/l, 20 mg/l, 40 mg/l, Mn=2.35 mg/l have been noticed which has been determined due to high turbidity in the acidified sample, because of additional dilution of Fe content in sediment particles.
- f) **Table 4.6:** The table shows fluctuation of different parameters as Fe, Mn, NO₃⁻, NO₂⁻, EC, pH, turbidity at R2 sealed well during the project. Only 1 outlier in the data "Fe= 20 mg/l has been noticed which might have been due to above mentioned reason. The average Fe content of the sealed well is observed around 4.2 and Mn content around 0.1.
- g) **Table 4.7:** The table shows fluctuation of different parameters as Fe, Mn, NO₃⁻, NO₂⁻, EC, pH, turbidity at R3 sealed well during the project. Certain outliers in the data such as Fe= 20 mg/l, 9 mg/l have been noticed. The average Fe content of sealed well has been observed to be 3.6mg/l and Mn is less than 0.05 mg/l.
- h) **Table 4.8** The table shows cross checking of lab analysis of different samples taken from R1, R2 and R3 sealed wells of Nawalparasi district. The data of soil test P. Ltd.(authorized lab for this project)has been referred throughout this project and additional lab data of NESS P. Ltd. and that of laboratory of DWSS have been taken as references for cross checking only.
- The average data of cross checking of iron parameter in water samples have not been observed to vary in a great extent among all the three labs and quite similar cases where observed in the cross checking of Mn parameter in the exactly same water samples. However very dramatic variation (high standard deviation) was observed in between the data of As test even in the exactly same water samples. The data of NESS P. Ltd. varies at a very large range with that of Soil test P. Ltd. as compared to the variation in lab data in between DWSS and Soil test P. Ltd.

4.3 LOG-DATA of different sealed wells installed during the project.

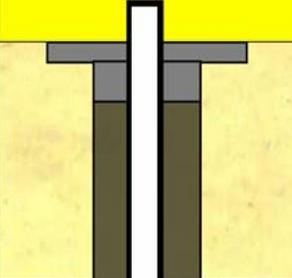
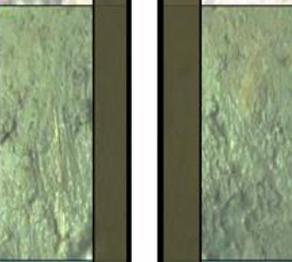
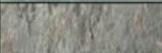
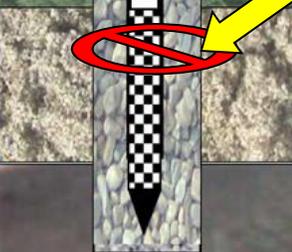
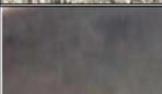
LOG-DATA OF 200 FT. SOIL STRUCTURE @ KUNUWAR:February, 2011

Drilled Depth (ft.)		Soil Type	Remarks
From	To		
0	10	Yellowish Clay (Loam)	With very less amount of gravel mixed
10	14	“ “	More Gravel mixed
14	16	“ “	“ “
16	20	Fine Sand	Mud mixed and Yellowish-brown in colour
20	24	Coarse Sand	Clean Sand with bright grey colour (1st Aquifer)
24	26	Greenish Clay	Very Tough, Appears white- grey colour on dried
26	26'4"	Greenish Clay	Very Fine Sand Mixed
26'4"	29	“ “	Plain
29	38	“ “	Few pebbles
38	47	“ “	Snails mixed clay
47	51	Greyish Clay	
51	53	Greyish Clay	Less Tough Coarse Texture
53	57	Greyish Clay	Fine Pebbles Mixed
57	60	Greenish Clay	Small Stone Mixed
60	64	Fine Sand	Fine sand with silt, Good Grey Color (2nd Aquifer)
64	68	Grey Clay	Dark colored with pebbles
68	73	Yellowish Clay	
73	74	Grayish Clay	Pebbles Mixed
74	77	Clay	Mixed with fine Sand and Coarse pebbles
77	83	Yellowish Soft Clay	Sample was less dense
83	85	Yellowish Clay	Gravel Mixed
85	95	Grey Clay	Gravel Mixed
95	104	Grey Clay	Large Proportion of Gravel
104	105	Yellowish Clay	
105	115	Grey Clay	Dark Color
115	120	“ “	With pebbles
120	124	“ “	
124	125	“ “	Gravel Mixed in large proportion
125	140	Grey Clay	
140	145	Clay	With less gravel
145	149	Clay	Soft sample(less Dense)
149	150.5	Clay	Small Stones Mixed clay with large proportion of stones and drill pipe stuck on the layer (Hard Mass)
150.5	155	Fine sand	Reddish sand, silt mixed
155	160	Grey Clay	Stones mixed
160	163.5	Grey Clay	Sets like cement
163.5	165	Clay(Black)	
165	170	Greenish clay	Small Pebbles mixed
170	173	Greenish Clay	No Pebbles
173	175	Black Clay	Hard Sample
175	185	Black clay	Very tough
185	195	No samples	Pipe got clogged (soil samples didn't came out)

AQUIFER SEALING DESIGN @ KUNUWAR

R1'

: March, 2011

Drilled Depth (ft.)		Soil Type	Picture of Soil Texture	Remarks	AQUIFER SEAL DESIGN
From	To				
0	10	Yellowish Clay		With very less amount of gravel mixed	
10	14	" "		More Gravel mixed	
14	16	" "		" "	
16	20	Fine Sand		Mud mixed and Yellowish-brown in colour	
20	24	Medium Sized Sand <div style="border: 1px solid black; padding: 2px; display: inline-block; font-weight: bold;">0 ppb</div>		Clean Sand with bright grey colour (1st Aquifer)	
24	26	Greenish Clay		Very Tough, Appears white- grey colour on dried	
26	26'4"	Greenish Clay		Very Fine Sand Mixed	
26'4"	29	" "			
29	38	" "		Few pebbles	
38	47	" "		Snails mixed	
47	51	Greyish Clay			
51	53	Greyish Clay		Less Tough Coarse Texture	
53	57	Greyish Clay		Fine Pebbles Mixed	
57	60	Greenish Clay		Small Stone Mixed	
60	64	Medium Sized Sand <div style="border: 1px solid black; padding: 2px; display: inline-block; font-weight: bold;">120 ppb</div>		Medium sand with silt, Good Grey Color (2nd Aquifer)	
64	68	Grey Clay		Dark colored with pebbles	

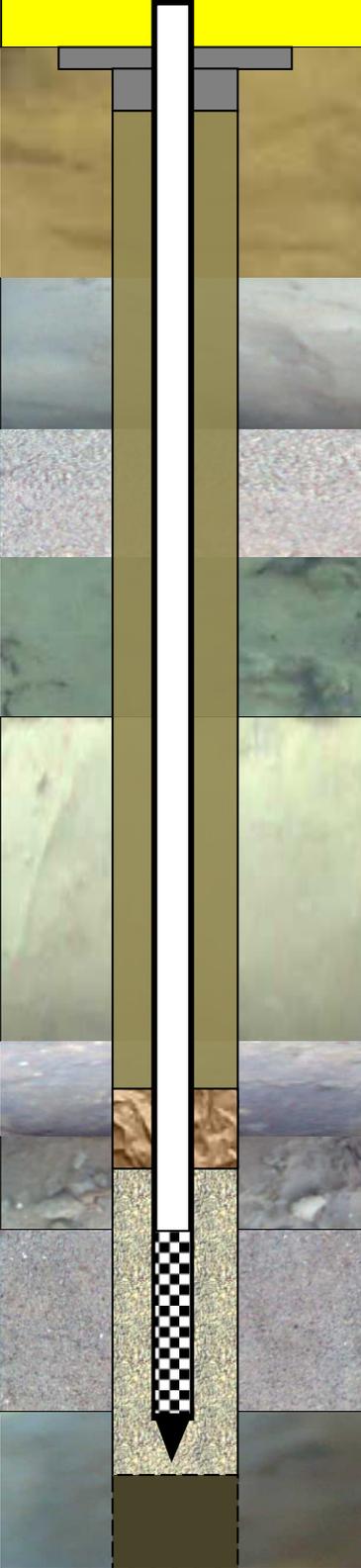
Drill bit collapse



: April, 2011

AQUIFER SEALING DESIGN @ KUNUWAR

R1

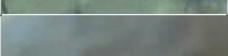
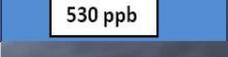
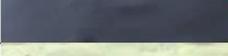
Drilled Depth (ft.)		Soil Type	Picture of Soil Texture	Remarks	AQUIFER SEAL DESIGN
From	To				
0	12	Yellowish Clay		Top Soil	
12	20	Medium Dark Greyish Clay		As= <0.06 µg/g	
20	24	Fine Sand <div style="border: 1px solid black; padding: 2px; display: inline-block; font-weight: bold;">0 ppb</div>		Clean fine Sand with bright grey colour As= 0.26 µg/g	
24	33	Sandy Loam		Yellowish Green As= 0.13 µg/g	
33	53	Light Mud Coloured Clay		Tough in nature	
53	55	Dark Greyish Clay		Snails intermixed	
55	57	Brownish Clay		Pebbles Mixed As= <0.06 µg/g	
57	65	Medium Sized Sand <div style="border: 1px solid black; padding: 2px; display: inline-block; font-weight: bold;">120 ppb</div>		Medium sand with silt, Good Grey Color As= <0.06 µg/g	
65	70	Brownish Clay		Dark colored with pebbles As= <0.06 µg/g	

Arsenic Aquifer Sealing/ RWSS

: March, 2011

AQUIFER SEALING DESIGN @ KUNUWAR₃

U3

Drilled Depth (ft.)		Soil Type	Picture of Soil Texture	Remarks	AQUIFER SEAL DESIGN
From	To				
0	5	Yellowish Clay		Top Soil As= 2.92 ppb	 <div style="background-color: black; color: white; padding: 10px; font-size: 12px; margin-top: 10px;"> <p>Sealing Grout Mixture(starting from 90 ft. below the ground up to ground level).</p> <p>Day 1st</p> <ul style="list-style-type: none"> • Pouring grout up to ground level. • Record the rate of grout sinking inside the bore hole <p>Day 2nd</p> <ul style="list-style-type: none"> • Continue filling up of the sank level inside borehole by Sealing grout up to Ground Level. <p>Day 3rd</p> <ul style="list-style-type: none"> • Leave the system for 24 hour rest (to allow setting of the grout). <p>Day 4th</p> <ul style="list-style-type: none"> • Construct Surface pad(2'X2'X6") </div> <div style="margin-top: 10px; font-size: 10px;"> <p style="background-color: orange; padding: 2px;">Mud mixture(2 ft)</p> <p style="background-color: lightblue; padding: 2px;">0.5 mm sand (upto93')</p> <p style="background-color: pink; padding: 2px;">Gravel pack (up to 95ft.)</p> <p style="background-color: purple; padding: 2px;">6 ft. filter (98-104)</p> <p style="background-color: orange; padding: 2px;">3-5 ft. overdrill</p> </div>
5	10	Medium Dark Greyish Clay		No gravels seen	
10	15	Medium Dark Greyish Clay		Fine gravels/pebbles in small proportion	
15	20	Greyish clay		Fine & coarse gravel mixed	
20	25	Grayish clay (Light green in colour)		Very tough	
25	28	Greenish clay		Small pebbles in less proportion	
28	35	Dark grayish clay			
35	40	Dark Blackish clay		Hardens very fast	
40	45	Dark Blackish clay			
45	48	Light grey Clay		Gravels mixed	
48	50	Greenish Clay		Mixed with silt	
50	55	Dark black clay		Sand mixed clay	
55	60	Dark black clay		Mixed with fine sand As= 15.2 ppb	
60	65	Sand	530 ppb	Light in colour As=2.05 ppb	
65	75	Greenish clay(LOAM)		Pebbles mixed As=10.49 ppb	
75	80	Light Mud colored clay		Very less Pebbles mixed	
80	85	Greenish Clay			
85	90	Light greenish clay			
90	97	Greyish clay		Mixed with fine sand in large proportion As=7.49 ppb	
97	104'-6"	Fine sand	11 ppb	Brown colour As=5.16 ppb	
104'-6"	107	Blackish Clay			

: June, 2011

DRILL - LOG @ PARATIKAT * ABUSED *

U2

Drilled Depth (ft.)		Soil Type	Picture of Soil Texture	Remarks	AQUIFER SEAL DESIGN
From	To				
0	10	Yellowish clay		Top-Soil	
10	10'-6"	Sand		Red (no silt seen) mixed with soil	
10'-6"	24	Yellowish clay			
24	24'-6"	Sand		Without silt Red	
24'-6"	40	Yellowish clay			
40	45	Sand	100 ppb	Less Silt (Brownish) As= 0.2 µg/g	
45	50'	Clay black		Pebbles mixed in large proportion As= 0.59 µg/g	
50	53	Grayish clay			
53	55	Grey clay		Snails mixed	
55	60	Black clay			
60	70	Grey clay			
70	75	Black cotton soil		As= 1.18 µg/g	
75	87	Sand	5 ppb	As= 0.60 µg/g	
87	90	Arsenic Aquifer Sand	As= 0.19 µg/g		

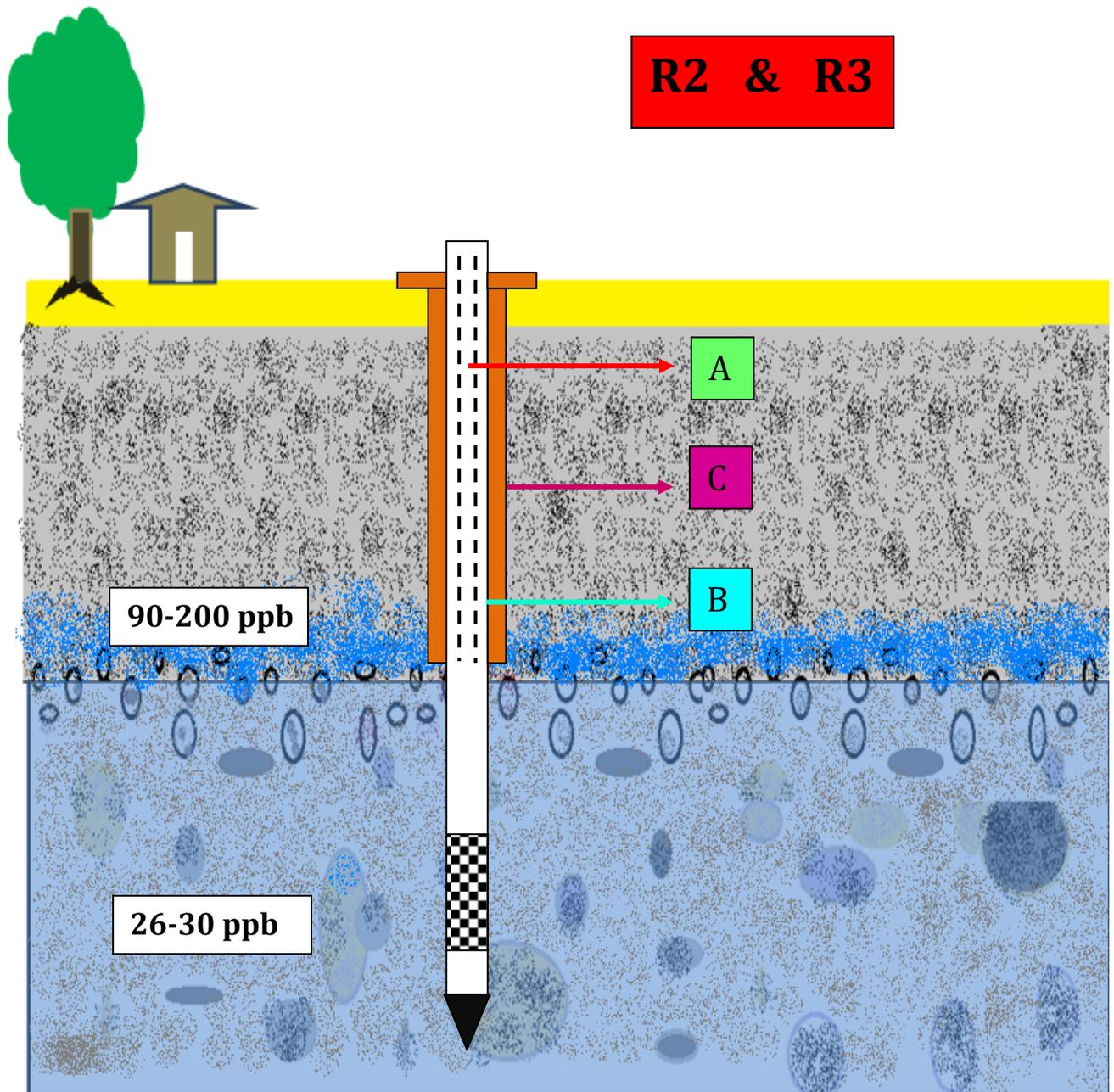
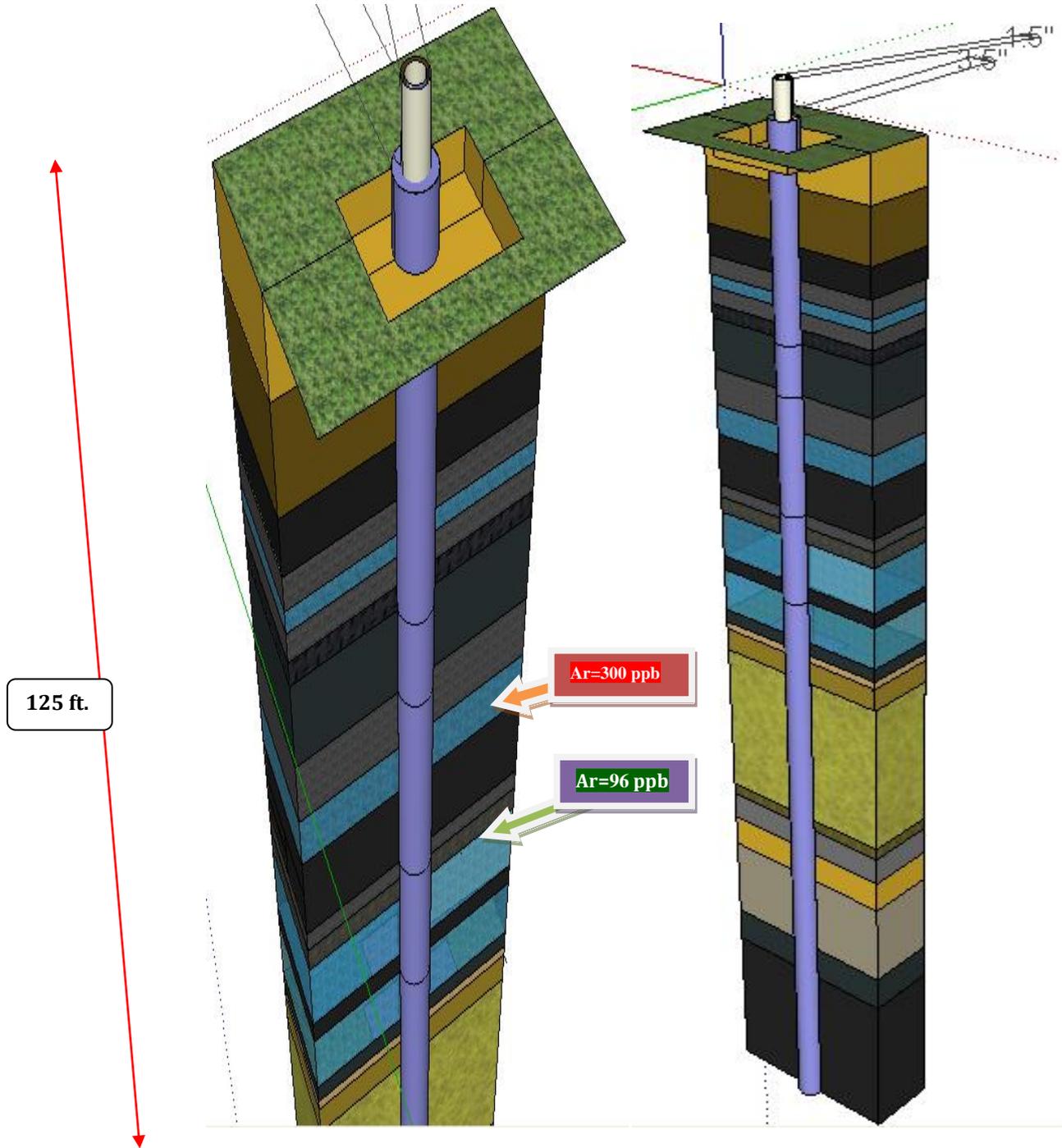


Fig 33: Schematic Representation of the series of major steps carried out in the Sludging & Hammering Method @ Pratappur.

STEP A) = Sludging Method 1 (sludging done for once)

STEP B) = Stone Hammer Method:

STEP C) = Sludging Method 2: (sludging done for 5-6 times around 4" pipe & lastly with drill bit)



5. ORGANISATION OF TEAM

The organizational structure of the team for this project comprises of young researcher engineers who has been working in developing and designing this sealing technology as per the suitability of the hydrogeology of Nepal since last few years. There is also an effective indirect involvement of several national and as well as international experts of the concerned fields through their sharing of technical informations and their guidelines, as the international collaboration is also equally inevitable in the cases of such pioneering researches.

Project Members :

- | | |
|-----------------------|----------------|
| 1. Mr. Mahesh Neupane | Civil Engineer |
| 2. Ms. Amrita Gautam | Civil Engineer |
| 3. Mr. Manoj Kafle | Civil Engineer |
| 4. Mr. Santosh Khanal | Civil Engineer |

Project Supervisor(Consultant Side):

Prof. Dr. Bhagwan Ratna Kansakar
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Institute Of Engineering (I.O.E.), Tribhuvan University, Nepal

Project Immediate Supervisor(Contractor side):

Mr. Guneshwor Mahato
WSS Specialist, RWSSP-WN, Pokhara

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6. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

R1 sealed well have been found to be working as a good reference for studying as reverse hypothesis of Sealing Concept as 0 ppb (As) aquifer lies above 120 ppb (As) aquifer. Sealed wells R2 and R3 located at Ward No. 3 of Pratappur VDC of Nawalparasi District have been observed to be successful to withdraw water of lower arsenic concentration (<50 ppb) whereas above lying aquifers at 35 ft. depth are found to have arsenic concentration of higher concentration (>50ppb).

A dramatic variation was observed in between the data of Arsenic test even in the exactly same water samples in 3 different labs. The data of NESS P. Ltd. varies at a very large range with that of Soil Test P. Ltd. as compared to the variation in lab data in between DWSS and Soil test P. Ltd. Even though, the most contradictory results of rechecking in Soil Test for well R3; as shown in Table 4.8; puts forward the questions about the quality work of the lab. Meanwhile, variations in concentration of iron and manganese have been found relatively lesser in cross checking results; which clarifies the sensitivity of arsenic test by AAS method.

A mixture of sludging method and stone hammering method has a potential to work as both scientific and technically feasible method for mud and rock lithology as of Nawalparasi District of Nepal, however, an appropriate manual rock-drilling method is yet to be promoted for better results. Locally prepared Bentonite granules cannot be the perfect alternative for industrially manufactured Bentonite chips/pellets.

Arsenic contamination was found to be higher in upper part and goes on decreasing to the lower part as seen from graphs mentioned earlier. But presence of iron in great amount even in deep aquifers still seems to be a challenge. Therefore, mitigating arsenic contamination issues only doesn't seem to address the actual challenge of accessing safe drinking water in the communities. No microbial contamination was observed in the sealed tube wells. Results that have been recorded from Arsenator and AAS method were not found to be very much correlated.

Drilling technology for sludging method and corresponding sealing technology is found to be much cheaper than in combined hammering and sludging method. No matter, 2 sealed tubewells have been constructed at rocky lithology site; we are still not satisfied with sealing mechanism, due to the lack of appropriate drilling technology. Both of the wells @ Pratappur stopped penetrating further inside beneath 57 feet even when hammering was kept running for several days. Had we got a better drilling technology, we would have gone up to 100 feet depth and sealing could be done from 60-70 ft. to the ground level. Nevertheless, sealing in both bore holes have been done from 38 ft. to the ground level.

6.2 Recommendations

Based on the research work, the following recommendations have been made:

- Sealing Technology has great significance in context of South Asian groundwater arsenic contaminated zones where relatively lesser arsenic concentrated aquifers are located at a greater depth. A better exclusive and detailed research work should be carried on in this sealing topic especially in machine drilled deep boreholes, in collaboration with international expertise in well sealing works. Piped water supply in arsenic affected villages through sealed deep tube wells has a great sustainable vision in addressing Arsenic mitigation challenges in a very effective way.
- A lot of work has been found to be done in this sealing concept in American and European countries. Especially, code of ASTM and API works as a good reference for replicating or making further research study in South Asian arsenic affected belts. There is the need of appropriate drilling technology for reaching upto the deep lying aquifers in the boulder zone in the regions like Pratappur.
- Commercial purpose labs are not good for lab test in research works like this one. Out of the three labs visited, lab of DWSS seems to be better acquainted with updated technologies for lab testing. Rather than looking for NS Standard lab, it is better to appoint lab in the basis of ISO 170025 or “Quantification Number” or “tolerable limit of lab tests”.
- An extensive search for the promotion of manual rock drilling technologies appropriate in context of Nepal is a must. “Rota Sludge and Hammering Technique” which is a low cost manual both hard-rock and soft-soil drilling technology should be promoted.
- Further study should be done for determining electric logging of soil and study lithology and multi-aquifer zones for extracting uncontaminated groundwater for different household purposes.
- For the contamination of Iron and turbidity, aeration and filtration can be followed for the safe water needed for domestic purposes.
- Furthermore sample monitoring wells should be installed with proper sealing and it’s frequent monitoring studies should be done so as to judge it’s performance and efficiency.

7. PHOTOGRAPHS OF SEALING @ PRATAPPUR REGION



Fig: Grouting Stage(1.5” GI pipe being used as tremie pipe)



Fig: Water inside the borehole overflowing out due to grout displacement.



Fig: B:C:W grout being mixed in proportion prior to batching down.



Fig: Batching down of grout through tremie pipe



Fig: 3rd Step Sludging method being carried on for creating annular gap.



Fig: Labour working inside the ditch created by heavy erosion. See ponding inside due to inside seepage from nearby large ponding

REFERENCES:

1. Standard Operating Procedure Three Monitoring Well Design And Installation; U.S. Environmental Protection Agency Environmental Response Team; 2003
2. American Society for Testing and Materials, Philadelphia, PA., Volume 04.08
3. IOWA Administrative Code, Chapter 567-39, Requirements for Properly Plugging Abandoned Wells.
4. Investigating cross-contamination of aquifers : Paul M. Santi; John E. McCray; Jamie L. Martens; Environmental Expert; Hydrogeology Journal;2006
5. Remr Technical Note Cs-Mr-3.7,Crack Repair Method: Grouting (Portland-Cement And Chemical)
6. Grouting technology. US Army Corps of Engineers, Washington, DC, Jan 1984. Engineer Manual 1110-2-3506.
7. Chemical grouting. US Army Corps of Engineers, Washington, DC, May 1973. Engineer Manual 1110-2-3504.
8. Water Well Design and Construction, University of California, Division of Agriculture and Natural Resources, 2003
9. Borings, posts and power poles, revised oct. 98
10. Guidelines for Ground Source Heat Pump Wells, Department of Environment Protection, Massachusetts Department, 2009
11. Flexible grout composition and method; United States Patent; 4886550
10. Grouting Composition and Methods for Grouting Conduits in Well Bores; United States Patent;4948428
12. Plugging Abandoned Wells, Wyoming Department of Environmental Quality, Water Quality Division, June 1998
13. Drilling Operations; Chapter 3; EM 1110-1-4000, 1998
14. Assessment and Comparison of Grouting and Injection Methods in Geotechnical Engineering; European Journal of Scientific Research; ISSN 1450-216X Vol.27 No.2 (2009), pp.234-247
15. Smooth Grout 30; Product Bulletin; HDD Mining & Waterwell Group;2007
16. Quality Control Of Bentonite/Cement Grouts For Environmental Use; WEISS, William J., Geology & Geophysics, Texas A&M University,2005
17. Cement-Bentonite Grout Backfill for Borehole Instruments; P. Erik Mikkelsen; Geotechnical Instrumentation News, 2002
18. Groundwater Overexplotiation Pushes Arsenic into Deeper Aquifers;

- nature. Jan, 2011
19. BGS-MML (1998). British Geological Survey, Mott Macdonald Ltd.
 20. Bishta, S., Khadka, M., Kansakar, D., & Tuinhof, A. (2004). Study of Arsenic Contamination in Irrigation Tube wells in the Terai, Nepal.
 21. Clark, D., & Whitney, J.W. (2000). Options for Hydrogeological Investigations on Arsenic Occurrence in Groundwater in Nepal. A report to UNICEF Nepal/National Arsenic Steering Committee of Nepal/US Embassy, U.S. Geological Survey, Kathmandu.
 22. DWSS/UNICEF (2002) A study on health effects of arsenic contaminated drinking water in Nawalparasi district, Nepal. A report ENPHO, Kathmandu, Nepal.
 23. DWSS (2004). Department of Water Supply and Sewerage, Annual Report, Nepal.
 24. DPHE-BGS (2001). Arsenic contamination of groundwater in Bangladesh. Department of Public Health Engineering and British Geological Survey. BGS Technical Report wC100119 Volume 2, 3,4.
 25. ENPHO/DWSS (2003). Distribution of Three Gagri Arsenic Removal Filter in Nawalparasi. A Report Prepared for Water Supply & Sanitation Division Office (WSSDO), Nawalparasi.
 26. ENPHO/DWSS/UNICEF (2002). A Study on Health Effects of Arsenic Contaminated Drinking Water in Nawalparasi District, Nepal. Report prepared for Department of Water Supply & Sewerage / UNICEF by ENPHO, Kathmandu.
 27. ENPHO/NRCS/1 (2000). Research Report on Groundwater Arsenic Contamination in Terai, Nepal (Bara, Parsa, Rautahat, Nawalparasi, Rupandehi, Kapilvastu, Banke and Bardiya). A preliminary Investigation Report prepared for Nepal Red Cross Society/Japanese Red Cross Society.
 28. ENPHO/NRCS/2 (2001). Household Health Survey around arsenic contaminated tubewells in Nawalparasi district. A report prepared under Drinking Water Quality Improvement Program of Nepal Red Cross Society and Environment & Public Health Organization, Kathmandu.
 29. ENPHO/NRCS/3 (2003). Health Impact Study on Population Consuming Arsenic Contaminated Water from Nepal Red Cross Society installed tubewells - Nawalparasi, Bara, Parsa and Rautahat District. A report prepared under Drinking Water Quality Improvement Program of Nepal Red Cross Society and Environment & Public Health Organization, Ktm.
 30. ENPHO/NRCS/4 (2003). An Overview of Arsenic Contamination and its

- Mitigation in Nepal Red Cross Society Program Areas (Jhapa, Sarlahi, Saptari, Bara, Parsa, Rautahat, Nawalparasi, Rupandehi, Kapilvastu, Banke and Bardiya) Drinking Water Quality Improvement Program. Nepal Red Cross Society/Japanese Red Cross Society and ENPHO.
31. ENPHO/RWSSSP (2002). A Report on Health Survey in Nawalparasi District. RWSSSP - Project Area. Report prepared for Rural Water Supply and Sanitation Support Program (RWSSSP) and Nepal - Finland Cooperation Project by ENPHO, Kathmandu.
 32. ENPHO/RWSSSP (2003). A Comprehensive Report on Groundwater Arsenic Contamination - RWSSSP Program Area (Kapilvastu, Rupandehi and Nawalparasi District). A Report prepared for RWSSSP/Nepal - Finland Cooperation by ENPHO, Kathmandu.
 33. GWRDP-UNDP (1989). Shallow groundwater exploration in Terai, Nawalparasi District (west) GWRDP-UNDP technical report No. 5, 21p.
 34. GWRDP (2004). Ground Water Resource Development Project, Technical Report Nawalparasi District, Nepal.
 35. IHA (2002). International Hydropower Association, Country Report, Nepal.
 36. Khadka, M., Kansakar, D., Bishta, S., Regmi, S., Vaidya, M., Singh, T., et al. (2004). Study on Distribution of Arsenic in Groundwater in and around Parasi Bazaar, Nawalparasi District, Nepal.
 37. Kanskar, D.R. (2004). Geological and Geomorphological Characteristics of Arsenic Contaminated Groundwater Areas in Terai, Nepal.
 38. Maharjan, M., Shrestha B.R., Shrestha K.B., Raut (Khadka), R., Shrestha, R.R., Shrestha, S.D., et al (2005). Arsenic contamination in groundwater resources in Kathmandu Valley.
 39. NASC (2001). Nepal's Interim Arsenic Policy & Preparation Report. Report prepared for the Nepal National Arsenic Steering Committee by Ad-hoc committee working for a national policy on control and mitigation of arsenic in drinking water, Department of Water Supply and Sewerage, Nepal.
 40. NASC (2003). Summary of Known Arsenic Occurrence in GW in Nepal as of September 2003. Internal Report of the National Arsenic Steering Committee.
 41. NASC/UNICEF (2007). Mapping Arsenic Information into GIS and Publication of the Report - The State of Arsenic in Nepal 2005. A Report produced by the National Arsenic Steering Committee (Nepal) and GENESIS Consultancy (P) Ltd. with of Development Network (P)

- Ltd., National Development Research Institute and MULTI Software (P) Ltd. funded by UNICEF.
42. NBSM (2001). Nepal Bureau of Standards and Measurements, Kathmandu, Nepal.
 43. NBSM (2002). Nepal Bureau of Standards and Measurements, Kathmandu, Nepal.
 44. NRCS/ENPHO (2003). Health impact study on population consuming arsenic contaminated water from Nepal Red Cross Society installed tubewells, Nawalparasi District. A Report, ENPHO, Kathmandu, Nepal.
 45. Osti, G.R. (2005). Investigation of the Arsenic Contamination of Groundwater in Sunwal Village Development Committee (VDC) in Nawalparasi District of Nepal, M Sc thesis, University of Ghent, Belgium.
 46. Panthi, S.R. (2002). Guidelines for national drinking water standards and calcium carbonate scaling problems in Nepal, M Sc thesis, University of Ghent, Belgium.
 47. Shah, R., Thakur, P., Gurmaita, H., & Paudel, K. (2003). Studies for Possible Sources of Arsenic Poisoning of Groundwater in Terai Plain of Nepal. Final Report, MoPPW/DWSS/WHO-Nepal.
 48. Sharma, R. (1999). Research Study on possible contamination of groundwater with arsenic in Jhapa, Morang and Sunsari Districts of Eastern Terai of Nepal. Report from Department of Water Supply and Sewerage/WHO, Kathmandu.
 49. Tandukar, N. (2000). Arsenic Contamination in Groundwater in Rautahat district of Nepal - an Assesment and Treatment, M Sc thesis, Institute of Engineering, Pulchowk Campus, Nepal.
 50. Tandukar, N. (2001). Scenario of arsenic contamination in groundwater in Nepal.
 51. Yamamura, S. (2003). World health Organization, Drinking Water Guidelines and Standards.
 50. WHO, (2003). Guideline for drinking water quality, 3rd edition, Geneva.

ANNEX-I

Discharge of both wells=10-15 lps

1. Drill-Log Of Mini O/H Tank (Depth 85m) @ Gopigunj :

Source: Water Well Drilling, Water Supply Project-Semari; Asian Drilling Company, Maharajgunj, Ktm

S.No.	Positioning of Strata/Layer (in metre)		Soil Type
	From	To	
1	1	9	Gravel + Clay + Sand
2	9	21	Sand(fine)
3	21	37	Tiny boulders & Clay intermixed
4	37	40	Gravel + Fine sand
5	40	74	Boulder + Gravel [SLOTTED PIPE]
6	74	85	Gravel + Clay intermixed

2. Drill-Log Of Mini O/H Tank (Depth 150m) @ Naudiya

Source: Water Well Drilling, Water Supply Project- Naudiya; Asian Drilling Company, Maharajgunj, Ktm

S.No.	Positioning of Strata/Layer (in metre)		Depth of different strata (in metre)	Soil Type
	From	To		
1	0	1	1	Top Soil
2	1	4	3	Clay yellowish
3	4	14	10	Clay sandy with blackish
4	14	21	7	Course Sand
5	21	26	5	Yellowish Clay
6	26	30	4	Course sand
7	30	36	6	Fine gravels
8	36	50	14	Bolder Cutting [SLOTTED PIPE]
9	50	58	8	Clay Blackish
10	58	72	14	Clay Yellowish
11	72	78	6	Course Sand [SLOTTED PIPE]
12	78	86	8	Sandy clay
13	86	90	4	Fine Sand
14	90	98	8	Clay yellowish
15	98	104	6	Sand Clay
16	104	120	16	Sandy Clay
17	120	138	18	Clay Yellowish
18	138	144	6	Course Sand
19	144	150	6	Clay Backish