Action against arsenic

A project to introduce filters for families with an arsenic contaminated water supply in the Municipality of Telica, Department of León

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Background

In 2007, arsenic was first identified in boreholes in the communities of Unión España and Nuevo Amanecer in the north of the Municipality of Telica, Department of León. Between March and November 2010, in looking for a site to drill a new borehole to supply these communities, arsenic was discovered in many more wells at concentrations in excess of 10 ppb, the permissible limit set by the World Health Organisation and adopted in Nicaragua under the CAPRE standards. Concentrations of up to 900 ppb have so far been proven.

About arsenic

Arsenic is an important drinking-water contaminant. Drinking water rich in arsenic over a long period leads to arsenic poisoning, referred to as arsenicosis. This results in various health effects including skin problems (such as colour changes on the skin, and hard patches on the palms and soles of the feet), skin cancer, cancers of the bladder, kidney and lung, diseases of the blood vessels of the legs and feet, and possibly also diabetes, high blood pressure and reproductive disorders. Symptoms can start to appear over a period of 2-10 years. Arsenic is a ubiquitous element found in the atmosphere, soils, rocks, natural waters and organisms the world over. High arsenic concentration levels in water are principally restricted to groundwater, with some exceptions. It is mobilised in the environment through a combination of natural processes such as weathering reactions, biological activity and volcanic emissions as well as through anthropogenic activities.

Telica Arsenic Study

An initial investigation of arsenic pollution emerged from a hydrogeological study which was undertaken to find an alternative source of water for the communities of Unión España and Nuevo Amanecer in a geothermally active area to the north of Volcán Telica (Longley, 2010). From July to December 2011, an investigation which included a hydrogeological and hydrochemical study to determine the extent of the contamination and an epidemiological and dermatological study to identify adverse health impacts of past exposure was undertaken by Nuevas Esperanzas and a medical team led by Dr Alina Gómez and jointly financed by the World Health Organisation, Pantaleón and Grupo Pellas (two sugar companies with interests in the area), Students for 60,000 (a US voluntary organisation) and Nuevas Esperanzas. A summary of this study is given below.

Area of study

Following the preliminary investigation, the principal concern of this study was for various rural communities in the north of the Municipality of Telica including Unión España, Nuevo Amanecer, Bella Vista, El Ocotón and Los Cementos. The geographical area for the project was significantly larger than the area where the specific communities known to have been affected by arsenic are located (Map 1). From initial investigations it appeared that a 'contaminant plume' of arsenic was emanating from the geothermal field at San Jacinto – Tizate and flowing northwards and westwards through the shallow groundwater system into various tributaries of the Río Estero Real. At the margins of this contaminant plume, lower levels of arsenic were recorded and to the southwest an area unaffected by arsenic was encountered. On the basis of this preliminary information, the target area for the project was basically defined by the limits of this contaminant plume, most of which is located in the Municipality of Telica. Since there was also evidence of arsenic contamination in the neighbouring Municipality of Chinandega, it was decided that the hydrogeological investigation should not be limited to Telica but should also include parts of neighbouring municipalities. During the course of the study, however, arsenic was also found in this area away from the contaminant plume. This complication meant that it was not possible to determine the limit of the arsenic affected area to the north and east of the plume. In view of the lack of a clear boundary, a somewhat arbitrary limit was set in the east around the Valle Las Zapatas in the Municipality of Larreynaga. To the north, the limit was set in the area of the Río Galilao, even though arsenic has previously been detected as far north as Mina El Limón.

Objectives and expected outcomes

This project aimed to achieve the following:

Hydrogeological study

- Map the physical extent of high arsenic concentrations in groundwater in Territory No. 2 of the Municipality of Telica and the surrounding area.
- Map the variability of arsenic concentrations, in area and with depth, within the affected area.
- Assessment of the variability of arsenic concentrations over time (within the limitations of the project duration).
- Relate the presence of arsenic to other physico-chemical parameters (e.g. temperature, pH, conductivity, oxidation-reduction potential (ORP), chlorides, iron)
- Determine the most likely hydrogeochemical process(es) which have given rise to this problem.
- Identify alternative sources of water which may be arsenic-free.

Epidemiological/dermatological study

- Determine the number of people who have been exposed to high levels of arsenic and the extent to which they have been exposed over time.
- Make an early diagnosis of dermatological diseases associated with arsenicosis in residents of the communities of Unión España, Nuevo Amanecer, La Sirena and Bella Vista.
- Determine the prevalence of cutaneous pathologies related to the ingestion of arsenic in the target population.
- Raise awareness of the presence of arsenic in the affected area and train residents in how to identify symptoms potentially related to arsenicosis.

The expected outcomes of the project were:

- An understanding of the occurrence of arsenic in groundwater in the affected area.
- A register of people affected by arsenic classified according to severity.
- An evaluation of the health impact of this problem.
- A strategic plan for further diagnosis and treatment of those affected by arsenic poisoning.
- A greater awareness of the problem of arsenic pollution amongst residents of the affected areas.

Mapping of arsenic and other parameters

A total of 154 water sources were visited as part of this study and all were analysed in the field for arsenic as well as a range of other physical and chemical parameters. All water quality data collected as part of this study were imported into GIS software so that any combination of parameters could be plotted onto base maps. This data was supplemented with some additional data points from the 70 groundwater sources tested prior to the present study. This was especially useful in the areas not revisited. In addition, arsenic data from surface water sources was included. Map 2 shows the distribution of arsenic in four different classes of concentrations (consistent with the classification used in all other parts of this study) including both groundwater and surface water. The surface water data points should be interpreted somewhat differently from the groundwater points as they do not necessarily represent the concentration of arsenic in the aquifer at that point but rather the average arsenic concentration of the baseflow which reaches the river from the groundwater catchment to that point. Where springs were sampled at (or very close to) the source they are considered representative of groundwater, however, and are thus included in the groundwater database.

Conceptual interpretation of arsenic occurrence

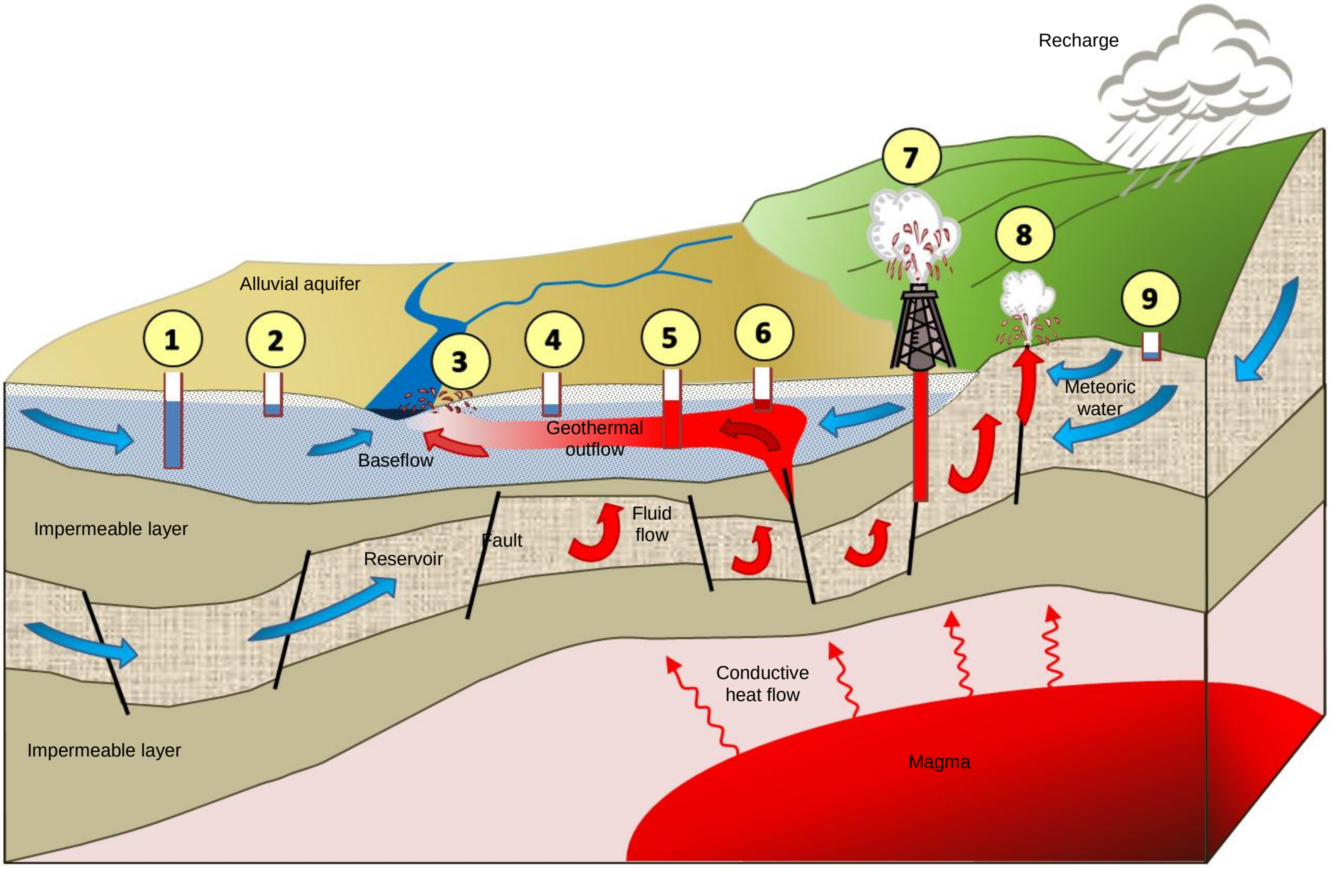
Arsenic occurrence in groundwater can be classified according the particular mechanism by which it is mobilised. Ravenscroft *et al* (2009) describe four chemical associations, each linked to a particular mobilisation mechanism. The four types are:

1. Near-neutral, strongly reducing water, rich in bicarbonate, iron and/or manganese. These waters are associated with the reductive-dissolution mobilisation mechanism and will be dominated by As(III).
2. Alkali-oxic waters with pH >8, containing dissolved oxygen and/or nitrate and sulphate. These waters are associated with the alkali-desorption mobilisation mechanism and will be dominated by As(V).
3. Acid-sulphate waters of pH 1-6 with high sulphate concentrations and often iron. These waters are associated with the sulphate-oxidation mobilisation mechanism and will also be dominated by As(V).
4. Geothermal waters, distinguished primarily by temperatures well above the background and usually a correlation of arsenic with chloride.

It was clear at the outset of this study that the mobilisation mechanism most strongly suspected of giving rise to the highest levels of arsenic in the study area was geothermal. The premise of the mapping of arsenic and other parameters was that an outflow from the geothermal field was mixing with shallow groundwater from the alluvial aquifer and flowing northwards and westwards towards the tributaries of the Río Estero Real. For the central part of the study area, this hypothesis is strongly supported by the data collected. Although arsenic was not detected in some wells which fall within the area influenced by the geothermal outflow, all of the highest values are found in this area. The fact that not all data points perfectly fit this model is to be expected since the geothermal outflow is mixing with shallower groundwater influenced by direct recharge and other hydrogeochemical processes. Since the geothermal fluids are being introduced to the shallow aquifer from below, it is not surprising that some shallow hand-dug wells which only penetrate one or two metres below the water table do not appear to intercept this water.

Whilst all the wells with >50ppb of arsenic also have temperatures in excess of 33°C, it is also clear that not all hot water contains high levels of arsenic. The hottest water encountered in the study area is found in the hot springs in El Ñajo at around 300 metres above sea level on the slopes of Volcán Telica. These springs are located very close to active fumaroles and the water temperature is above 55°C. However, these springs only contain traces of arsenic and have relatively low conductivities. At this elevation, however, this observation is not particularly surprising. Whilst they clearly belong to the geothermal system, they are located well above the regional water table. Most of the geothermal input into these springs comes from vapour and there is no direct contact with the geothermal brines. The shallow aquifer system on the plains below, however, is several hundred metres lower in elevation and direct contact with geothermal brines is more likely.

The following diagram illustrates the conceptual understanding of the geothermal system and the presence of geothermal arsenic in the shallow groundwater system. It also illustrates how some water can be hot without containing arsenic and how some wells which fall within the area of the geothermal outflow are also free from contamination.

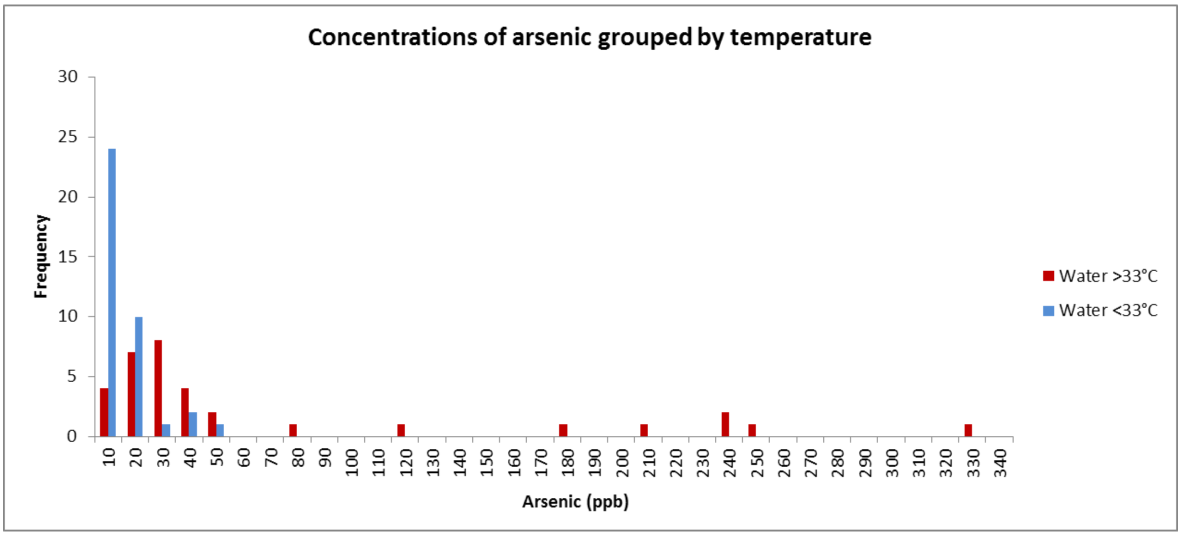


The water sources numbered 1-9 can each be explained as follows:

1. A drilled well in the alluvial aquifer away from the influence of the geothermal outflow and separated by the baseflow-fed river. Water temperature would be normal in this well and it would not be expected to contain geothermal arsenic.
2. A hand-dug well which penetrates only a few metres below the water table. This is also away from the influence of the geothermal outflow.
3. Hot springs which discharge water from the geothermal outflow into the river system. It is likely that these springs will have high levels of arsenic. The springs in Paso Picado fall into this category.
4. A shallow hand-dug well which tests negative for arsenic despite being surrounded by other wells containing arsenic. This is because it does not intercept any water which has mixed with the geothermal outflow. Some wells in Los Cementos appear to fall into this category.
5. A drilled well intercepts water which has mixed with the geothermal outflow. This well may have very hot water with high chloride and arsenic. The borehole in Unión España is such a well.
6. A shallow hand-dug well which intercepts the water influenced by the geothermal outflow. This may have high levels of arsenic, as is the case in El Ocotón.
7. A deep geothermal borehole penetrates the impermeable ‘cap rock’ and reaches the geothermal reservoir itself. The water from this well will be much hotter and more saline than any well in the alluvial aquifer. It may also contain extremely high levels of arsenic.
8. A hot spring associated with fumaroles on the side of the mountain such as is found in El Ñajo. Here, steam rising from the geothermal reservoir mixes with meteoric water giving rise to hot springs with low dissolved solids (and no significant arsenic).
9. Meteoric water in perched aquifers on the hillsides may be unaffected altogether by the geothermal system (e.g. the highest spring in Agua Fría).

Whilst the geothermal mechanism can explain much of the arsenic distribution in the centre of the study area, it appears that this is not the whole story. Arsenic was also found in the range 10-50 ppb in many wells in the east of the study area. The water from these wells has very different characteristics from those associated with the geothermal outflow. Apart from being cooler, the water in this area is more likely to be of bicarbonate type than chloride. It also corresponds with the area with some of the most reducing waters.

By separating the database of water sources according to temperature (using 33°C as the cut-off), the frequency distribution of arsenic concentrations for hot water can be compared with that of cold water as shown in the graph below:



This illustrates that all high levels of arsenic (>50 ppb) are from sources >33°C. It also shows that in the range 1-20 ppb, most of the sources were cold. Whilst this may simply reflect the relationship between temperature and arsenic concentration, it could also indicate that a different mobilisation mechanism has given rise to arsenic in the range 1-20 ppb in non-thermal waters. Combining this observation with the mapping of arsenic, temperature, alkalinity and ORP, it appears that arsenic in groundwater in the area of Los Patos may have resulted from the reductive-dissolution mobilisation mechanism.

Definition of hydrogeological zones

Since early attempts to correlate arsenic with other parameters based on the entire dataset from this study proved to be unsuccessful, it was decided to subdivide the study area into distinct hydrogeological zones according to which hydrogeochemical processes are thought to dominate. Four zones are proposed and are shown on Map 3. The rationale behind these zones is as follows:

Zone 1: Perched aquifers and fumarolic springs
This zone includes all the springs on the slopes of Volcán Telica, some of which are hot and others of which are cold. They are derived from meteoric water and vapour from fumaroles. These springs are generally at least 100 metres above the water table in the alluvial aquifer and are unconnected hydraulically. They generally have low conductivity and chlorides and arsenic is virtually absent. However they may have high sulphates, as is the case in El Ñajo where gas bubbles of hydrogen sulphide can be seen rising through the water column. To delimit this zone, the 200 metres contour was used as all wells which intercept the alluvial aquifer are located below this elevation and all meteoric springs are found above it.

Zone 2: Eastern section, upper reaches of the Río Estero Real catchment
This zone includes the parts of alluvial aquifer in the east of the study area which do not appear to be significantly affected by the geothermal outflow. The water in this zone appears to be mostly of bicarbonate type and may be strongly reducing. This zone has no eastern limit although Valle Las Zapatas was arbitrarily

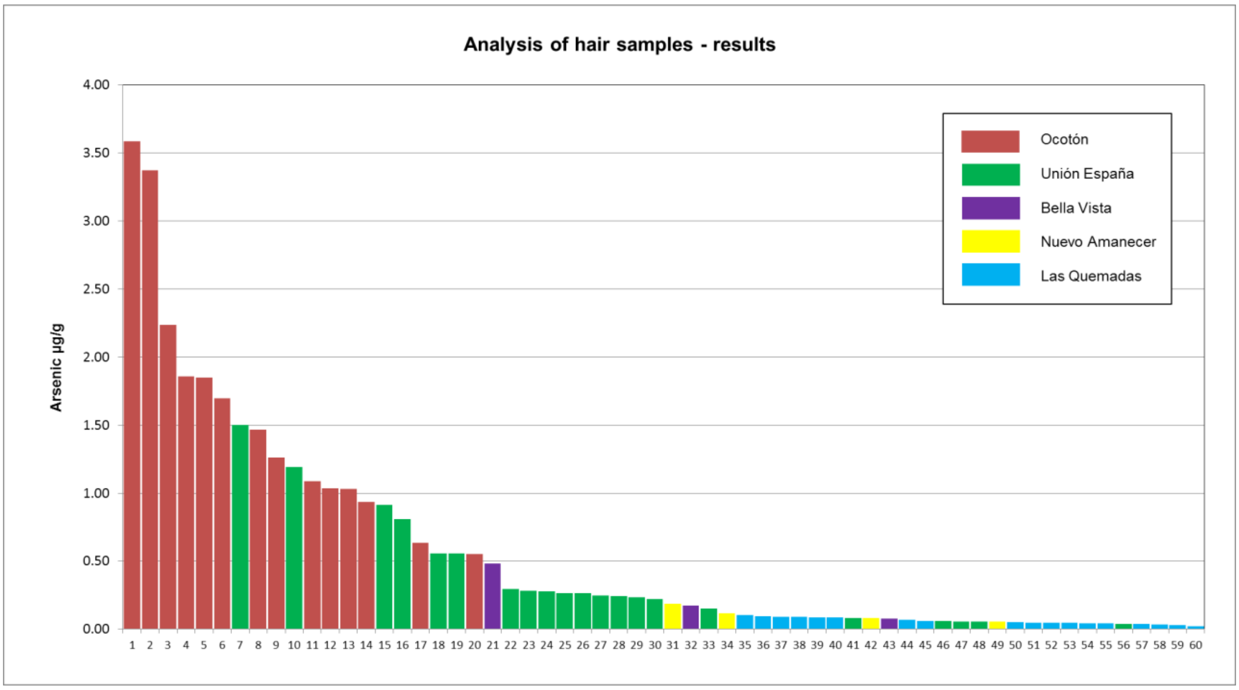
used as the boundary for the present study. The western edge of this zone is defined as the limit of influence of the geothermal outflow from San Jacinto – Tizate. To draw this line on the map the 'no flow boundary' created by the diorite intrusion was used in the south. This line was extended northwards in accordance with groundwater flow, as indicated by the new groundwater contours until this flow line reaches a tributary of the Río Galilao. Since this perennial river appears to be in hydraulic continuity with the aquifer, the river is used to define the northern section of the western boundary.

Zone 3: Volcán Telica geothermal outflow
This zone covers the centre of the study area and includes all of the communities of the greatest interest. It is dominated by hot water with high chlorides and has several water sources with arsenic >50ppb. The southern limit of this zone is defined by the 200 metre contour which separates this zone from Zone 1. The eastern boundary borders Zone 2 as described above. The western boundary was defined with the objective of separating the geothermal outflow from Volcán Telica from that associated with Volcán Casita. To do this, a groundwater flow line was used starting in the valley between the two volcanoes in the area of Las Marías. This somewhat tentative flow line was traced as far as the Río Olomega. From this point downstream, the river becomes the boundary.

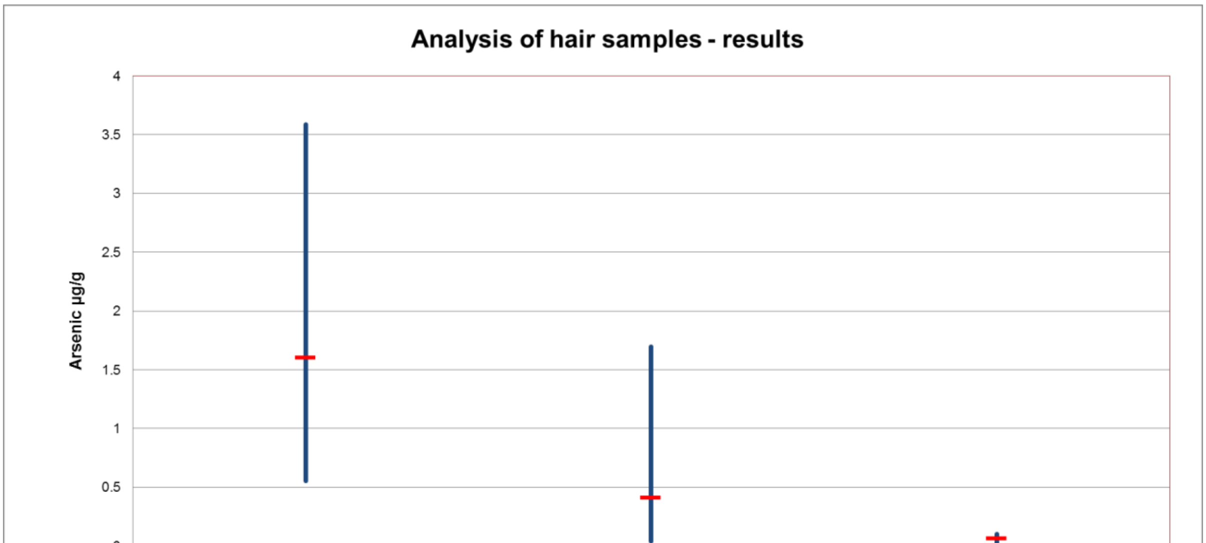
Zone 4: Volcán Casita geothermal outflow
This zone covers everything to the west of Zone 3 and below 200 metres in elevation. Despite having much in common with Zone 3, only one well was found to have arsenic >10ppb. It should be noted, however, that only the eastern part of this zone has been extensively sampled. A full investigation of the geothermal outflow from this system is recommended before any conclusions are drawn about the differences between these geothermal systems.

Biomarkers

An important link between the hydrogeological and health aspects of this study was the use of biomarkers. It is understood that this is the first time biomarkers have been used as part of an arsenic investigation in Nicaragua and thus this component was not without risk. It appeared from the literature, however, that biomarkers can provide an invaluable connection between water sampling and human impact. Biomarkers indicating exposure to arsenic such as hair, nail and urine samples can detect toxic levels of arsenic in such samples before skin lesions appear (Chowdhury *et al.* 2000). It has even been argued that the measurement of arsenic in urine is a better measure of exposure than analysis of drinking water (Concha *et al*., 2006). However, for the purposes of the present study it was decided that hair rather than urine would be the most useful. One of the reasons for this is that hair samples provide a longer term record of arsenic exposure than urine. In the case of at least two of the target communities included in the clinical work, the primary concern was past exposure to arsenic rather than present exposure. Most women in the study area have long hair which may represent up to five years of growth. The use of hair samples as biomarkers can allow historic exposure to be detected, even where the patient has stopped drinking arsenic contaminated water for two or more years. Of course the disadvantage of using hair is that it introduces a gender bias in the sampling methodology. Whilst some samples were taken from men with short hair, these samples obviously only reflected more recent exposure arsenic. In some cases it was not even possible to obtain enough hair from men for any kind of analysis at all. In total, 60 hair samples were taken from patients in five communities, 49 of which were from women and 11 of which were from men. The results of these analyses are shown below, ranked from highest to lowest in order of arsenic content and colour-coded according to community.



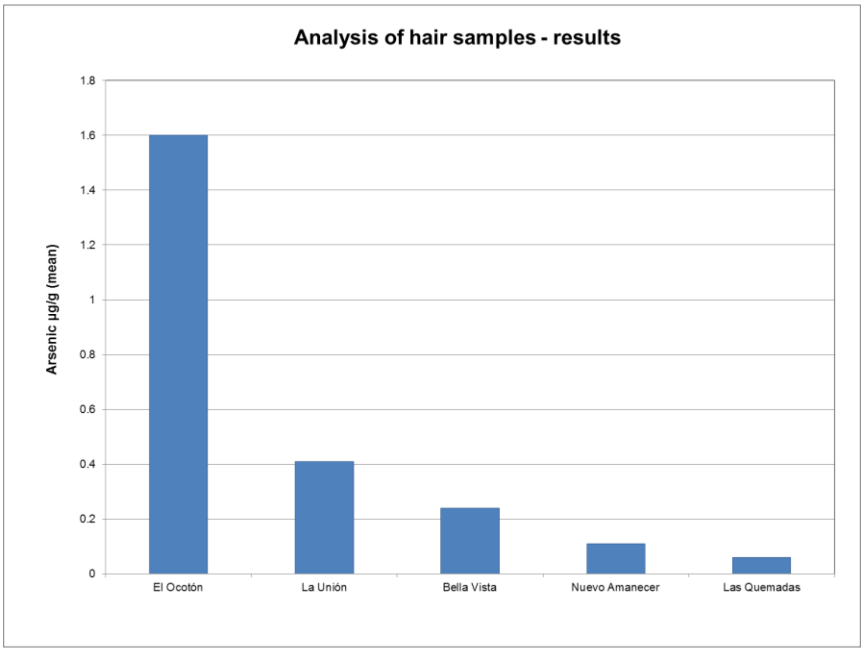
The results are immediately striking. Ocotón is a small community where exposure to high levels of arsenic (approximately 250 ppb) is ongoing. The highest six values were all recorded from this community and the seventh highest was from a 19 year-old woman who left Ocotón to live in Unión España six months before the sample was taken. Las Quemadas was used as an intentional control sample as no arsenic has ever been detected in the only water source ever used by this community. Between these two extremes, most of the samples are from Unión España where the highly contaminated borehole (73-900 ppb As) was put out of use 2 years and 3 months before the samples were taken. Whilst high levels of arsenic were recorded in hair from both women and men in Ocotón where ingestion of arsenic is ongoing, all of the samples from other communities which contained arsenic in excess of the range found in the control sample were from women with long hair. This demonstrates that the results obtained were consistent with total ingestion of arsenic over a period of several years. It is likely, therefore, that if the borehole in Unión España had not been put out of use in 2009, arsenic concentrations in hair samples would have been significantly higher. A comparison of the ranges of arsenic found in hair samples and the mean for each of these three communities is shown below:



	El Ocotón	La Unión	Las Quemadas
Maximum	3.586	1.695	0.102
Minimum	0.553	0.039	0.019
Average	1.6	0.41	0.06

From studies in West Bengal it is proposed that arsenic >0.8 µg/g in hair is considered evidence of recent exposure to arsenic (Guha Mazumder, 2003, cited in Ravenscroft *et al.*, 2009). However it is noted that the normal range is 0.08 - 0.250 µg/g. Whilst 16 of the 60 samples taken in the present study exceed the 0.8 µg/g threshold, 26 samples exceeded the 'normal range'. In this study the control sample showed a range of 0.019 – 0.102 µg/g. 34 samples exceeded this range.

Although very few samples were taken from the communities of Bella Vista and Nuevo Amanecer, the average arsenic concentration in hair samples by community is consistent with arsenic levels found in the sources of drinking water used over the last five years. Average arsenic concentrations in hair are plotted by community on Map 4 and are shown in the graph below:



In Bella Vista, two of the three samples were from women who currently consume water with arsenic in the range 10-50 ppb and one was from a man who currently consumes water with arsenic in the range 1-10 ppb (this sample had the lowest arsenic of the three from Bella Vista). In the case of Nuevo Amanecer, the water currently consumed is from the spring in Las Quemadas. From 2007 – 2009, the water consumed was from the borehole in Nuevo Amanecer (10-50 ppb). It is therefore not surprising that the average arsenic concentration in hair samples fell between those of Bella Vista and Las Quemadas.

The focus of this interpretation of the biomarkers has been to relate the occurrence of arsenic as determined in the hydrogeological investigation to human exposure. The dermatological/epidemiological study will report separately on the significance of the biomarker results in terms of health impact. However, it can be concluded that the results of these analyses are entirely consistent with the water quality studies coupled with the census information which related communities, families and, in some cases, individuals to specific water sources used for consumption over the last five years. This aspect of the study has clearly demonstrated the link between arsenic in the environment and consumption at toxic levels.

Arsenic risk assessment

This study has clearly demonstrated that naturally-occurring arsenic in groundwater in the north of the Municipality of Telica has given rise to a significant public health concern. Close to 1,000 people have been exposed to high levels of arsenic in their drinking water over a period of several years and biomarkers have proven cases of chronic arsenic intoxication. The information derived from this hydrogeological study must now be used to develop a strategy to deal with this problem based on clear risk assessment criteria. Crucial to this strategy is an understanding of the geographical distribution of arsenic which was a key objective of this study. It is important to identify areas of particular risk, not only to prevent more people being exposed to arsenic, but also to mitigate the health impacts for those who have already been exposed.

The maps produced as part of this study can be used to identify specific arsenic-contaminated water sources as well as broad geographical areas where there is a significant risk that potential sources may be affected. In the broadest possible terms, the area defined as 'Zone 3' on Map 3 should be considered the highest risk. Within this zone it is clear that there are some areas of lower risk, but care should be taken in considering an area 'safe' because of variations of arsenic concentration with depth and over time, as illustrated by the historical measurements of arsenic in the boreholes in Unión España and Nuevo Amanecer. A more comprehensive and user-friendly risk map which allows government institutions, NGOs and other stakeholders to make informed decisions will be developed using the data collected as part of this study after a more thorough consultation process.

Whilst it is clear that arsenic-free sources of water exist within the areas of higher risk, in most cases these are shallow hand-dug wells. In considering risk it is important to look beyond arsenic concentrations and, in particular, take note of the poor bacteriological quality of water associated with shallow hand-dug wells. If the only way to access arsenic-free water in the high risk area is from shallow wells which draw water only from the first few metres below the water table, then it is likely that one type of risk will be replaced with another. This is thus an 'indirect risk' of the presence of arsenic. For this reason it is recommended that all groundwater within the area of the geothermal outflow from Volcán Telica is considered to be high risk. Any intervention or strategy to address the arsenic problem which involved the use of shallow wells must give careful consideration to all aspects of water quality and appropriate safeguards must be put in place to ensure that water is safe to drink in every respect.

Conclusions of the Telica Arsenic Study

In summary, this hydrogeological study concluded that the primary mobilisation mechanism for arsenic in the north of the Municipality of Telica is geothermal. Hot fluids appear to be outflowing towards the north from the geothermal field associated with Volcán Telica and mixing with the shallow alluvial aquifer. These fluids are dominated by Na-Cl and have very high concentrations of arsenic. On mixing with shallow groundwater, these concentrations are reduced somewhat and the resulting contamination of wells in the alluvial aquifer is thus locally variable. Some shallow groundwater appears to be unaffected, whilst other sources are highly contaminated. Unfortunately around 1,000 people have been exposed to some of the most highly contaminated sources for many years and some are continuing to drink from these sources. Those who have consumed water from these sources during the last five years show evidence of chronic arsenic intoxication in hair samples.

Away from the geothermal outflow from Volcán Telica, a second mobilisation mechanism, reductive dissolution, may be responsible for arsenic contamination of the alluvial aquifer in the range 10-50 ppb. These waters are strongly reducing and are bicarbonate rich. The arsenic in this area is more dispersed and affects specific wells rather than whole communities. No biomarkers are available for the communities affected by this source of arsenic and the health effects of this lower level contamination have not yet been investigated. The existence of this second mechanism means that no eastern or northern limit of arsenic contamination has yet been defined.

Proposal for filter project

This filter project is to run in conjunction with the Telica Arsenic Study as a pilot project providing water filters for families currently drinking arsenic contaminated water. The filters are expected to bring the arsenic levels to within the 10ppb standard set by the WHO. The project is intended both as an immediate solution to some of the worst affected cases of arsenic contamination and as a trial of an appropriate technology which could be applied more widely across the region.

Objectives and expected outcomes

This project aims to achieve the following:

- Provide an immediate solution for 23 families (~115 people) who currently consume arsenic > 30 ppb.
- Assess the effectiveness of the Kanchan filter and the Aqua Clara filter at removing arsenic at the levels found within the study area.
- Field test 25 filters, monitoring their use with a view to expanding the programme in the future (considering all aspects of water quality, not just arsenic, and taking account of user feedback on issues such as taste and ease of operation).
- Assess the need for separate treatment for pathogens.

Selection of participants for the filter trial

From the conclusions of the Telica Arsenic Study, two categories of communities were prioritised for intervention to reduce exposure to arsenic:

- Communities exposed to arsenic >50 ppb where no alternative arsenic-free sources exist.
- Communities exposed to arsenic in the range 10-50 ppb where the nearest arsenic-free source is more than 100 m away.

Fortunately the number of people still exposed to arsenic >50 ppb is very small. In Ocotón two families depend on a well with 250 ppb of arsenic and of all those affected by this problem they are considered the highest priority. Both families will be included in the filter trial (subject to their agreement). Also within this category is Aguas Calientes. This is part of a much larger property and those that are exposed to high levels of arsenic are workers who drink from a well on the property containing 175 ppb As. It is thought that around 100 workers drink this water at times and it is also the main source of water used for food preparation. Two filters will be installed for these workers. In both Ocotón and Aguas Calientes, the arsenic-contaminated water sources are both hand-dug wells. Although no bacteriological testing has been done in Aguas Calientes, in Ocotón the water was found to have around 2,000 *E. coli*/100 ml, making this source ‘very high risk’, for both faecal and arsenic contamination. It will be important in both these communities to introduce filter technologies which address both arsenic and pathogenic contamination and to assess their effectiveness at removing both types of contaminant.

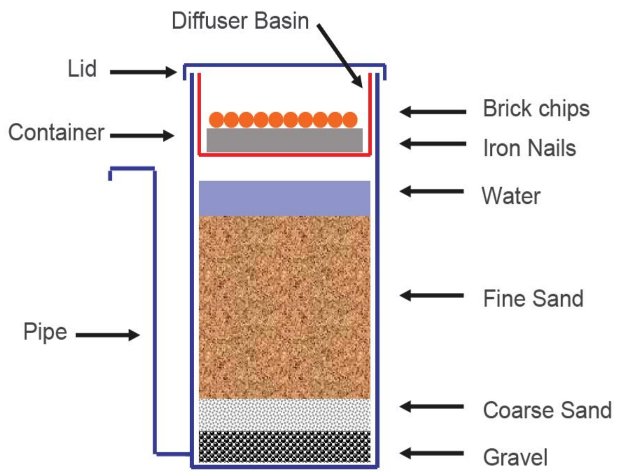
In the second category are the communities of Unión España, Nuevo Amanecer and Bella Vista. In the case of the first two communities, most people currently consume water from the arsenic-free spring in Las Quemadas. However, the first phase of the new water system for this community should be operational in January. The aim of this phase is to provide water for washing and bathing to reduce the burden on carrying water from the spring. The source of this water is the borehole in Nuevo Amanecer which contains around 40 ppb of arsenic. Work on the distribution system for this water is nearing completion and it is expected that after more than two years without mains water, these communities will once again have a piped supply in January 2012. This is only the first stage of the water project for these communities which should eventually see a second source from a spring piped to public collection points. This second source is arsenic-free and would be used for drinking and cooking only (the source does not yield enough to meet all water needs of the communities). The second stage of the project has not yet been funded, however, and it is therefore of some concern that the communities will have piped water which contains arsenic in the meantime and will use this for drinking even though it is being made clear that they should continue to collect the arsenic-free water from the spring for consumption. Since it is not known if and when the second stage of this project will be completed, it has been decided, in consultation with the Mayor's office, that a 'belt and braces' approach is advisable.

Around twelve households from these communities will be included in the pilot scheme with a view to introducing filters for all families in the event that the second phase is delayed or that the filters seem a better option. The participants from Unión España and Nuevo Amanecer will include those who showed levels of arsenic above the background in the analysis of hair samples as well as those who show some clinical manifestations of arsenicosis. One of the most urgent needs for those already affected is to reduce their ongoing exposure to arsenic. Twelve patients in these communities showed symptoms of hyperpigmentation, hyperkeratosis or cutaneous tumours and all will be given the opportunity to participate in the filter trial. The final number included from Unión España and Nuevo Amanecer may vary according to the willingness of individual households to participate in the trial.

Most families in the community of Bella Vista have their own well. Arsenic is present in most wells at concentrations of up to 39 ppb. Nine households currently use wells with arsenic in the range 30-39 ppb and all these will be offered the opportunity to participate in the pilot project. Although there are alternatives, some families would have to walk several hundred metres to collect water from an arsenic-free source rather than use their own well and it is considered unlikely that they would do this in practice, even though they know in theory which wells are safer. As with Ocotón and Aguas Calientes, wells are hand-dug and are likely to be of poor bacteriological quality. The treatment solutions introduced must remove arsenic and improve bacteriological quality.

The community of Los Cementos will not be included in the filter pilot project. Although arsenic is present in wells in this community at concentrations of up to 170 ppb, no house is more than 100 metres from an arsenic-free source. In the case of this community, it is considered that awareness raising and continued surveillance of the wells may be a more cost effective way of reducing exposure to arsenic than the introduction of treatment technologies. Although this study has identified other households exposed to arsenic in the range 10-50 ppb in the area affected by the reductive-dissolution mobilisation mechanism, these have not been included in the filter project because arsenic levels are generally lower and because this area has not yet been studied in as much detail as the area affected by geothermal arsenic.

Methodology



The main filter to be used for this project is based on the Kanchan Arsenic Filter which was developed in Nepal. It combines slow sand filtration with adsorption on iron oxyhydroxides in a large plastic bucket. A perforated pipe, with a tap at the end, is set in a layer of gravel and covered with coarse sand and then fine sand. Above this, a perforated plastic tray (diffuser basin), containing brick chips and 5 kg of iron nails, is suspended from the top of the bucket. Water poured into the tray causes rusting of the nails, and the fresh rust adsorbs arsenic. The fine sand below filters the iron particles. The filter removes 85-95% of arsenic in waters containing tens to hundreds of ppb As, and can produce 15-20 litres of water per hour.

A trial filter has been built by Nuevas Esperanzas using components purchased locally in León and tested using water from the hand-dug well in Ocotón which has 250 ppb of arsenic as well as 2,000 *E. coli*/100 ml. The Kanchan filter was found to be very effective at removing arsenic (>98% reduction), bringing the highly contaminated water from Ocotón to within the WHO/CAPRE standard in all three samples analysed. However, the Kanchan filter did not improve the bacteriological quality at all with the effluent water containing extremely high coliform counts. Where bacteriological contamination is present, the Kanchan filter will therefore be used in conjunction with a ceramic filter to remove bacteria or treatment with chlorine. A second type of filter will also be trialled alongside the Kanchan filter. Five filters will be provided by Aqua Clara. These are also based on the biosand technology but use a titanium medium to adsorb arsenic.

Around 25 filters will be installed in the communities of Ocotón, Aguas Calientes, Unión España, Nuevo Amanecer and Bella Vista and residents will be asked to use the filter for three months. Training will be given and a social worker will accompany the technical staff on initial visits to provide support and advice as necessary. Samples of influent and effluent water will be taken every month for physico-chemical and bacteriological analysis as well as analysis for arsenic. The effectiveness of the Kanchan filter in combination with a ceramic filter (Filtron) and with chlorination will also be tested. It is proposed that the filters tested be located as follows:

Ocotón

- 1 Kanchan filter will be tested, to be used in conjunction with the Filtron ceramic filter.
- 1 Aqua Clara arsenic filter will be tested.

Aguas Calientes

- 1 Kanchan filter will be tested, to be used in conjunction with the Filtron ceramic filter.
- 1 Kanchan filter will be tested, to be used in conjunction with chlorination (tablets).

La Unión & Nuevo Amanecer

- 9 Kanchan filters will be tested with no subsequent treatment for pathogens.
- 3 Aqua Clara arsenic filters will be tested

Bella Vista

- 4 Kanchan filters will be tested to be used in conjunction with the Filtron ceramic filter.
- 4 Kanchan filters will be tested to be used in conjunction with chlorination (tablets).
- 1 Aqua Clara arsenic filter will be tested

It should be noted that the above is subject to modification according to the willingness of families to participate in the trial. The monthly testing will include the following parameters for the influent and effluent water:

Parameter	*Method*
Arsenic, ppb	Digital Arsenator
E. coli/100 ml	Oxfam-DelAgua kit
Turbidity, NTU	Wagtech turbidity meter
pH	Hanna multiparameter meter
Conductivity, µS/cm	Hanna multiparameter meter
Free chlorine, mg/l	Photometer (where water has been chlorinated)

For every ten samples analysed in the field for arsenic, one will be sent to a laboratory (CIRA-UNAN) for analysis using hydride generation atomic absorption spectrometry (HG-ASS). Additional parameters may also be tested in the course of the pilot project according to the professional judgement of the principal investigator.

Duration

The project will be undertaken over a period of six months, but ongoing support after project completion will be provided as part of the wider programme in the area. Work will begin in January 2012 with the construction of the Kanchan filters and preliminary visits to potential participants. The field trials are expected to begin in February and end in May with final analysis complete by the end of June 2012.

Budget

The total budget for this project is £6,007 of which **£3,488** is requested from the Oxford-León Association and Trust. The budget is made up as follows:

All costs are in GBP

	units	*number*	*unit cost*	*cost*
Project budget				
Staff time				
Principal Investigator (Dr Andrew Longley)*	man days	18	96.42	1,735.56
Technical assistant	man days	14	54.62	764.68
Community coordinator	man days	10	32.44	324.40
Field assistant	man days	14	26.70	373.80
Technician (construction of filters)	man days	10	21.63	216.30
Staff expenses				
Subsistence	man days	48	1.90	91.20
Laboratory samples				
Arsenic analysis by HG-AAS (CIRA-UNAN)	sample	15	27.59	413.85
Materials				
Materials for Kanchan filters	filter	20	28.00	560.00
Filtron ceramic filters	filter	6	16.00	96.00
Transport				
Use of 4x4 vehicle	km	2,400	0.27	648.00
Indirect project costs*	@15%			783.57
TOTAL				**£ 6,007.36**
* funded by Nuevas Esperanzas				
Funding required				**£ 3,488.23**

Note that Aqua Clara have agreed to provide five of their filters without cost.

About Nuevas Esperanzas

Nuevas Esperanzas is a UK-registered charity (No. 1116109) and an international NGO registered with the Government of Nicaragua (No. 3537). Nuevas Esperanzas is a professional organisation serving poor communities in Nicaragua through projects which provide practical and technical assistance in support of long-term sustainable development. Nuevas Esperanzas is based in León and has worked in many parts of Nicaragua including León, Chinandega, Estelí, Matagalpa, Granada and the North Atlantic Autonomous Region (RAAN). The organisation has had a continuous presence in the Municipality of Telica since 2004 and has developed a close working relationship with community leaders, the Mayor's office and the Ministry of the Environment and Natural Resources (MARENA). Nuevas Esperanzas has 13 permanent staff covering technical disciplines including civil engineering, agroecology and social science, and supporting functions such as logistics, administration and accounting. The organisation has a small office in León, two 4x4 vehicles and a wide range of technical equipment for surveying and the physico-chemical and bacteriological analysis of water in the field.

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