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Analysis of the water resources in the rural village of Andavadoaka, S.W. Madagascar, with the objective of designing a sanitation programme using biogas technology

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Summary

The lack of improved water sources and adequate sanitation is a global problem. Lack of resources has resulted in 2.2 million fatalities every year due to diseases associated with these environmental conditions.

Madagascar has very limited improved water sources (14% rural, 66% urban) and sanitation coverage (7.5% rural, 27% urban) (WaterAid 2006).

The rural village of Andavadoaka (population 1,200), southwest Madagascar, has improved water sources, but no sanitation facilities. The aim of this study is to investigate the quality of the village's water supplies to enable the identification of contamination sources, and from this develop a potential sanitation plan using biogas technology.

All available drinking and bathing water sources were sampled in and around the village. These samples were tested for their microbial and chemical content, specifically designed to indicate the level of faecal contamination. In addition, geological, hydrological, and climatic data were collected on site, as well as the recording of social attitudes.

Microbial and chemical analysis of water samples showed that the Vezo people's 'free defecation' behaviour and unrestricted animal transport had caused gross contamination of many of their water sources.

The pathogenic strain *Esherichia coli* O157:H7 was consistently isolated in several sites, including the most heavily used wells, highlighting the disease potential of this contamination. Elevated ammonia and nitrate levels as well as the presence of hydrogen sulphide in several sample sites indicated that one of the major sources of contamination was human sanitary waste. The outbreak of cholera in 2000 that made 25 people ill and caused 2 fatalities in the village confirms that contamination has already caused serious health effects.

Water depth measurements indicated the area around Andavadoaka suffered significantly from drought and that what little water provisions were available need to be protected.

A sanitation programme could be successful in Andavadoaka if implemented properly. The Vezo would need to be educated in the benefits of a biogas sanitation plan to create sustainable resources from human and animal waste, as well as improved health and hygiene as a result of effective sanitation.

The amount of feed (human/animal waste) available in the area could run two biogas digesters within the village. The Northern plant could potentially produce on average 6.3m^3/day of methane - enough to run a refrigeration system that could improve the storage capabilities of the fishermen's catches, allowing them to sell a fresher product at a greater price. The Eastern plant could potentially produce around 15m^3/day - enough to run a small irrigation system in the dry season and support a small 'cottage industry' in the wet season.

If this type of sanitation plan was to be introduced, it could bring significant resource development for the village of Andavadoaka.

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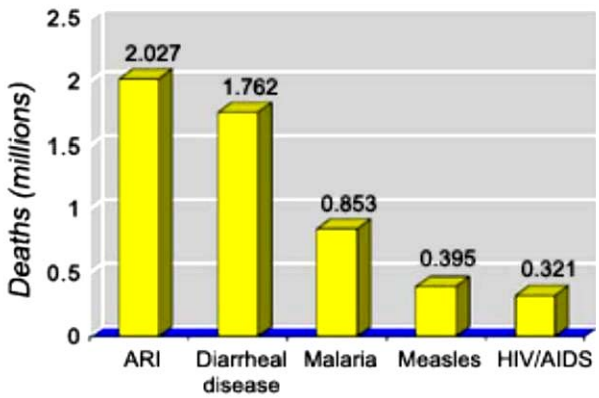
1.0 Introduction

1.1 Global Overview

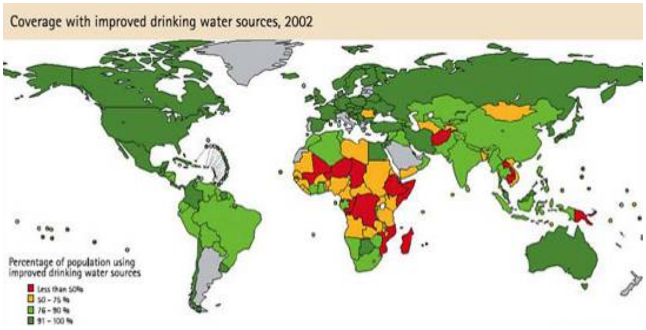
Every year around 4 million people suffer and 2.2 million people die from diseases associated with inadequate water supply, sanitation and hygiene (Andersson 2005). Children are typically at risk and it has been estimated that 1 in 10 children under the age of 5 in the developing world, die, with diarrhoeal diseases being one of the main causes. The World Health Organisation (WHO) recognised that 2.6 billion people are without adequate means of excreta disposal (approaching 70% of the developing world) and 1.6 billion without access to safe drinking water (IRC 2005). These figures are set to double by 2015, due to population growth mainly in Africa and Asia (WHO & UNICEF 2000). Diarrhoeal diseases have been shown for some age groups, e.g. children under five, to be a bigger killer than HIV and Malaria put together (Figure 1). This prevalence is down to the fact that many homes and communities in the developing world do not have access to sanitation facilities causing a major problem with sewage entering their water supplies, subsequently resulting in serious contamination of their water resources. The provision of safe drinking and bathing water is an essential step in reducing these preventable illnesses

Figure 1. The extent diarrhoeal diseases have to play in child mortality, 2005. (WHO, 2005)



Water supplies can easily become contaminated by human and animal excreta, as many practice 'open-field' defecation. Custom may dictate these practices, as there are many misconceptions of what is classed as unhygienic. Many of these traditional sanitation practices are uncontrolled and can pose serious health risks. Improved sanitation aims to contain and safely dispose of human excreta (Davis *et al.* 1993). Figure 2 shows the widely distributed severity of the problem.

Figure 2. Global coverage of improved drinking water sources, 2004. Countries coloured red are suffering with only 50% coverage. (OMS 2004)



1.2 Sanitation services in Madagascar

Madagascar is the fourth largest island in the world and lies off the southeast coast of Africa. It is one of the poorest countries in the world, with 70% of the population below the poverty line (Wateraid 2006). The people are dependant on subsistence farming and fishing for an income. The majority of the population live in rural areas, and many of these rural villages do not have access to safe drinking water or sanitation facilities. Figures show that at present, only 14% of the rural population have access to safe water supplies and 66% of the urban population (an obvious division can be seen). Sanitation facilities are only available to 7.5% of the rural and 27% of the urban population, showing an even more desperate and dangerous reality (Wateraid 2006).

Madagascar has a population of around 17 million, with 72% living in the rural area. A major concern within this country is that 71% of the Malagasy people have no access to safe drinking water and about 87% do not have adequate sanitation services (African Development Fund 2005). This low coverage has severe consequences for health, inevitably affecting education and economic growth. The World Bank Human Development Index for 2001 indicates that 70% of endemic diseases in Madagascar can be attributed to drinking unsafe water and lack of hygiene, with 6 million working days being lost annually.

1.3 Sanitation in the village of Andavadoaka

Andavadoaka is a small, coastal fishing village located in southwest Madagascar, with a population of 1,200, the majority of which are "Vezo". It lies approximately 150 km north of the regional capital of Toliara and 50 km south of Morombe (Figure 3).

Figure 3. Aerial photograph of Andavadoaka village, looking north

Since 2003, Blue Ventures Conservation has been developing research and conservation initiatives in the village, with the aim of conserving local marine and coastal ecosystems, developing more sustainable fisheries, and addressing barriers to resource management in the area. Critical to this work, is the socio-economic research that is helping to understand the Vezo people's way of life in this remote coastal region.

A census in 2004-5 revealed that 70% of the 1,200 people that live in Andavadoaka rely on fishing to make a living (Langley *et al.* 2006). The census also revealed the extent of infrastructure within the village, with no paved roads, electricity or telephone communications. The village's water supply comes from a shallow aquifer, which becomes salty towards the end of the dry season, in addition to five wells located in and around the village, one of which has a pump installed by the Toliara development agency. The village has no solid waste management system. Currently domestic animals, including pigs, goats and zebu (cattle), eat most organic waste, and other waste is burnt on the outskirts of the village. The medical clinic uses a burn pit for disposal of its used materials. However this is not lined and contains hazardous medical waste.

There is no sewage system and there are only a few septic pits, none of which are maintained or emptied. Most villagers use the beach or scrub forest for personal waste.

1.4 Aims of the Andavadoaka sanitation project

Analysing the quality of the water in and around the village (used for drinking and bathing), will determine weather the Vezo community's sanitation behaviour is consequently polluting their water sources, causing sewage contamination and the spread of potentially infectious disease.

The water samples (collected from an array of sites) will be analysed for their microbiological activity. This will include testing for: *Enterobacteriaceae*, *E.coli* (including analysis for the pathogenic O157:H7 strain), *Salmonella* (including analysis for different, potentially pathogenic strains) and *Staphylococcus aureus*. The samples will also go through chemical analysis for their nitrate and ammonia content, pH, and salinity levels.

Testing for pathogenic strains is extremely valuable in the investigation of possible water-borne disease outbreaks. It is hoped that this analysis will help paint a realistic picture of how the severe lack of sanitation and sanitation education in Andavadoaka is potentially affecting the health of the Vezo people.

In order to resolve the potential health risk, a sanitation plan needs to be designed specifically for the village. To understand the Vezo community's attitude towards sanitation, behaviours, and the potential for a programme (materials and skills available etc), a social survey will be conducted. A small amount of hydrogeological data will be collected; this will help determine ground water height, so as to implement the most suitable sanitation facility.

2.0 Materials and Methods

2.1 Materials

To test the microbial and chemical content of the water samples specific equipment was required:

- 25ml sterile collection containers
- 50ml sterile syringes
- Cool bag for transport, fridge for storage
- 275ml sterile pots
- 52ml sterile flip top pots
- Plastic sterile Petri dishes
- Sterile 10µl loops
- Sterile gloves
- High accuracy scales
- Magnetic stirrer hotplate
- Autoclave (121.5°C)
- Incubator (36°C)
- Incubator (41.5°C) with shaker
- Category 2 fume hood
- Water bath (45°C)
- Enrichment broths: Buffer peptone water, Rappaport-Vassiliadis broth, Muller Kaufmann tetrathionate novobiocin broth, Modified triptone soya broth with VCC.
- Agars: Xylose Lysine Desoxycholate (XLD), Brilliant Green Agar (BGA), Cefixime-Tellurite Sorbitol-macConkey agar (CT SMAC), Violet Red Bile Glucose Agar (VRBGA), and Baird-Parker Medium.
- Latex test for *E.coli* O157:H7 strain and salmonella.

2.2 Water Sampling

For preliminary tests water samples were collected from 3 different sites, the 2nd set included 6 sites and the 3rd and 4th sets included 10 sites. These 10 sites encompassed all water sources that were accessible in the area (Figure 4). 100ml of water was collected from each site using sterile syringes and placed in 4x 25ml sterile screw top pots. They were transported back to the UK and stored in the fridge.

Microbial parameters- The 'index' organisms being tested for are: *E. coli* (including latex test for O157:H7 pathogenic strain) (CDC, 2006), *Salmonella, Staphylococcus aureus* and *Enterobacteriaceae* (thermophilic 'feacal' coliforms), which will test for any sewage contamination of the water.

2.3 Microbiological testing

2.3.1 Enterobacteriaceae

To make Violet Red Bile Glucose Agar (VRBGA), 800ml of distilled water was mixed with 31.8g and placed on the magnetic stirrer hotplate. The mixture was heated gently until just boiled and then cooled to 45°C in a water bath. The preliminary tests included a diluted sample (in case of high bacterial numbers), 2 normal concentration samples for each site, and a control.

1ml of sample was placed into a petri dish with a pipette before covering with a layer of agar. This was mixed by swilling each dish each dish around 7 times clockwise and 7 times anticlockwise before leaving to solidify. Once solidified, a second layer was poured on top in order to create an anaerobic environment for the bacteria to grow in, before incubation at 37°C for 24 hours.

The analysis of the plates included colony counts on the agar, but did not extend to identifying specific species of bacteria.

2.3.2 E. coli + the specific isolation of the O157:H7 strain

25g of the Cefixime-Tellurite Sorbitol-macConkey agar (CT-SMAC) powder was added to 250ml of distilled water, autoclaved and then cooled to 45°C (if <40°C the agar will solidify and if >50°C the antibiotics will be inactivated). Once at 45°C, 2 different antibiotics (CT) were added. The mixture was gently shaken and poured into Petri dishes (250ml made approximately 13 plates).

It was a requirement for the samples to be enriched before application onto the plates, thus 5ml of water from each sample site was added to 15ml of modified triptone soya broth in sterile containers. They were then incubated in an incubation shaker at 36°C for 6 hours at 150 rpm. After the incubation 10 µl was applied to the plates using sterile loops and again replicated 3 times. A plate with no inoculation was also used as a negative control. The plates were then incubated at 37°C for 18-24 hours.

After the incubation process the plates were analysed in a category 2 fume hood, as they may have contained potentially pathogenic bacteria, for the

Figure 4. Satellite image of Andavadoaka village and the sites sampled

presence of *E. coli*. If any clear-creamy colonies appeared (Figure 9) a latex test (OXOIDE) was preformed to identify whether the colony was the O157:H7.

To perform the latex test a drop of agglutinating latex was applied to a mixing plate with a drop of sterile distilled water, the potential colony was removed from the plate using a sterile loop and mixed into the two drops joining the fluids. If the fluid started to coagulate then it was a positive identification for the O157:H7 strain. This occurs because antigens on the surface of the latex modules bind to the O157:H7 cells.

2.3.3 *Salmonella* (preliminary only)

To 25ml of the water from each sample site, 225ml of sterile Buffered peptone water was added for enrichment. This mixture was then incubated at 36°C for 18 hours. After the incubation period, 100µl of enriched sample was placed into a container with 10ml Rappaport-Vassiliadas (RV), and 1ml of enriched sample into another container filled with 10ml Muller Kaufmann tetrathionate novobiocin broth (MKTTN). These were then incubated at 41.5°C and 36°C respectively, for 24 hours.

After this second incubation, these selectively enriched samples were sub-cultured onto a solid media Xylose Lysine Desoxycholate (XLD) and Brilliant Green Agar (BGA), which contain selective agents and pH indicators. The samples were applied to the agars using a sterile 10µl application loop, RV on the left of the plate and MKTTN on the right. This was again replicated three times and a negative control used, totalling 19 plates. These 19 plates were incubated for a third time at 36°C for 24 hours.

The samples were analysed in sterile safe conditions using a category 2 fume hood. Potential *Salmonella* positives on XLD agar showed as red colonies with a black centre (Figure 10). On the BGA the colonies would have appeared pink/red. If colonies were identified, then a select few were removed and transferred to a nutrient agar and incubated at 36°C for 24 hours. The aim of this was to purify the sample and remove all traces of the negative medium, in order that agglutinating latex could be reliably used (method the same as *E.coli* latex test mentioned previously).

Salmonella testing was not carried on as preliminary testing showed that it was not present. A positive reading was initially read for one sample, but further investigation found that it was not *Salmonella*.

2.3.4 *Staphylococcus aureus* (preliminary only)

31.5g of Baird-Parker agar was added to 500ml of distilled water before autoclaving at 121.5°C to sterilize. Once cooled this was poured into sterile Petri dishes and left to solidify. Then 500µl of the sample was pippetted on to the agar and spread over the surface using a sterile loop. For each site this was repeated three times with a negative control, all at normal dilution. The plates were incubated at 36°C for 48°C hours. If *S. aureus* was found it would have appeared as round, black colonies, possibly surrounded by a precipitated halo of lighter agar (Figure 11).

S. aureus was only used in preliminary tests as there was no true presence in any sample. The positive reading for one sample was due to contamination of the plates, as the colonies were growing on the plate rim.

2.4 Physical and Chemical analysis

2.4.1 Nitrates/ Ammonia

To test for nitrate and ammonia levels a Skalar flow analyser was used. Standards were made to calibrate the Skalar:

Mg l^{-1}	NO_3	NH_4
0	0	0
2	0.1	1
4	0.2	2
6	0.3	3
8	0.4	4
10	0.5	5

All samples had to be diluted, as the initial trial indicated very high concentrations in specific sites. The samples were diluted 2 fold using distilled water. Once the washes, standards and diluted samples were placed in sequence on the rotating plate they were run through the Skalar. Once read, a graph was produced showing the levels of both nitrate and ammonia.

2.4.2 Salinity

An electrical conductivity reader was placed in each sample to read the electrical conductivity of the water, indicating salinity level. The level was measured in milliSiemens cm^{-1}.

2.4.3 pH

The pH of a solution refers to its concentration of hydroxyl ions (OH^-), indicating whether it is acidic, neutral, or alkaline. A pH probe was placed in each sample to measure this.

2.4.4 Physical appearance

The samples were visually analysed for signs of aggregate (mould/ slime etc) colour and odour. The visual description of the site where the water was extracted was also recorded.

2.4.5 Well depth & water height

The depths were measured on site using a heavy ended measuring tape and by calculating the rim to bottom depth and subtracting the rim to base depth (ground level). The water height was calculated by subtracting the rim to water depth from the rim to bottom depth. These calculations served to give an indication of water table height.

2.4.6 Site and Social survey

A set of questions were prepared before the expedition to Madagascar, and were answered by local community members. The questions helped to indicate social attitudes towards sanitation and water health and to determine available skills, materials and locations for biogas plants in the village (see Appendix: 8.3). Information was also collected on the physical and chemical properties of the catchment area and the magnitude and range of human and animal activity.

3.0 Results

3.1 Site description and well depths

In order to investigate the quantity of water available it was necessary to calculate the well depth and water height. The results of these investigations can be seen in Figures 5 and 6. The water table depth calculations show that the wells with the shallowest ground water tables were: Well East, Chez Leon well and Spiny Forest well. The water table was significantly deeper in Well South compared to the other sites.

As seen in Figure 5, in the 3 weeks between the first and second data collection dates the water table for most of the sites became shallower, except for Well South and Well Irrigation.

The data in Figure 5 also suggest that there is evidence of faeces in close vicinity to several water sources, with the village's main defecation field very close to Well South.

3.2 Results from preliminary tests

The results from preliminary water quality tests (see Figure 7) showed that there were positive readings for *Enterobacteriaceae, E.coli & Salmonella* in Well South and *E.coli* in Andavadoaka beach water. There were elevated levels of ammonia in all three sites, going beyond natural levels, which are <0.01mg/l of water. Coco Beach pipe saw higher levels of nitrate compared to other sites. Well South showed a high salinity reading for drinking water.

The data suggested that all 5 sites sampled showed positive readings for *Enterobacteriaceae* and *E.coli*. Significantly high *Enterobacteriaceae* numbers were seen in Well East and Coco Beach pipe. *E. coli* O157:H7 strain was found in Well East, Well South and Coco Beach pipe. Elevated levels of nitrate and ammonia were found in Coco Beach pipe; the colour of this sample was a dull yellow and contained white aggregate. Well South had a high salinity reading for drinking water, and Well East showed a salinity level that matches seawater levels.

Figure 5. Well depth & water height measurements with a description of the site

Site	Water type/ usage	Well description	Ground to rim (m)	Rim to base (m)	Date: 7/3/2007 Rim to water surface (m)	Date: 7/3/2007 Well water depth (m)	Date: 28/3/2007 Rim to water surface (m)	Date: 28/3/2007 Well water depth (m)
Andavadoaka beach	Sea	NA	NA	NA	NA	NA	NA	NA
North beach	Sea	NA	NA	NA	NA	NA	NA	NA
Ecolodge well	Potable	1m dia rc structure, no evidence of faeces	0.40	2.50	2.40	0.150	2.46	0.09
Well in field by spiney forest	Portable	Unlined, irregular structure, potential for collapse	Ground level	3.60	dry	-	-	-
Chez leon well	Portable	1m dia new rc rings with border wall & base slab, very busy	0.40	7.00	6.70	0.30	6.90	0.10
Well East	Portable	1m dia rc structure, heavily used	0.67	5.00	4.30	0.70	4.60	0.40
Spiney forest well	Washing/ laundry	1m dia concrete structure, no evidence of faeces	0.70	5.50	4.80	0.70	5.20	0.30
Well near irrigation pond	Washing/ laundry	1m dia new rc rings with border wall & base slab, not busy	0.60	3.30	2.60	0.60	2.40	0.90
Well South	Portable	1m dia rc structure, close to defecation field	1.15	2.17	2.13	0.04	1.40	0.77
Coco beach pipe	Washing/ laundry	NA	NA	NA	NA	NA	NA	NA
Halfmoon beach	Sea	NA	NA	NA	NA	NA	NA	NA

Figure 6. Water table depth calculations (Calculated by subtracting rim to ground from rim to water)

Site	Depth from ground surface on the 07/ 03/ 07 (m)	Depth from ground surface on the 28/ 03/ 07 (m)
Ecolodge well	2.00	2.06
Chez Leon well	6.40	6.50
Well East	3.63	3.93
Well South	4.10	4.50
Well Spiny (600m)	2.00	1.80
Well irrigation	0.98	0.25

Figure 7. Results from the preliminary water samples, collected January 2007 (includes 5 sites)

	Sample site															
	Andavadoaka beach			Well East			Well South			Coco beach pipe			North beach			control
	1	2	3	1	2	3	1	2	3							
Microbiological analysis																
E. coli-																
CT SMAC	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	0
Latex test (O157:H2)	0	0	0	x	x	x	x	x	x	x	x	x	0	0	0	-
Enterobacter-																
VRBGA	x	x	0	x	x	x	x	x	x	x	x	x	0	x	x	0
plate count	3	6	0	487	1225	1082	2	4	5	3603	3567	3301	0	3	1	-
Chemical analysis																
Nitrate (mg/l)	0.6	-	-	0	-	-	0.2	-	-	34.92	-	-	0	-	-	-
Ammonia (mg/l)	0	-	-	0.12	-	-	0.2	-	-	5.2	-	-	0	-	-	-
pH	7.86	-	-	7.63	-	-	8.27	-	-	8.41	-	-	7.61	-	-	-
EC (mS cm)	58.7	-	-	58.3	-	-	4.8	-	-	1.7	-	-	58.5	-	-	-
Physical apperance																
	Small amount of aggregate (mold)			Small amount of aggregate (mold)			Small amount of aggregate (mold)			Yellow colour A lot of aggregate (pale)			clear			

Key
x = target Bacteria Present
0 = No target bacteria present

Figure 8. The results from the 2nd set of water samples, collected March 2007

	Sample site															
	Andavadoaka beach			Well East			Well South			Coco pipe pipe			North beach			control
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
Microbiological analysis																
E. coli-																
CT SMAC	x	x	x	x	x	x	x	x	x	0	0	0	x	x	x	0
Latex test (0157:H2)	0	0	0	x	x	x	x	x	x	0	0	0	0	0	0	0
Enterobacter-																
VRBGA	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	0
plate count	52	14	37	847	644	538	732	587	371	11	17	5	192	101	186	-
Chemical analysis																
Nitrate (mg/l)	0	-	-	17.12	-	-	0.34	-	-	40.4	-	-	0.02	-	-	-
Ammonia (mg/l)	0	-	-	0	-	-	0.24	-	-	0	-	-	0.06	-	-	-
pH	7.67	-	-	8.51	-	-	8.11	-	-	8.41	-	-	7.75	-	-	-
EC (mS cm)	62.1	-	-	2.4	-	-	4.8	-	-	2.3	-	-	60.9	-	-	-
Physical apperance																
	Rotten egg' smell Aggregate			Small amount of Aggregate			Small amount of aggregate			Yellow colour			Small amount of aggregate			

Key
x = target Bacteria Present
0 = No target bacteria present

	Sample site															
	Eco lodge well			Spiny forest well			Chez leon well			Half moon beach			Well near irrigation pond			control
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
Microbiological analysis																
E. coli-																
CT SMAC	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	0
Latex test (0157:H2)	x	x	x	x	x	x	x	x	x	0	0	0	0	0	0	-
Enterobacter-																
VRBGA	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	0
plate count	1125	746	992	20	20	27	86	85	100	7	10	9	724	642	742	-
Chemical analysis																
Nitrate (mg/l)	0.04	-	-	0.34	-	-	41.84	-	-	0.38	-	-	0.24	-	-	-
Ammonia (mg/l)	0	-	-	0	-	-	0	-	-	0.24	-	-	0.02	-	-	-
pH	8.53	-	-	8.44	-	-	8.51	-	-	7.74	-	-	8.42	-	-	-
EC (mS cm)	1.7	-	-	3.5	-	-	2.3	-	-	61.5	-	-	0.5	-	-	-
Physical apperance																
	Rotten egg smell' Black heavy sediment			Small amount of Aggregate			Small amount of aggregate (brown mold)			Small amount of aggregate (mold)			Rotten egg smell' aggregate (mold)			

Key
x = target Bacteria Present
0 = No target bacteria present

Figure 9. Results from the 3rd set of water samples, collected April 2007

	Sample site															
	Andavadoaka beach			Well East			Well South			Coco pipe tap			North beach			control
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
Microbiological analysis																
E. Coli-																
CT SMAC	x	x	x	x	x	x	x	x	x	0	0	0	x	x	x	0
Latex test (0157:H2)	0	0	0	x	x	x	x	x	x	0	0	0	0	0	0	0
Enterobacter-																
VRBGA	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	0
plate count	260	272	227	220	252	236	446	449	432	177	135	142	3	6	11	-
Chemical analysis																
Nitrate (mg/l)	0	-	-	0.78	-	-	0.2	-	-	46.96	-	-	0.1	-	-	-
Ammonia (mg/l)	0.07	-	-	0	-	-	0	-	-	0	-	-	0	-	-	-
pH	7.62	-	-	8.44	-	-	8.38	-	-	7.84	-	-	7.67	-	-	-
EC (mS cm)	61.5	-	-	2	-	-	4	-	-	0.5	-	-	61.1	-	-	-
Physical apperance																
	Rotten egg smell' Black sediment			Small amount of Aggregate			Slight smell of diesel aggregate (mold)			Rotten egg' smell Yellow colour			Clear			- -

Key
x = target Bacteria Present
0 = No target bacteria present

	Sample site															
	Eco lodge well			Spiny forest well			Chez leon well			Half moon beach			Well near irrigation pond			control
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
Microbiological analysis																
E. coli-																
CT SMAC	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	0
Latex test (0157:H2)	x	x	x	x	x	x	x	x	x	0	0	0	0	0	0	-
Enterobacter-																
VRBGA	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	0
plate count	26	18	34	72	162	221	53	47	58	16	22	12	25	9	6	-
Chemical analysis																
Nitrate (mg/l)	0	-	-	0.08	-	-	42.96	-	-	0.08	-	-	0	-	-	-
Ammonia (mg/l)	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-	-
pH	8.33	-	-	8.39	-	-	8.36	-	-	7.67	-	-	8.48	-	-	-
EC (mS cm)	1.3	-	-	3.7	-	-	2.7	-	-	60.8	-	-	0.04	-	-	-
Physical apperance																
	Rotten egg' smell Black heav sediment			Rotten egg' smell			Small amount of aggregate (mold)			Rotten egg' smell Heavy black sediment			Small amount of aggregate (mold)			- -

Key
x = target Bacteria Present
0 = No target bacteria present

3.3 Water sample results

The results from bacterial testing of the 2nd (March 2007) and 3rd (April 2007) samples are shown in Figures 8 and 9. Gross levels of *Enterobacteriaceae* colonies were seen in: Ecolodge well, Well East, Well South, Chez Leon well, Well near irrigation pond and North beach. *E. coli* O157:H7 strain was found in all 6 wells in and around the village. Water in the wells showed a higher pH than the sea water, meaning well water was more alkaline. The salinity level was again high in Well South. Elevated levels of ammonium were seen in Well South and Half Moon Beach, with the Ecolodge well, Well near irrigation pond and Andavadoaka beach emitting a 'rotten egg' smell. Coco Beach pipe water was again discoloured. In addition, during the 3rd set of testing, Well South had a distinctive smell of diesel. Figure 11 shows the extent of contamination.

4.0 Discussion

The 1st, 2nd, and 3rd sets of water samples showed significantly higher bacterial reading than in the preliminary set, therefore the differential bacterial readings could have been due to the length of time between on site water collection and analysis in the lab. Preliminary samples were collected in August 2006 and were refrigerated until analysed in October (2 month lay period), where as the other 3 sets were analysed within 3 weeks. Timing is an important consideration when testing for bacteria as the rate of decay may be exponential and thus they become undetectable after a certain period (Mims *et al.*, 2001). Another consideration for any sample taken from the field is that raised temperature and exposure to UV increase bacterial decay rate. S.W. Madagascar can experience high levels of both meaning the exact bacterial content may not have been fully realised. Evaporation, especially in the arid south, causes chemical concentrations to be higher, i.e. nitrogen (British Geological Survey, 2002). With environmental and logistical factors influencing results, precise quantitative data can not be accurately measured. Therefore, results should be viewed with caution. However, every effort was made in this investigation to attain as realistic a picture as possible.

Results have shown gross sewage contamination of many of the water supplies in Andavadoaka. The 'free defecating' behaviour of the Vezo people and the activities involved in zebu holding and transportation have affected the quality of their water supplies. The water sources showing the most contamination were: Well East, Well South, Well Irrigation and Coco Beach pipe.

4.1 Individual wells

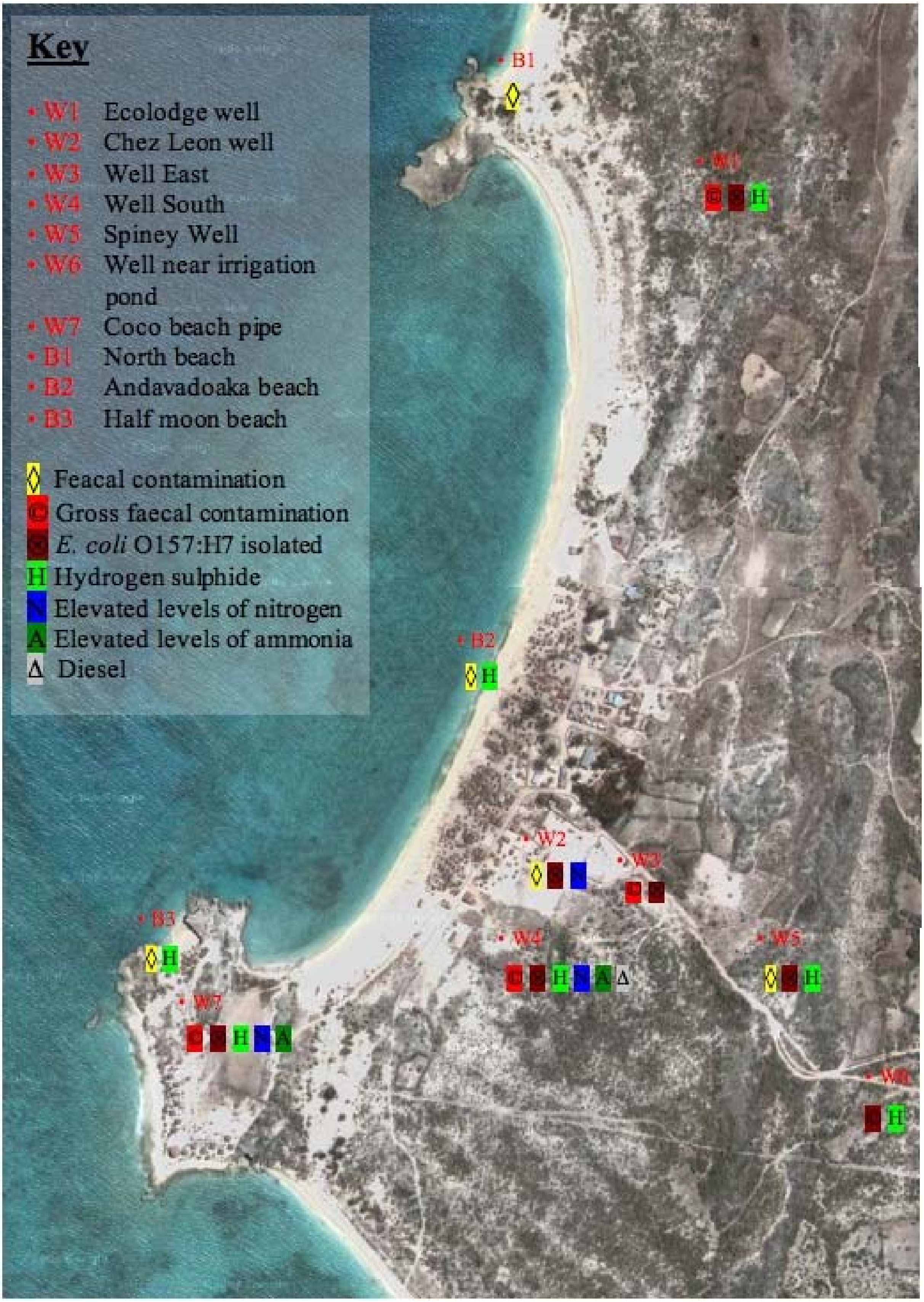
4.1.1 Well East

Well East is one of the three most recently built wells: it was built in 2004 by the housing association (Figure 10). The site showed consistently high *Enterobacteriaceae* numbers and the presence of *E.coli* O157:H7. High *Enterobaceriaceae* numbers pose a serious health risk as this family of bacteria include genera such as: *Escherichia*, *Proteus*, *Enterobacter*, *Salmonella*, *Shigella and Pseudomonas*. Many species within these genera are pathogenic and can cause diseases including gastrointestinal tract infections, urinary tract infections and upper respiratory tract infections (Mims *et al*., 2004). These diseases play a major role in child mortality. WHO drinking water quality guidelines state that feacal coliforms should not be present in a 100ml sample of water (WHO, 2004). Well East is one of the most heavily used wells in the village, imparting a high exposure risk.

Here the water availability is very low, with the water table depth at around 3.7m below ground level. The shallow nature of the water table could have caused an influx of sea water, explaining the high salinity value for this site in the 1st set of water samples.

Figure 10. Photo of the well at the entrance to the village (Well East).

Figure 11. Satellite image of Andavadoaka village with the Microbial and chemical results plotted for each sample site.



4.1.2 Chez Leon Well

Built around 1950 by the Catholic Mission, Chez Leon is the most heavily used well due to its central location within the village, and consequently has the lowest water level (>6.4m below ground). This well presents significant contamination of *Enterobacteriaceae*, and together with the consistent presence of *E.coli* O157:H7, poses a serious health risk.

The nitrate level in this well was significantly higher than any other site sampled in the village, being around 42mg/l. This is close to exceeding drinking the water guideline limit of 50mg/l (WHO, 2004). The nitrate level in Chez Leon Well corresponded with the nitrate level found in the Coco Beach pipe sample, which was around 44mg/l. This correlation could indicate the source of enrichment, as the 2 separate sites are in close proximity to the few toilet facilities that exist in the area. There was no sewerage system: the sewage was piped down into a hole 2m below the ground. This would have diffused or leached into the ground water (depending on the water table level), consequently contaminating nearby water sources (Dillon, 1997).

4.1.3 Well South

Well South is the oldest well and was built by the villagers (Figure 12). This well was significantly contaminated, running a high *Enterobacteriaceae* count. It was also noted that this well was consistently contaminated with *E.coli* O157:H7. The chemical analysis showed increased levels of ammonia compared with other sites in the village. Ammonia is typically found in water at natural levels around <0.01mg/L; concentrations above this indicate gross contamination by sanitary waste (Payment *et al.*, 2003). This well was close to one of the main defecation fields, therefore suggesting that the waste was leaching down to the groundwater, contaminating this well.

As stated in the results, the last sample taken from this site had a distinctive smell of diesel. Diesel contains compounds that dissolve in water, one of which is the toxic compound trimethylbenzene, which has a guideline limit of 0.01mg/l in water (WHO, 2004). The diesel could have entered the watercourse through a small spill from a vehicle or workshop. There is a weekly transport of supplies from Morombe (a town north of Andavadoaka) for which a pick up truck is used. Another transport truck comes in to collect fishermen's catches. The pick up and drop off point for the truck is very close to Well South. Further investigation would have to be undertaken to identify the source of the diesel.

Salinity levels in Well South were higher than any other well in the village. This well had the closest proximity to Andavadoaka beach, suggesting that a small amount of seawater may be recharging the water table. The water table calculations indicated that the water table was 1m from ground level in the first reading, and had recharged significantly to a depth of 0.25m below the ground in the second reading. These readings indicate that Well South had the highest water level in the village. There may be two reasons for this. Firstly, the well received a higher influx of water helping it to recharge. More significantly, the villagers view the water from the older well as unhealthy (due in part to the high salinity level) and therefore less water was extracted by the villagers. This view may have developed from an incident, highlighted in the survey, of an outbreak of cholera 7 years ago. The outbreak brought several fatalities amongst the Vezo people. Being one of the oldest wells, Well South may have been one of the few wells in use at that time.

Figure 12. Photo of Well near Alo Alo gardens (Well South)

4.1.4 Spiny Forest Well

High *Enterobacteriaceae* counts were seen and *E.Coli* O157:H7 was consistently isolated in this well. The 'rotten egg' smell noted in one sample may have been due to the lack of oxygen in the water. Anaerobic, sulphide-reducing bacteria, such as *Clostridium perfringens* produce hydrogen sulphides, and could have given the water the 'rotten egg' smell

(Environment Agency, 2004). The lack of oxygen could be an indicator of a high Biological Oxygen Demand (BOD) in the ground water in that area. There is increased activity in zebu transportation and holding behind the village. This indicates that the potential source of the contamination was from the faecal matter produced by the cattle, inevitably reaching the ground water via leaching. *C. perfingens* is an associated bacterium of human faecal matter, indicating that there were increased defecating activities in this area, consequently contaminating the water sources. The health risk associated with these bacteria is that it plays a role in the onset of chronic inflammatory diseases, such as inflamed bowel disease (Loubinoux *et al*., 2003).

This well was one of the 3 wells with the lowest water levels, at around 4m below the ground, indicating frequent use. The villagers were seen to predominantly use this well for washing and laundry as it was further from the village allowing for more privacy and space.

4.1.5 Well near Irrigation Pond

This well was the furthest from the village and one of the newly built wells. Significant contamination was found at this site. The source was likely to be zebu dung as the well was located alongside the main track into and out of the village, as well as being close to farmed land where zebu were held and transported frequently.

The 'rotten egg' smell at this site was due to the water being stagnant, as water was not extracted on a frequent basis. The water level was one of the highest (2m below the ground), coinciding with its infrequent use.

Salinity level was significantly lower here than in any other well, mostly likely due to its location, as it was the furthest from the sea. This further supports the idea that the other wells with higher salinity were experiencing influxes of seawater.

4.1.6 Ecolodge Well

This well was not used frequently by the villagers, due to its location - there was little activity in the area, apart from a few roaming zebu. Yet the well was significantly contaminated, running high *Enterobacteriaceae* counts and with a consistent presence of *E. coli* O157:H7. The water consistently possessed a 'rotten egg' smell, indicating that the water was stagnant.

The well was named 'Ecolodge well' because of plans to build an eco lodge in the vicinity and to use this well as a water source. The well was too contaminated for this use, as contamination ran beyond all drinking water guidelines and possessed the potential for disease outbreaks. To remedy this area a zoning scheme needs to be introduced, keeping the zebu away from the water source. It was their presence in the vicinity that was contributing to the significant contamination.

4.1.7 Coco Beach Pipe

The water supply to the Coco Beach resort (south of the village) was pumped via a water tower 2km east of Andavadoaka, making it a separate water supply from the village. The high concentration of nitrates (~45mg/l) and *Enterobacteriaceae* numbers indicates that contamination had occurred through sewage entering the system via a damaged pipe from the toilet facilities close by. The consistent yellow colouring of the water may have been a result of rust in the pipe, lending further evidence of pipe damage. An extremely high ammonia level was found in one sample (5.2 mg/l), indicating fresh sanitary waste. The sample also contained what looked like fragments of tissue, which is used for anal cleansing on site.

The conclusion that the contamination was via a damaged pipe and not through the contamination of the water source itself was due to the fact that the preliminary sample was taken from a different area of the Coco beach resort (representing a different part of the pipe network). The preliminary sample was the only site that showed no evidence of sewage contamination.

There is a guideline for nitrate levels in drinking water (50mg/L) as high levels can cause a disease called methemoglobinemia, or "blue baby" disease. As babies have a less mature digestive tract there is the chance for more ingested nitrate to become nitrite. It is this nitrite that turns heamoglobin into methomoglobin, reducing oxygen carrying capacity in the blood and consequently starving the baby of oxygen (McCasland *et al*., 1998).

4.1.8 Halfmoon Beach

Halfmoon Beach (Figure 13) was not a beach that was used for defecation as it was privately owned by

Coco Beach resort, but a small amount of contamination was seen, with *E. coli* present. An elevated ammonia level was present (1.2mg/l), and the water possessed a 'rotten egg' smell, indicating that the source of the contamination could be fresh sanitary waste. There was a set of toilets 10m back from the beach, where the waste is disposed of into a hole 2m underground. This gives weight to the possibility that the sewage is diffusing into the groundwater and being transported to sea, entailing a potential health risk.

Figure 13. Photo of Halfmoon Beach.

4.1.9 Andavadoaka Beach

The central beach of Andavadoaka (Figure 14) was frequently used for defecation, mainly by children. Children's faeces present a higher risk, as children are more likely to contract diarrhoeal diseases and thus carry the bacteria in their gut more frequently. This defecation behaviour has resulted in significant contamination. The site also consistently had a 'rotten egg' smell. The high BOD in these coastal waters imparts a potential environmental issue, as fragile reefs line the coast. The low oxygen availability could cause serious perturbation in ecological dynamics, which could adversely affect the reef habitat.

The contamination of the coastal waters also poses significant health concerns, as there are many infections that are caused by sewage contaminated waters. Beach water infections can affect the skin, ears, eyes and respiratory system. Whilst in Andavadoaka, it was noticed that cuts and grazes would become continually infected, indicating the current contamination is already presenting a genuine health risk.

Figure 14. Photo of Andavadoaka Beach.

4.1.10 Physical characteristics of the area

The geological characteristics of the area were represented in the pH readings. The well water consistently averaged a pH value of 8.3 – this was due to the area predominantly being made up of limestone, thus ground water percolating through the substrate would undergo an increase in pH. The salinity was high for all well sites in the village, indicating that sea water may regularly influx the water table due to its shallow nature. Shallow water tables and low rainfall in the catchment indicate the area was prone to drought.

The water level readings showed that many sites were becoming noticeably shallower over a relatively short period (3 weeks). This was a consequence of the change in seasons as the wet season was coming to an end and the dry season was just beginning at the time of the sampling. This indicated that the table would be considerably lower later in the dry season, suggesting cause for concern when considering water availability.

The microbiological and chemical analysis has revealed some very serious implications for health and for the environment. There are clear signs that there is a desperate need for sanitation.

The Vezo people do not use toilets in their homes as the elders have a fady (taboo) against defecating inside walls. This behaviour is based on a hygiene belief. It was acknowledged in the survey that this is a belief held mainly by the elders, whereas the younger generations are more open to change and hold weaker fady beliefs.

The outbreak of cholera in 2000 motivated the villagers to build a few toilets, but their use was not sustained. This behaviour indicated that the Vezo people recognize the link between sanitation and diarrheal diseases, and are open to making changes. The reason the toilets were not sustained could be due to the fact that only a few were built, reducing the possibility of mass use, and thus a mass dissemination of behaviour change. Furthermore, the location of one toilet was placed in open view on Andavadoaka beach (see Appendix: 8.3.1); Vezo adults express a degree of privacy in their defecating behaviour suggesting that location would not have inspired acceptance.

If a properly structured hygiene education programme was implemented and a sanitation facility was designed and constructed by the Vezo people, then the implementation of a disposal facility into Andavadoaka could be fully accepted.

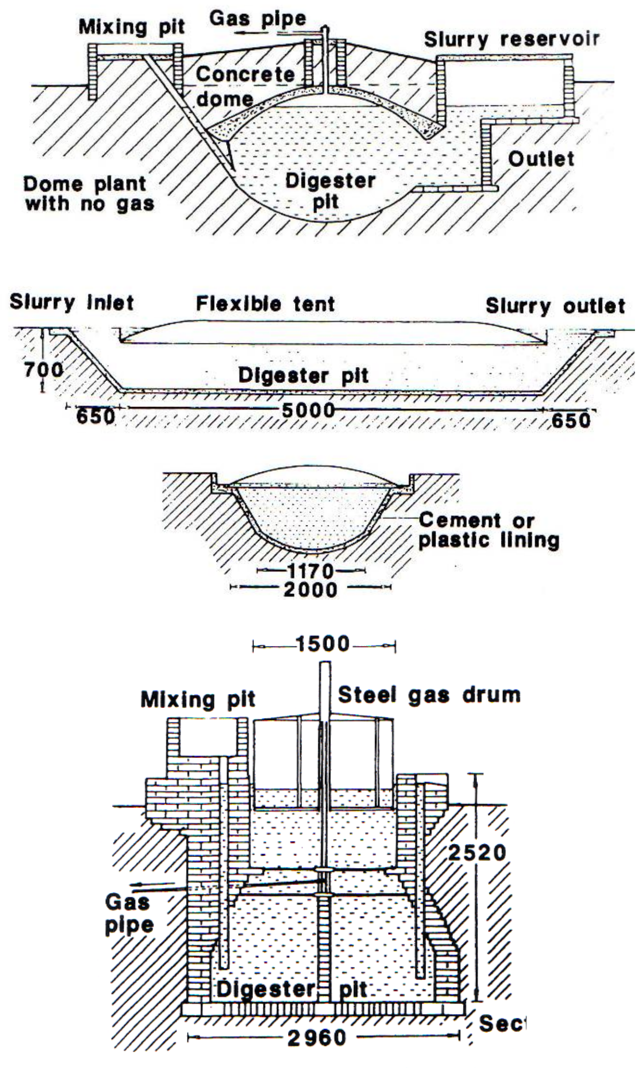
The village has a lack of natural resources available to them, thus implementation of a sanitation system that could use the waste as a resource would be the most beneficial. Biogas technology can take waste and, using a digester, produce a renewable energy source and pathogen free fertilizer. The introduction of biogas would enable the safe containment of human waste and provide two important resources, making the option of a sanitation facility more appealing to the villagers.

4.2 Biogas

Biogas technology can be a successful sanitation facility, controlling waste, and preventing contamination of important water sources for an individual home or community. It also has the extra benefit of utilising a locally available resource to produce renewable, high-grade gas at low cost. This energy can be used in modified stoves and lamps, and in engines to drive machinery and water pumps. Biogas also has a solid end product that can be utilised as a nutrient rich, pathogen free fertiliser.

Biogas technology is relatively low-cost, but for a small community it can demand high capital investment. This is a major problem when trying to disseminate the technology to people who could benefit the most from it; loans can be taken on the condition that the system could supply a payback scheme. Substantial government and aid organisation subsidies have shown the best way to tackle the problem, but require the government firstly to be interested in the scheme, to recognise the benefits and to financially commit. Figure 15 shows a number of designs of biogas technology.

Figure 15. From top down: Fixed dome design; Flexible bag digester; Floating-drum design (Fulford, 1988).



The benefits of biogas technology are shown in Figure 16. For Andavadoaka, biogas offers more than just a sanitation option, which may enable the village to accept the technology and pursue its use. If the Vezo people can see the benefits of the cost-free energy and fertiliser produced from processing their human waste, it will help encourage the acceptance of sanitation. Without the direct benefits biogas can bring, a sanitation programme may not be viable for success in Andavadoaka due to the elders' traditional beliefs.

Figure 16. Benefits of biogas technology.

Level	Benefit
Family	- Clean and convenient energy - Time and labour saving in cooking and fuel collection - Reduction in pollution levels in kitchens (reducing respiratory illness) - Cost-free organic, nitrate-rich fertiliser
Community	- Reduce pressure on sources of biomass fuels (reduce extent of local deforestation) - Better health and sanitation through the removal of dung from the inhabited local environment

4.3 Sanitation Plan

In order to choose the appropriate biogas system for Andavadoaka, certain criteria need to be calculated and considered (FAO/CMS, 1996).

4.3.1 Site characteristics

Predominantly, the plan would look to use human faeces. However, there is also the option of utilising zebu and goat dung. The amount of available dung can be calculated to determine the size of the digester needed.

Human: Population x wet dung per day (kg) = Total feed available

1200 x 0.2 kg = 240 kg/day

Zebu: Population x wet dung per day (kg) = Total feed available

12 x 10 kg = 120 kg/day

The total present population has been used as an appropriate figure, because even though a certain number will not choose to use the toilet facilities, the population is rapidly growing. The apparent overestimation of people using the toilets will account for the potential population increase.

4.3.2 Hydrological, geological and climatic characteristics

Southwest Madagascar receives only 400-800 mm of rain a year, the lowest in the country. Most of the rainfall occurs between December and March (BBC, 2006). For monthly air temperatures see Figure 17 below.

The area is predominantly limestone and the substrate medium in and around the area is mainly sand with patches of light rock. As a result, the shallow water table fluctuates in depth.

With this information it can be concluded that the climatic temperature would be appropriate for an anaerobic digester to run optimally.

4.3.3 Site Location

Having two biogas sites in the village would reduce digester size, and therefore the demand for space. It would also allow the gas produced to be distributed proportionately and ensure the toilets would be close enough to all areas of the village for ease of use (and thus continued use). The locations would correspond to the main sites for defecation - northern and eastern - helping to integrate the facility with the present behaviours.

A small biogas system will also be incorporated into the construction of the Ecolodge. This will be run and maintained at first by Blue Ventures. It will act as a showcase and marketing strategy to educate the

Figure 17 The regional monthly air temperature in Southwest Madagascar (BBC 2006).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Highest Temp (°C)	30	30	32	31	29	27	27	28	28	29	30	31
Lowest Temp (°C)	22	23	22	20	17	15	14	15	16	18	20	22
Precipitation (mm)	95	89	36	18	16	15	6	6	8	22	12	97

village on the benefits of a digester if plans have not already been put into place by the time of the Ecolodge's completion.

4.3.4 Plant Designs

A fixed-dome design would be the most appropriate option for the 3 proposed digesters (two in the village and one at the Ecolodge), as they will be low in maintenance, and require cheaper materials that can be locally obtained.

The village population allows for around 240kg wet dung/48kg dry feed. This amount would require the 2 village digesters to have a volume of ~14.1m^3, with a storage volume of 5.6m^3 and a retention time of 70 days - the necessary time for human faeces to be fully digested and for the pathogens to be completely destroyed. This would mean the plant type CP20, as described in Fulford (1988) would be used. This size will also allow for a small increase in use or population growth. See Figure 18 for a schematic of the proposed northern digester. For application purposes the CP20 system would be feasible for the Northern site.

The Eastern site has the opportunity to use a large enough plant to be incorporated into an irrigation system. This would benefit local farmers, many of whom own numerous zebus that could be housed in provided sheds to enable their dung to be collected and channelled to the biogas system. An extended fixed dome design, such as an EP50, can be used here. An EP50 would require 300kg wet dung/60kg of dry feed, this would require an additional 6 zebu, on top of the 12 already available, to fulfil this requirement. The design has a digester volume of 39.9m^3, a storage volume of 47.2m^3 and a retention time of 78 days. See Figure 19 for a schematic of the proposed Eastern digester.

The proposed Ecolodge will house up to 30 people, allowing for around 6-8kg of available feed. This feed source could fuel a small digester with a working volume of 5m^3, which would supply 1m^3-1.5m^3 of biogas each day. This gas could be applied to lighting appliances.

The latrine of choice would be the multi-unit, pour-flush, squatting slab with ventilation. This is suitable because the pour-flush will enable the excrement to flow to the digester's mixing pit, with the extra water creating the right 1:1 solid/liquid ratio for the digester. The lid of the mixing pit should be a solar heater (made from aluminium, painted black) to ensure the feed is of an optimum temperature on entering the digester. The squatting slab would reproduce the Vezo's present open-field squatting behaviour, making the system easier to adapt to. The added ventilation will help with odours and any potential flies. Creating an aesthetically pleasing environment is essential if the users are going to believe it is a hygienic option. Hand washing facilities will also be available. See Figure 20 for schematics of a proposed latrine.

Figure 18 Plan of Northern digester design (Fulford 1988)

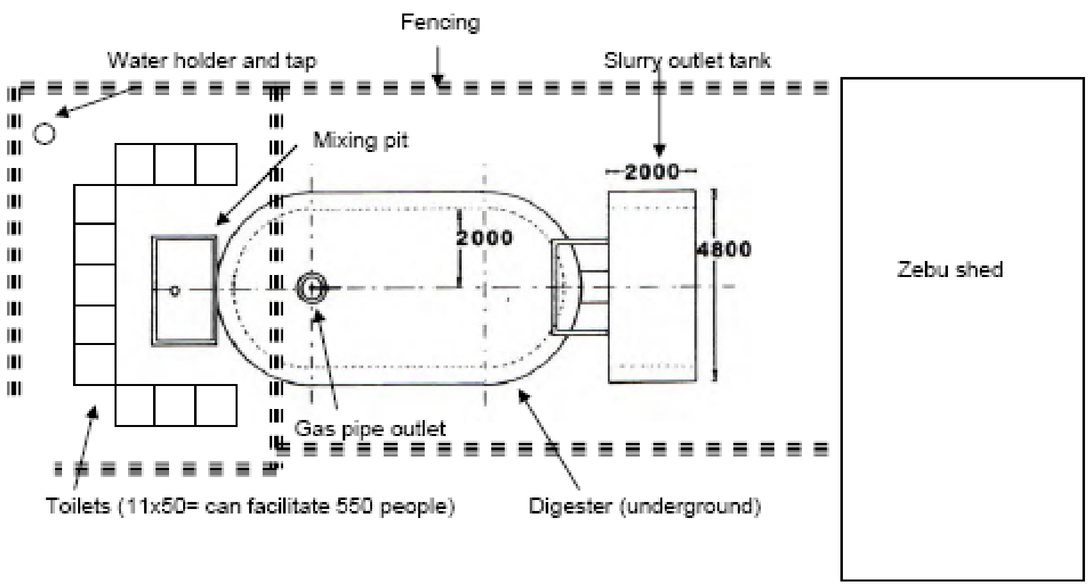


Figure 19. Arial plan of the proposed Eastern digester design.

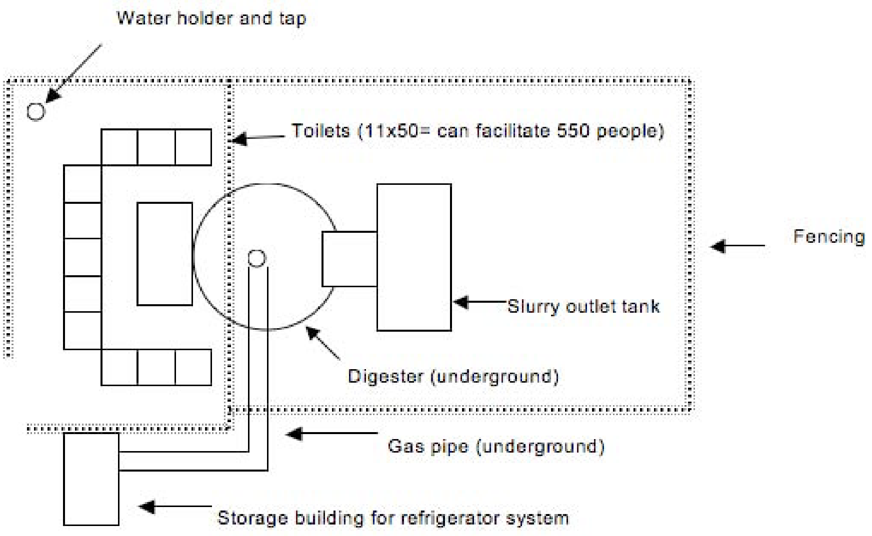
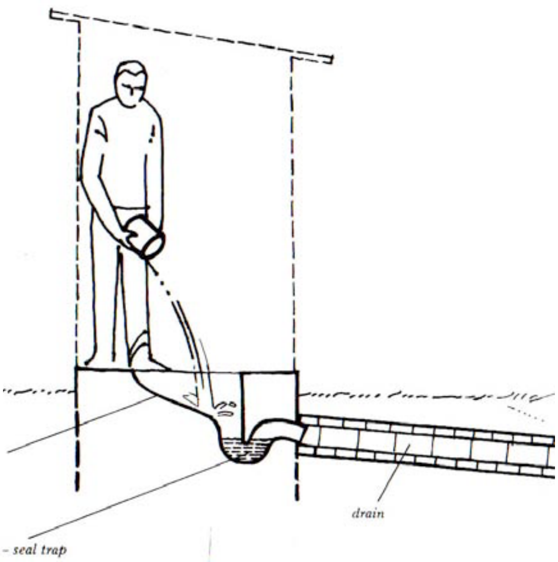


Figure 20. Cross-sectional view of proposed latrine (Wilbad & Kilama 1985).



4.3.5 Gas and fertiliser production and application

The gas production at the Northern plant would vary due to the temperature flux throughout the year. Production would range from 2.8m^3/day at 20°C, to 3.7m^3/day at 25°C, to a maximum of 6.1 m^3/day at 30°C. The Eastern plant will produce 7.4m3/day at 20°C, 9.4/day at 25°C and 15.5/day at 30°C.

Andavadoaka would experience the lowest gas production from the start of June to the end of September, but the systems have the potential to run at their optimum all year round.

Biogas has a high calorific value of 21.5 kJ/l and can be used in many appliances, including modified lamps, stoves, refrigerator burners, generators and engines. The village would need to be fully involved in the design process in order to understand their needs and consequential uses for the biogas.

From a social and economic stance point of view, it can be seen that the Vezo people could benefit if the gas from the Northern plant was applied to a refrigeration burner (freezer appliance). This application would extend the storage time possible for their fisheries catches, thus giving them an opportunity to sell further afield, enabling them to earn more and decreasing their reliance on the fishing cooperative Copefrito.

This could possibly be a crucial move, as Copefrito have shown that they have a widening field of sellers, and if they were to move on from Andavadoaka, it would leave the Vezo community in a vulnerable position. Currently they are solely reliant on Copefrito to sustain their main economic livelihood (fishing). A refrigerator burner requires 0.14m^3/hour, to keep the freezer on all day: a gas requirement of 3.36m^3/day. This would mean that a large freezer could be run all year round, and through the wet-season (when temperature is higher) a second freezer could be run.

The Eastern plant could be applied to several scenarios. The most beneficial option for economic development would be to use the biogas to help power an irrigation system. One such system has been applied near Birgunj, Nepal and has been successfully running for 6 years. A SD500 plant design was used to fuel a 4kW engine that pumps 700m^3 of water from a stream 3.3m below ground. This occurs for 7 hours/day and requires the waste of 30 buffalo to feed the plant. The effluent from the plant is fed into the irrigation system to be washed onto the fields. Andavadoaka could apply the same type of system in the dry season to increase their arable land potential, but irrigation specialists will need to review the situation in order to find the most effective way of obtaining and using the area's water resources. The water that would be used for irrigation in Andavadoaka has a low salinity level (~ 0.2 ds/m); giving a range of possible crop developments. Many crops are grown in Madagascar, including coffee, vanilla and sugar cane. Andavadoaka already grows sugar cane, beetroot and corn, showing that there is an agricultural infrastructure in the area.

Excess gas that is not used for irrigation in the dry season could be used to run a refrigerator, enabling the farmers to milk their zebu and store their milk. This could then be a commercial product that can be sold to the village (which would drastically improve child health and adult nutrition).

In the wet season when irrigation is not needed the farmers could apply the gas to a small 'cottage industry', where they could process the milk to form cheese, again as a commercial product, or other crop products, such as vegetable oils, soaps and flour. This scenario has huge economic potential for farmers in the area.

The fertiliser produced can also benefit the farming community: the soil quality is poor in the area and lacking in nutrients. The digester's substrate is rich in nitrogen, which is an essential nutrient for vegetation. The Vezo people do not use fertiliser at present, thus the farmers would need firstly to accept the concept of using human waste and secondly understand the application process (so as to protect the groundwater from excessive applications etc).

The sanitation system as a whole will need to be maintained. A daily cleaner would have to be employed as well as 2 biogas technicians. The technicians would be from Andavadoaka and trained to enable them to advise on its functionality and to maintain the facility. They would also be responsible for ensuring that the systems receive enough feed and that the feed is mixed well and enters the digester in a batch process. They would have to remove the water from the gas-line traps on a weekly basis, and deliver the fertiliser to the purchaser. They would also be in charge of seeking replacement materials and fixing any problems.

4.3.6 Funding the programme

The programme could find funding through external aid organisations such as USAID, World Bank, and Wateraid, or internally from the National Water and Sanitation Fund (FNEA). A loan could also be an option, and would be taken out by the beneficiaries (fishermen using the freezers and the farmers using the irrigation system) with the payback coming from the extra sales. The upkeep and salaries for the cleaner and technicians, and supply of toilet tissue would come from the small fee every family would pay to use the facilities (e.g. on a yearly basis). This small fee will encourage partial ownership and consequently respect for the facilities and continued use.

4.3.7 Zoning Scheme

Along with the implementation of the sanitation facility, it is essential that the ground water close to the wells is isolated from potential contamination from animals and human excreta (from people who don't conform to using the latrines). A zoning scheme would need to be set up to protect the wells, with the potential use of fencing near the forest area. These "no-go" areas would need to be introduced and respected by the Vezo themselves. Figure 21 shows a potential zoning plan to protect the wells of Andavadoaka from contamination.

4.3.8 Water source improvement

As a part of the development programme the well facilities should be improved. The survey showed that the community saw the new wells as containing fresher water, which was not the case. Thus once improvements in water quality are realised and all accessible wells are of a good structural and functional quality it will revitalise their sense of healthiness of the water source. This will consequently decrease the intense pressure on the two original favoured water sources.

Bush Proof is a company operating in Madagascar that specialise in creating and improving water sources in rural areas, meaning that the infrastructure for assistance is already there.

4.3.9 Hygiene education

Proper hygiene education and implementing the simple task of hand washing will reduce the frequency of diarrhoeal diseases by a predicted 49%. This is an essential element of any sanitation programme if it is to be successful in decreasing sanitation-related diseases. Thus the programme must incorporate hygiene education sessions for the villagers.

This will be the first step of the programme, as it will help provide some understanding of the risks from disease, how their present behaviour is affecting their health and the health of their children. Most importantly, it will offer strategies to facilitate behaviour change and acceptance of the fundamental need for sanitation within the village.

Figure 21. Satellite image of Andavadoaka showing a potential zoning scheme to prevent the contamination of village wells

4.3.10 Programme Schedule

A sanitation programme needs to be well structured and organised if it is to be successful. Figure 22 shows temporal organisation of a suggested sanitation programme.

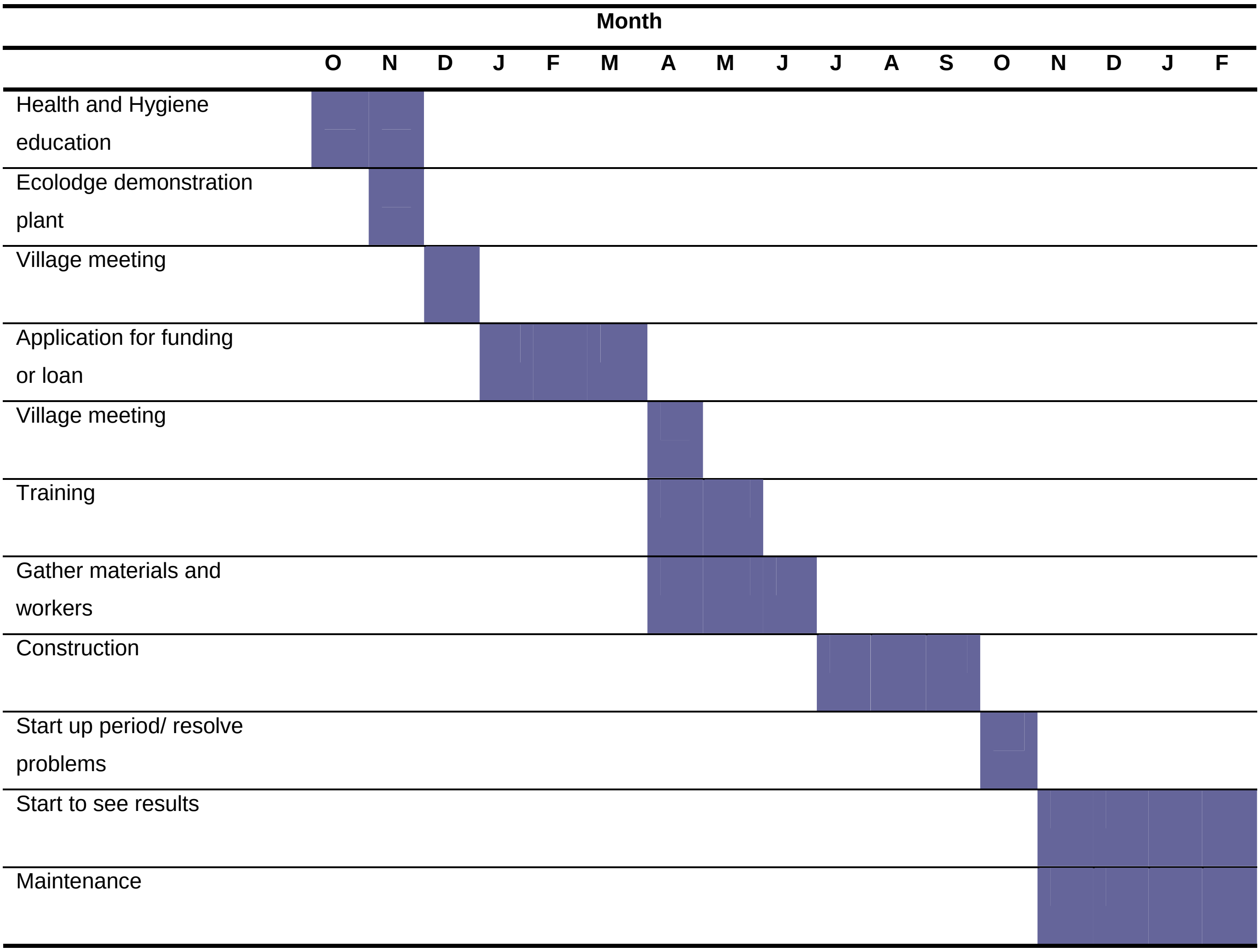
A methodology known as PHAST (Participatory Hygiene and Sanitation Transformation), developed by the UNDP, the World Bank and WHO, is a strategy that has been implemented in many African countries. The strategy looks to motivate change in sanitation and hygiene behaviours and to inspire community management within a sanitation programme. It involves community members in activities that promote self-assessment, community diagnosis, analysis of constraints on change, and planning for sanitation and hygiene changes (Shordt 2006). Applying this sort of strategy to the programme in Andavadoaka is essential for success.

Education is a key component to enable behaviour change, and ensure understanding of the biogas system and its maintenance needs. This is the only way to keep the system operating efficiently and maintain functionality, allowing prolonged confidence within the programme.

The construction of the digester and the latrines must start around July to allow for completion before the monsoon season starts and because air temperature is rising at this time of year, providing optimal conditions to ensure high gas production, giving the villagers confidence in the system.

After a few months the water should be tested again to see if the programme has taken effect. If laboratory testing is not available, then the tests can be preformed in the field using a simple test kit - analysing bacterial content, pH, nitrates, lead and pesticides. A follow up survey should also be conducted to assess whether the villagers have

Figure 22. The time frame required for the implementation of a sanitation plan in Andavadoaka



noticed any health improvements, and whether they are happy with the system so changes can be made if necessary.

5.0 Conclusion

The sources of contamination in the area have been identified as coming from human waste and zebu dung. The waste is entering the watercourse via leaching, and these highly contaminated water sources are being heavily extracted by the villagers - thus the most likely transmission for bacteria is via the faecal-oral route.

All 6 wells tested were found to be contaminated, with the most frequented wells exhibiting the most contamination, including contamination by the pathogenic *E.coli* strain O157:H7. The Vezo people do not practice hygienic sanitation behaviour (hand washing etc), so their environment will continue to be contaminated. This presents a high exposure situation, causing the potential for serious outbreaks of diarrhoeal disease, along with continual illnesses and infections of the eyes, skin and respiratory system.

Remediation of this problem can be achieved by changing the sanitation behaviours of the Vezo people through the introduction of a programme that incorporates hygiene education. This would help villagers learn about the transmission of disease, allowing them to understand why their behaviours have to change. A sanitation plan will only be successful and accepted by the village if they are consulted from the start and are involved in the design and construction process. This will also help the sanitation organisation to understand the needs of the community.

Materials and skills should be locally found and costs kept low. Members of the community need to be trained to maintain the digesters, allowing for efficient, continual use. The village's trained technicians and latrine cleaners will need to gain an income, thus a small user fee will be set up to allow for the upkeep of the facility (new parts, salaries etc). The small fee will increase the sense of ownership; fostering the attitude of sustained used and continual upkeep.

The biogas produced could be applied to a fisheries refrigeration system, increasing saleability of the fishermen's catches, as well as a small irrigation system (in the dry season) and a small cottage industry (in the wet season). All of this would develop and exploit the village's potential available resources, increasing the community's income and providing a more secure and stable future.

5.1 Limitations and recommendations

The major limitation of this study was the fact that the water samples had to be transported from Madagascar to the UK, causing storage and logistical problems. This subsequently meant that the samples could not provide reliable microbial quantitative data, only an indication.

Future research that could build upon the results of this study could include:

- Finding out the direction of the ground water flow, to give a clearer indication of source transport.
- Assessing the total water extraction by the villagers (by surveying the sites), and continuation of data collection on water depths. This would help to assess how prone the area is to drought and to quantify overall water availability.
- Measuring dissolved oxygen levels in the wells
- Unearthing a section of the Coco beach resort pipe to identify its depth and the locality of the damage, subsequently enabling clear conclusions to be drawn about the source of contamination and remediation of the problem.
- Tracking animal movement (zebu and goat), to define the areas most at risk from contamination of animal dung, subsequently enabling a more reliable zoning scheme.
- Understanding farming practices and the amount of land used for growing crops to estimate the potential use of the fertiliser and/or irrigation system that could be produced from a biogas digester.

- Investigating whether faecal contamination was human or non-human in origin, which could help make a zonation scheme more reliable. This could be achieved by identifying *Clostridium perfringens*, which is primarily associated with human waste. Other bacterial groups that could be tested for include the Bifidobacteria, a major component in the human intestine, the *Bacteroides fragilis* group, also found in the human intestine, and *Rhodococcus coprophilus*, which is absent in humans.

- Further chemical analysis that includes the identification of detergents and heavier hydrocarbons in the water. This would help to gain a more detailed picture of the pollution in the area.

Projects could include:

- Analysis of the total water availability to determine whether there is enough to: 1) support the ever-growing population, 2) enable the development of tourism (which will bring an influx of people requiring water), including the sustainability of the proposed Eco lodge, and 3) facilitate irrigation.

- Potential for agricultural and small industrial development - looking at water availability for irrigation, the potential crops that could be grown and sustained in the area, and the potential cottage industries, such as the production of milk and flour.

- Water management – identifying the extent to which the area is prone to drought and when the most critical periods are.

- Health and hygiene - this project would look at the current state of health the Vezo people are in, looking at nutrition and the frequency of illnesses. It could also look at their attitudes towards health and hygiene, and assess what they do/ where they go when someone gets ill. If a hygiene education programme was set up, behaviour change could be analysed before, during and after the programme to indicate the programme's success.

6.0 Acknowledgements

My thanks go to the other members of the Blue Ventures Team, for their help with data collection and sampling, and all their support along the way.

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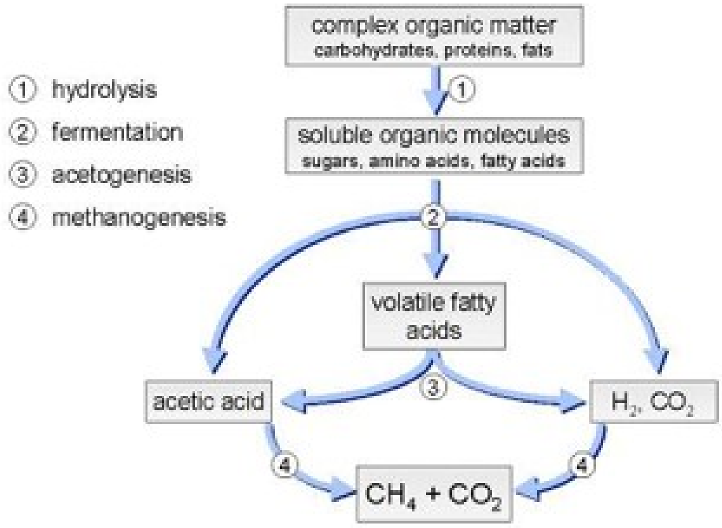
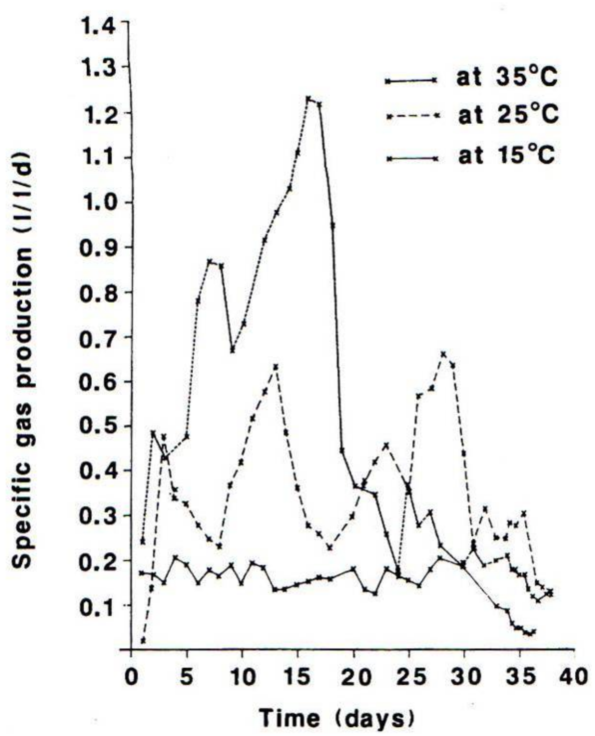
8.0 Appendix

8.1 Digestion process (www.water.mc.uccs.edu)



8.2 Gas production rate (Fulford 1988)



8.3 Area and social survey for the village of Andavadoaka, Madagascar.

Population: 1220 (growing rapidly)

8.3.1 Water and sanitation situation

Defecation behaviours

- There are no toilet facilities in the home or shared by the community. This is because:
  - The Vezo people believe it is Fady (taboo) to defecate within walls (stemming from a hygiene belief).
  - This belief is held more by the elders. The younger generations hold less strongly ingrained beliefs and are more open to change.
- The adults in the community defecate mainly when it is dark, in fields behind the village (where there is a degree of privacy).
- The children defecate anywhere, but mainly on Andavadoaka beach, in the day.
- Sticks of wood and paper are used for anal cleansing. Hand washing isn't practiced regularly.
- Several stool counts were taken on Andavadoaka beach on different days: 70 individual stools (at high tide/ 3pm), 40 (at high tide/ 4pm), and 65 (at high tide / 3pm).
- There was an incident of cholera 6 years ago (in 2000), which made 25 people ill and killed 2. A toilet was built, but its use wasn't sustained.
- There are toilet facilities used by the Catholic Mission and Coco Beach. The waste is disposed of via a pipe to a hole 2m below ground.
- The population of the village is growing and there is the inevitable prospect of increased tourism; with this comes the serious issue of waste management and water availability.
- Another observation was that any cut or graze experienced will always become infected, and heal very slowly. A few ear infections were also noted. This may be due to contamination of the surrounding waters.

An abandoned toilet on Andavadoaka beach

Zebu transport

Water supplies

- There are 6 wells accessible in the area: one is dry.

  - 3 wells were built in 2004 (one near the irrigation pond, one in the spiny forest and one near the entrance of the village). They were built by a government-run housing association.
  - The two wells in the village (near Alo Alo gardens and Chez Leon) are very old and were built by the villagers. There are 2 other wells: One well was built in 1950 by the Catholic Mission (west of the Catholic Mission) and the other 'Ecolodge' well was built along time ago, again by the villagers.
- The new wells are viewed as having fresher water.
- All villagers use all wells for drinking and washing.
- Well water used to be transported using metal buckets but now plastic ones are used.

Animal activity

- Many zebu (cattle) are owned by the villagers - they are used for transportation and farming.
- Zebu move throughout the village and are generally kept in the spiny forest (a few hundred metres from village).
- There are many goats that roam around the Coco Beach resort area.

Agriculture

- The Vezo grow crops such as sugar cane, beetroot and corn.
- They do not use fertiliser.

Biogas

Materials and skills available:
- Carpenters: many houses are made from wood.
- There is a mechanic.
- Locally: wood, cement-type material, a little plastic and scrap metal.
- Can transport: brick, pipe etc.

Transport options:
- Boutre (cargo boat)
- 4x4
- pirogue (canoe)
- zebu cart
- truck

Local conditions (i.e. temperature, climate, seasonal variations, humidity):
- Low humidity
- Seasonal variations:
  - Dry
  - Cyclones every year; can be destructive.

Organic sources and quantity available:
- Human waste
- Goats
- Zebu

- Chickens

Digester (location sites, toilet facility possibilities):

- To introduce the systems to the village the possibilities would be:
  1. On the Blue ventures camp, as there is accommodation with toilets for volunteers here.
  2. The Catholic Mission, which uses toilets and holds around 13 residents; this location is in the village.
  3. Mr Coco, as he has a hut in the village and again already has a toilet.

With at least one of these introduced, the village will be able to see how it works and the benefits it brings.

- The best location for any digester would be in a place that is away from a drinking source, i.e. on the outskirts of the village (but still convenient) in an area already used for defecation. Thus the most suitable site would be the unused patch of land north of the village, above the church. This site is already used for defecation and would be accessible to the fishermen for refrigeration convenience. The other site is east of the village where the defecation field exists but its proximity to the nearby wells needs to be taken into consideration.
- The toilet designs used in the area take on a small squatting slab, sat on a concrete base, surrounded by a wooden framework. Squatting slabs would be most acceptable to the Vezo people as it imitates their current behaviour, making it feel more comfortable. The Vezo make an issue of hygiene in relation to the presence of rats and flies, this lead to it being "Fady" to defecate within walls. Thus keeping the toilet aired and clean would be of high priority if the use of a toilet was to be accepted; a ventilated latrine would help with odour and flies, and a 'u' bend in the squatting slab will control any possibility of flies breeding in the pipe.

8.3.2 Assessing electricity uses and possible application of the biogas produced

- The circumstances at present are that the epibars (bar/dance place), the Catholic Mission, the village hotel, and Coco Beach resort (including Blue Venture's camp) use electricity. The village uses wood to cook.
- There is a small amount of farming on the outskirts of Andavadoaka, which includes produce such as sweet potato, sweetcorn and beetroot. Fertiliser would therefore be useful, especially as the area is very dry and the soil nutrient poor. The electricity produced from the biogas could also facilitate an irrigation system in the dry season and be used for a small 'cottage industry' in the wet season.
- The villagers depend on fishing species such as octopus, lobsters and a variety of fishes. The fishermen could benefit from extending the possible storage of their catches by using the biogas to facilitate a refrigeration system, consequently allowing selling further afield.

<u>Social organisation, community structure, attitudes, religion</u>

- Madagascar was colonised by the French and so their main religion is Catholicism, but the people are very superstitious and believe in the spirits of their ancestors. They are also very family-orientated with traditional western values.
- The village structure consists of 4 elders (the oldest members) each being in charge of a section of the village, there is also a village president as well as Mr Coco, who is the richest man and thus has some power.

General attitudes towards biogas; how much is known?

- The fady towards using toilets will be the biggest problem to overcome when suggesting the introduction of a biogas system. But when talking to a local villager it was mentioned that the Elders are the generation that are set in their ways. The 2nd and 3rd generations are less so and traditions are less prominent for them.
- A huge indication to how much is known and how big the problem of waste is the outbreak of cholera 6 years ago, where 2 people died. A very small percentage turned to using toilets, but this behaviour was not sustained.

8.4 Southings and Eastings of sample sites

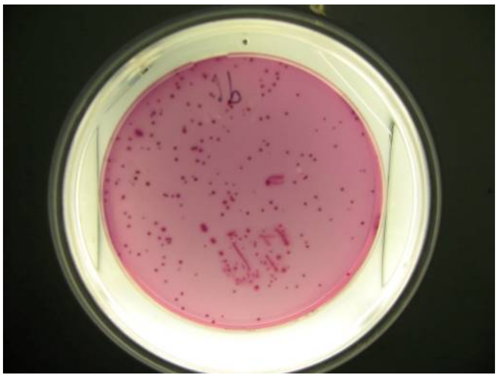
Site	Southings (deg)	Eastings (deg)
1	22.07243	43.23789
2	22.06374	43.23880
3	22.06452	43.24165
4	22.06648	43.24107
5	22.07236	43.23929
6	22.07337	43.24052
7	22.07444	43.24342
8	22.07571	43.24535
9	22.07392	43.23856
10	NA	NA
11	22.07440	43.23446

8.5 Sampling times

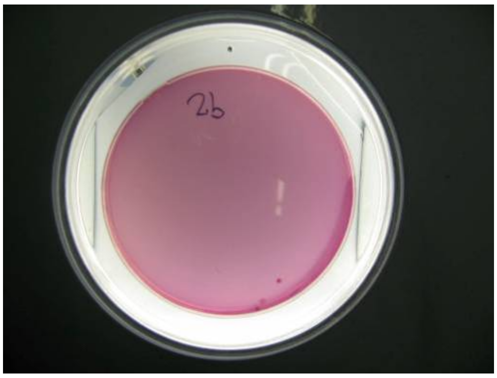
Set no.	Date of collection	Time stored	Andavadoaka	South well	Coco pipe	East well	North beach	Spiny well	Irigation well
Preliminary	1/7/06	9 weeks	x	x	x				
1st	3/1/07	3 weeks	x	x	x	x	x		
2nd	5/2/07	3 weeks	x	x	x	x	x	x	x

8.6 Bacterial cultures

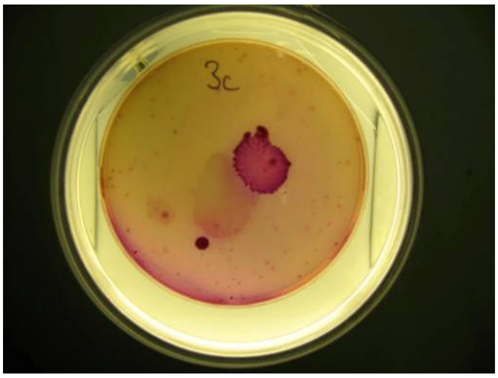
8.6.1 *Enterobacteriaceae* plates (set 3)



Andavadoaka beach



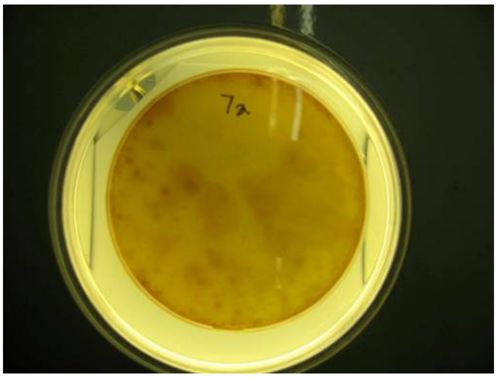
North beach



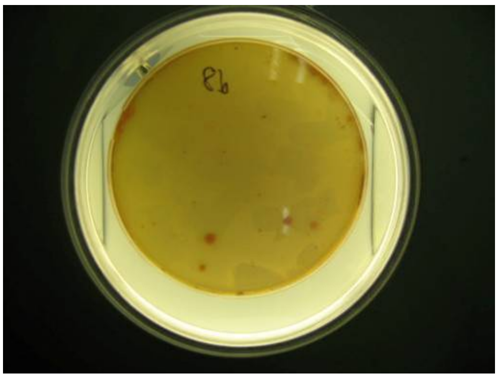
Eco lodge well

Chez Leon well

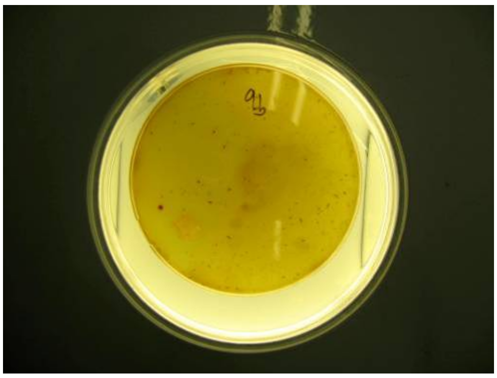
Well East



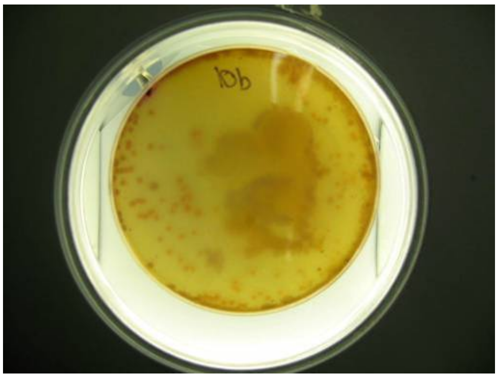
Spiny well



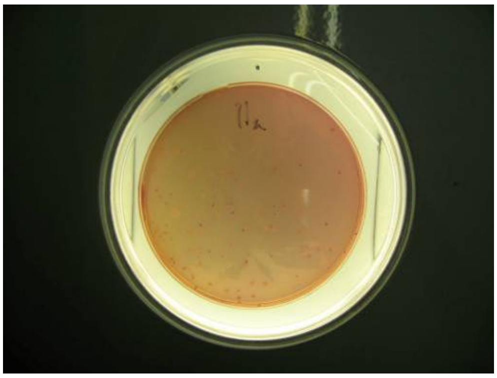
Well beside irrigation pond



Well South

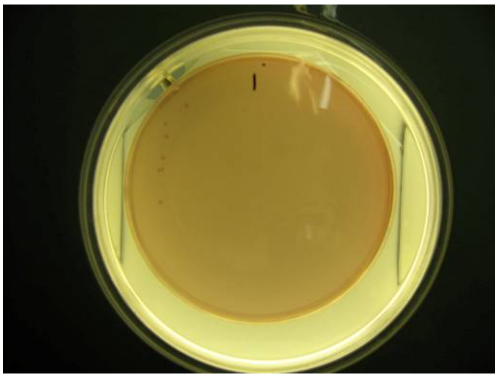


Coco Beach pipe

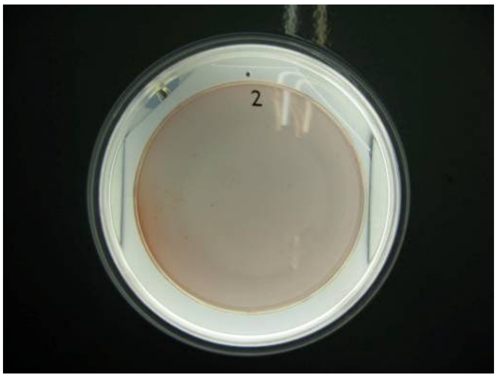


Halfmoon Beach

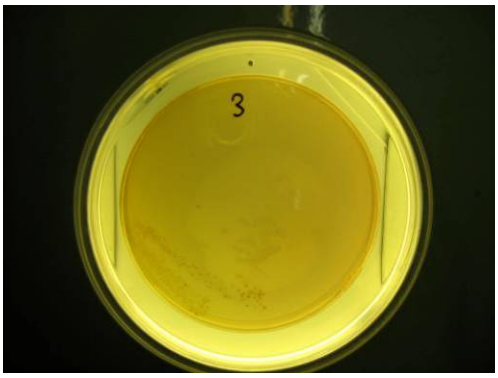
8.6.2 *E.coli* plates (set 3)



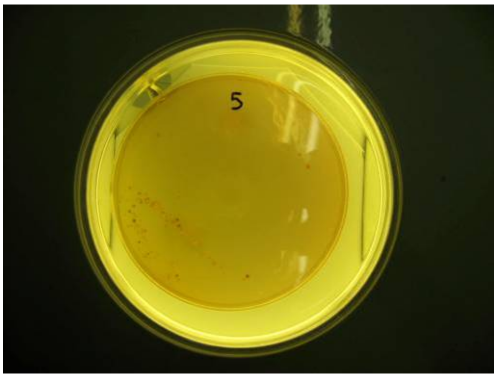
Andavadoaka beach



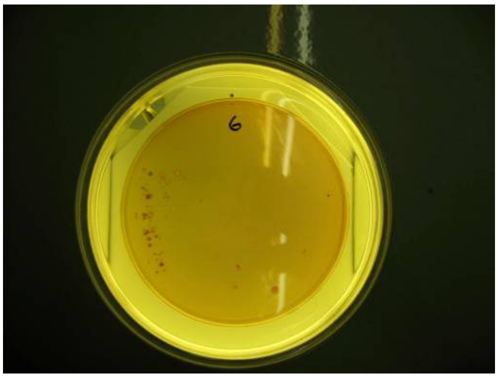
North beach



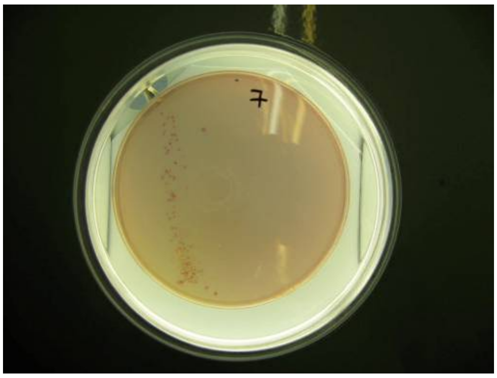
Ecolodge well



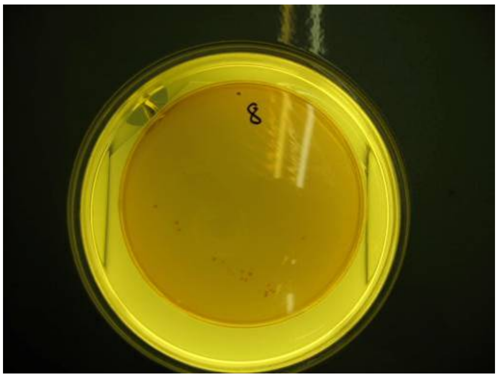
Spiny well



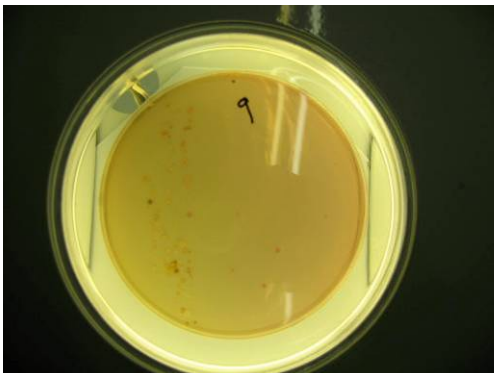
Well East



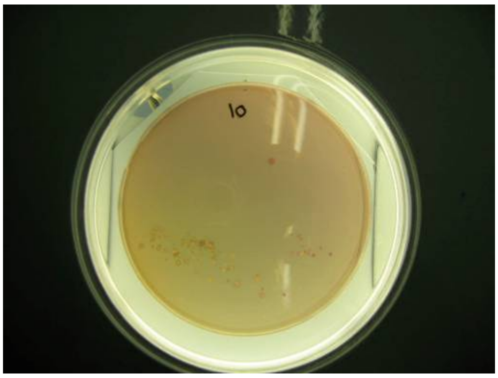
Spiny well



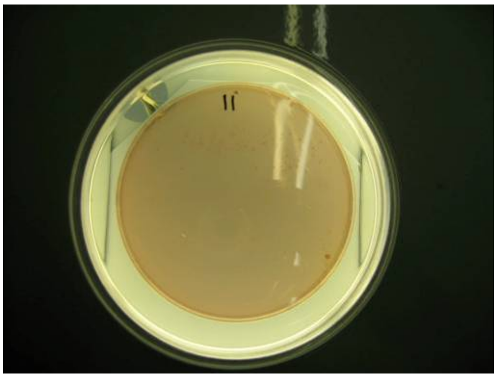
Well beside irrigation pond



Well South

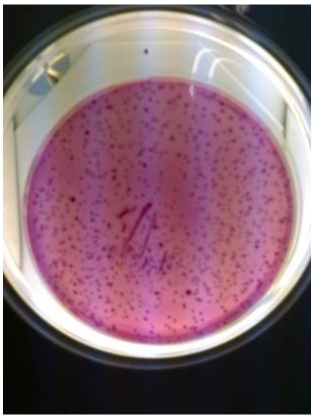


Coco Beach pipe



Halfmoon beach

Coco Beach pipe (set 1). (3500 cfu)



Well East (set 2). (1300 cfu)