Final Report
Rainwater Contamination
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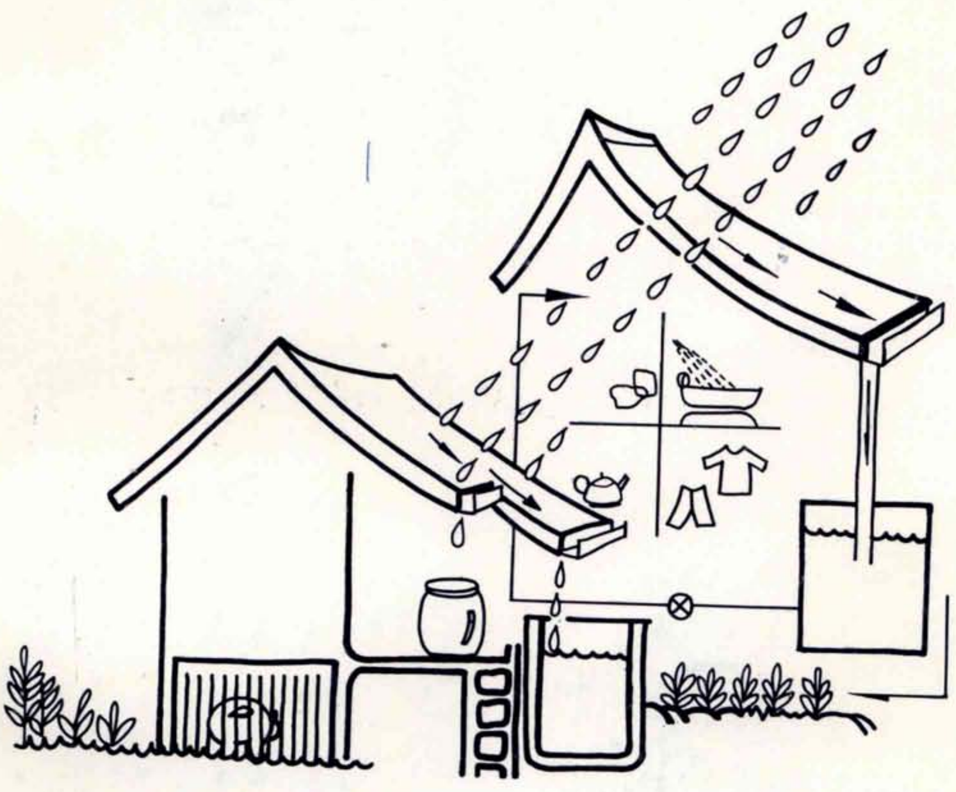
# EVALUATION OF RAINWATER QUALITY :
# HEAVY METALS & PATHOGENS



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Conducted by
Faculty of Engineering
Khon Kaen University
THAILAND.

# EVALUATION OF RAINWATER QUALITY : HEAVY METALS & PATHOGENS

A Final Report Submitted to

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by

**Faculty of Engineering**
**Khon Kaen University**
*Wanpen Wirojanagud*
*Patcharee Hovichitr*
*Pinthita Mungkarndee*
*Paiboon Bunyakarn*

**Faculty of Medicine**
**Khon Kaen University**
*Chariya Chomvarin*
**Environmental Health Center,**
**Region 4, Ministry of Health**
*Sarasin Auyyanonda*

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# PREFACE

One of the most important factors determining the health conditions of villagers, particularly in the Northeast of Thailand, is their lack of acceptable quality drinking water.

Water from deep wells in the Northeast usually contain high mineral concentrations making the water unpalatable to the villagers, while water from shallow wells, although palatable, is easily contaminated. Therefore, rainwater, a widely used water source, appears to be the most viable solution for providing acceptable quality and acceptable tasting drinking water for the village throughout the year.

Realising the benefits of using stored rainwater, the Thai-Australia Village Water Supply Project in conjunction with the Faculty of Engineering, Khon Kaen University (1984), promoted a national policy to implement a rainwater jar construction program which would provide sufficient rainwater storage to meet the needs of village households. However, even with a sufficient quantity of stored rainwater, the quality remains of questionable benefit to the villagers' health condition, as rainwater from roof catchment systems may be subjected to contamination via dirt or decaying debris on the roofs as well as the roofing material itself. The water stored in container may also be contaminated by using unclean storage containers.

Once the pathways of contamination are identified, mitigation measures may be carried out. Of course, the appropriate roofing material, gutter design, the manners in which rainwater should be stored, proper water handling, and rainwater usage practices must be considered for the mitigation to be successful. Therefore, the results from this study will be disseminated at the village level directly, and also to other governmental agencies (e.g. Department of Health, Accelerated Rural Development), and to a few non-profit private enterprises (such as, Population and Community Development Association) so that they may formulate the proper mitigation measures with these factors in mind.

Rainwater is a potentially safe and economic drinking water supply and it is hoped that the results from this research will help to improve the health, and sanitary conditions of water, in the villages.


| | |
|---|---|
| Principle Investigator: | Wanpen Wirojanagud |
| Co-Investigator: | Patcharee Hovichitr |
| Researchers: | Pinthita Mungkarndee<br>Chariya Chomvarin<br>Paiboon Bunyakarn<br>Sarasin Auyyanonda |


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# ABSTRACT

Rainwater would seem to be the most viable solution for providing enough acceptable quality drinking water to rural areas in developing countries. However, rainwater from roof catchment systems may be subjected to contamination from various sources, such as dirt, debris, decayed leaves, and excreta from birds and reptiles on the catchment systems' surface, thus affecting the potentially good quality of the stored rainwater.

In an attempt to assess the health risks associated with the consumption of rainwater, the quality of stored rainwater was analysed bacteriologically, using both indicator organisms and pathogen isolation, and chemically, by analysing heavy metal concentrations.

The route of contamination was also investigated by evaluating the quality of rainwater samples collected from various points along the route. They included roof and gutter systems, outdoor storage containers, and in-house storage containers. The source of the bacteriological contamination was investigated by using fecal coliform to fecal streptococci ratios (FC:FS).

The information on sanitary practices which appeared to affect the stored rainwater quality was also investigated by means of a questionaire and by visual observation.

The results from the bacteriological study of rainwater quality have shown that none of the rainwater samples collected met the drinking water quality standards established by WHO in 1971. All of the sampling points were bacteriologically contaminated, but higher rates of contamination were found in the samples collected from roof and gutter systems and in-house storage containers. The majority of the contamination at the roof and gutter system was of animal origin as well as most of the samples taken from the storage containers. However, it was found that the in-house storage containers had contamination of both animal and human origin. This indicated that in-house storage containers were subjected to secondary contamination via human mishandling as well as the initial contamination from animals.

Pathogenic contamination was found in a few of the samples collected from collection systems, outdoor storage containers, and in-house storage containers. The pathogens identified were *Salmonella group E* and *group C, Aeromonas sp.*, and *Vibrio parahaemolyticus.*

It was also found through the sanitary practices investigation that the unhygienic practices of the villagers were a major factor in bacterial contamination, and in secondary contamination of stored rainwater.

The heavy metals analysed in this study were Cd, Cr, Pb, Cu, Fe, Mn, and Zn. Most of the heavy metal concentrations taken from the various sampling points compared favorably with the WHO drinking water standards with two exceptions, Mn and Zn. However, Mn and Zn are considered to affect the aesthetic quality of drinking water only and were therefore, not significant to health.

The samples containing the high Mn and Zn concentrations were collected from roof and gutter systems (especially in the first rainfall samples). This was thought to be due to the metals being leached from the galvanized iron roofing material and thus, finding its way into the stored rainwater where the metals would settle to the bottom sediment layer of the storage containers through adsorption or precipitation.

The findings from this study indicate that any health risk evolving from the consumption of stored rainwater would be due to bacteriological contamination rather than from heavy metal contamination.

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# I. INTRODUCTION

A major concern of the Thai government's preventative health strategy is improving the quality of the village drinking water supply.

About 3,000,000 households in Thailand, 1,500,000 in the Northeast, lack sufficient water for a year round supply of drinking water. Due to considerations in the cost and quality of drinking water, rainwater storage would be considered the most viable alternative for supplying these drinking water needs. Traditionally, villagers rely on rainwater in the rainy season and ground water in the dry season. Thus, the present national policy is to implement a rainwater jar construcion project which will provide sufficient rainwater storage to meet the needs of these households within three to four years (1986-1990). This will be accomplished at a cost of 4,000 million baht.

## 1.1 Significance of the Problem

Considering the cost and labor expended for the provision of adequate rainwater storage, and the subsequent widespread use of rainwater for drinking, every effort should be made to minimize the health risks associated with the consumption of rainwater. To do this requires an assessment of the bacteriological and physical/chemical quality of rainwater.

The transmission of most water-borne diseases caused by pathogens, especially diarrhea, is via a fecal-oral route. This occurs when excreta from an infected individual (or occasionally from a healthy carrier who is asymptomatic for the disease) is transmitted to the mouth of another. Stored rainwater may serve as just such a transmission route if it is contaminated with fecal matter. In order to assess the role of rainwater in disease transmission, it is necessary to evaluate the rainwater quality in terms of fecal contamination which in turn, indicates the possibility of pathogen contamination.

Stored rainwater may also be contaminated with heavy metals. The possible sources for some heavy metals are: corroded collection surfaces (roofing materials), and/or other metal fixtures in the collection system, and bottom sediment containing concentrated levels of heavy metals being mixed with the upper layers of rainwater in a storage container. Most heavy metals, such as lead, chromium, and cadmium, are detrimental to health even at low concentrations.

This study will show the potential health risks associated with the consumption of stored rainwater by analysing the bacteriological quality (in terms of both indicator organisms and pathogens present) and the physical/chemical parameters (in terms of heavy metals present) of rainwater samples. This study will also demonstrate to what extent these risks are affected by various aspects of the rainwater collection and storage systems (e.g. corroded roofs or gutters made of galvanized iron).

## 1.2 Objective

The overall objective of this study is to investigate the quality of rainwater and the health risks associated with its consumption.

The specific objectives of this project include the following:

1) To investigate the effect of storage systems on the quality of rainwater collected, in terms of bacteriological and heavy metal contamination.

2) To determine the route of contamination in rainwater by testing samples at various sights along the handling route (from the point of rainwater collection in tanks to its final consumption), and by visual observation of water handling techniques.

3) To investigate the effect of water handling and usage practices on the level of secondary contamination.

4) To develop recommendations for the reduction of contamination in order to improve the quality of rainwater used for consumption.

## 1.3 Duration of the Study

This study was carried out over a two year period, from 1986 to 1988. Three villages were used as sampling stations.

# II. THEORETICAL BACKGROUND AND LITERATURE REVIEW

The lack of a safe, reliable source of year round drinking water is a persistent and serious problem in the Northeast of Thailand. To rectify this problem various aspects of the currently available water supply and its options were considered.

The best option was one which would minimize cost. This was considered technically feasible and socially appropriate while at the same time assuring good quality water according to the study conducted by the Thai-Australia Water Supply Project (1984). Results from this study are presented in Table 2.1. The water supply options considered included tubewells, open shallow wells, and sanitary shallow wells, ponds, and rainwater tanks and jars.

The most inexpensive option was open shallow wells at 49 baht/household/year. However, this advantage was offset by the poor quality of the water supplied by this source. This was due to both the villagers' unhygienic water collecting habits, and to the high iron and salt content frequently encountered in ground water in the Northeast.

Tubewells, which produced the best bacteriological water quality, (81% containing less than 2.2 organisms/100ml) failed not only because of their poor physical/chemical quality (only 12% passing WHO Standards), but also due to their high cost at 479 baht/household/year. Thus, rainwater jars and tanks with a low to moderate annual cost per household of 143 baht and 300 baht, respectively were two options more suitable to the average Thai village homeowner economically.

In addition to the acceptable cost, rainwater utilization has long been practiced and trusted as a drinking water source in Thai villages. This deemed rainwater tanks and jars as two socially appropriate options.

## 2.1 Previous Bacteriological Studies and their Implications

According to study discussed above (The Thai-Australia Village Water Supply Project, 1984) bacteriological test results showed that 69% of the samples taken from rainwater tanks and 67% of the samples taken from rainwater jars had MPN's less than the acceptable standard.

Another study conducted by the Department of Health (DOH) in 1984 found that bacteriologically, no source consistently provided high quality drinking water (Table 2.2). However, rainwater did show better quality than both water from shallow wells and water from public wells, yet it was still of poorer quality than water from the more expensive tubewells. This indicated that if rainwater could be safeguarded from contaminating organisms, it would be the most reliably safe and economic drinking water source in terms of its quality.

Results from a DOH study in Kalasin Province, revealed in its bacteriological analyses that some of the sources (rainwater tanks) had fecal coliform counts higher than the WHO Standard, but

**Table 2.1 Thai-Australia Water Supply Project (1985)***

| Source | Bacteriological Test Results Results as % of Samples | | Physical/Chemical Test Results | *** |
|---|---|---|---|---|
| | Meeting Standard (< 2.2 MPN) | Highly Polluted (> 240 MPN) | % Passing WHO Standard ** | Annual Cost/Household (baht) |
| Tubewell | 81% (1659) | 5% (1659) | 12% (319) | 479 |
| Open Shallow Well | 21% (4710) | 38% (4710) | 43% (89) | 49 |
| Sanitary Shallow Well | 72% (840) | 9% (840) | | 224 |
| Ponds | 18% (450) | 30% (450) | 8% (36) | 412 |
| Rainwater Tank | 69% (1587) | 6% (1587) | | 300 |
| | | | 90% (41) | |
| Rainwater Jar | 67% (497) | 7% (497) | | 143 |

Note (..) number in parentheses indicate number of samples

MPN = Most probable number

* from: Selection of Water Supply Facilities for the Northeast, Thai-Australia Water Supply Project; presented at: The Third Annual Conference on Appropriate Technology for Rural Development, February 16-17, Khon Kaen, Thailand.

** the guide lines used in making assessments are from the World Health Organization (WHO) 1983 document, WHO Guidelines for Aesthelic Quality and establish acceptable drinking water quality.

*** $\text{Annual cost} = \dfrac{\text{Amortised Capital Cost + Annual Maintenance Cost}}{\text{Number of Households Served}}$

based on the exchange rate of 28 baht = **$1** (US)

**Table 2.2 Summary of Results for the Analysis of the Physical/Chemical and Bacteriological Quality of Water in Northeastern Thailand, 1983**

| Source | Physical/Chemical Quality | | | | Bacteriological Quality | | |
|---|---|---|---|---|---|---|---|
| | Number of Samples | Results as % of Samples Good Quality | Acceptable Quality | Doesn't Meet Standard | Number Samples Samples | Results as % of Samples Good Quality | Doesn't Meet Standard |
| Shallow Well | 178 | - | 33.1% | 66.9% | 89 | 30.3% | 62.7% |
| Groundwater (Deep well) | 161 | - | 23.0% | 77.8% | 90 | 65.5% | 34.4% |
| Public Water Well | 5 | - | 20.0% | 80.0% | 6 | - | 100% |
| Rainwater Tank | 104 | 83.7% | 9.6% | 6.7% | 77 | 44.2% | 55.8% |

none of the samples were grossly polluted (Table 2.3). The bacteriological values ranged from 5 MPN/100ml to 46 MPN/100ml.

Table 2.4, lists results from another study, a joint project between the Armed Forces Research Institute of Medical Sciences (AFRIMS, 1984) and the Population and Community Development Association (PDA). This project established fecal coliform counts and isolated enteropathogenic bacteria from water sources in Mahasarakham Province, a province in the Northeast. Results showed that of 23 rainwater tanks being sampled over a 7 month period, 9 tanks had had high fecal coliform counts, while only 4% of the water sources sampled had enteric pathogens (*Shigella* and *Salmonella*) isolated.

The pathogens isolated were higher in number in water samples from jars and wells/ponds. In 7 months time, 14 out of the 16 jars had high fecal coliform counts with enteric pathogens in 2% of the cases (*Aeromonas* and *Salmonella*). For 9 wells/ponds, in 7 months time, 21 had high fecal coliform counts with enteric pathogens in 14% of the cases (*Aeromonas*, *Salmonella*, and *Shigella*).

This paper has analysed the contamination of rainwater using specifically selected indicator organisms and by isolating specific pathogens.

## 2.2 Indicator Organisms

An indicator organism is used to assess the level of fecal contamination. This is due to the difficulty in analysing the actual pathogens responsible for a disease state. These indicator organisms are more easily detected than the pathogens in question while not themselves being pathogenic.

In the past, total coliform counts have been used as an indicator of fecal contamination. It is now recognized that many species in the total coliform group are non-fecal in origin and are present naturally in unpolluted soils and water. Therefore, the total coliform group is not a specific indicator of fecal contamination and fecal coliform is considered a more specific indicator of fecal contamination (Evison and James, 1977).

The fecal coliforms include the genera: *Escherichia coliform* (*E. coli*), *Klebsiella*, and *Citrobacter*. *E. coli* is exclusively fecal in origin (Evison and James, 1977), while *Klebsiella* and *Citrobacter* are of uncertain origin and are possibly non-fecal. Therefore, *E. coli* was used as the indicator organism of choice to assure the fecal coliform's origin.

It may be noted that fecal streptococci has been suggested for use as another indicator organism as it is also of fecal origin. Therefore, the water samples in this study were cultured for the enumeration of total coliform, fecal coliform, *Escherichia coliform*, and fecal streptococci.

## 2.3 Isolation of Pathogens

As mentioned previously, fecal coliform indicates that there is some degree of fecal contamination

**Table 2.3 Title : Report on the Analysis results of Water Quality : by Environmental Science Section, Environmental Health Division, Department of Health.**

**Project to Protect Drinking Water**

**Kalasin Province**

| Location | Source* | Physical/Chemical Quality mg/l | | | | | | Turb. units | Bacteriological Quality Fecal coliform org/100 ml |
|---|---|---|---|---|---|---|---|---|---|
| | | Cu | Pb | Fe | Mn | Cl ⁻ | PH | Turb | |
| Wat Ba We Wag Samak Dee | RT | 3.91 | 0.91 | | | | | | 22 |
| Ban Wang School | RT | 9.63 | 0.41 | | | | | | 13 |
| Wat Ban Wang | RT | 12.31 | 0.41 | | | | 10.0 | | |
| Wat Ban Wang | DW | 7.85 | 0.36 | 4.95 | 1.73 | | | 78 | |
| Wat Ban Kong Baw | DW | 6.71 | 0.53 | 4.19 | | 7.00 | | | |
| Ban Kok Sri | DW | 6.42 | | 2.21 | | | | 58 | 13 |
| Ban Kon Pung School | RT | 7.41 | 0.72 | | | | | | |
| Wat Ban Kong Baw | RT | 7.27 | 0.73 | | | | | | |
| Ban Kok Sri | RT | 7.07 | 0.63 | | | | | | 17 |
| Ban Na Du Health Center | RT | 3.63 | 0.23 | | | | | | 46 |
| Ban Nong Pew Health Center | RT | 5.41 | 0.39 | | | | | | 46 |
| Ban Nam Bun | SW | | | | | | 5.5 | | 5 |
| Ban Kon Hwai | SW | 4.39 | | | | | 5.5 | | 46 |
| Ben Na Du | PW | 1.73 | | | | | | | |
| Hong He Witaya School | RT | | 0.28 | | | | | | 13 |
| Nong Bua Nuai School | RT | 8.95 | 0.58 | | | | | | 8 |
| Ban Kok Yai | DW | 8.26 | 0.69 | 2.95 | | | 5.5 | | |
| Ban Kok Yai | DW | 5.46 | | 1.23 | | | 5.0 | | |
| Hong He Witaya School | DW | 4.78 | | | | | | | |
| Some cha swang wit School | DW | | 1.88 | | | | 6.0 | | |

* RT = Rainwater tank (cement), DW = Deep well SW = Shallow well Turb = Turbidity

**Table 2.4 Number of water samples of source which contained 10 or more fecal coliforms and potential enteric pathogens from August, 1983 to February, 1984, Mahasarakham, Thailand.**

| Month | FC* | PDA Rainwater tanks; N=23 Pathogen** | FC | Tank/Jar N=16 Pathogen | FC | Well/pond N=9 Pathogen |
|---|---|---|---|---|---|---|
| August | 0 | None | 0 | None | 6 | None |
| September | 0 | None | 5 | None | 4 | Aeromonas(3) |
| October | 1 | Shigella(1) | 2 | None | 4 | None |
| November | 7 | Shigella(1) | 3 | Aeromonas(1) | 4 | Aeromonas(3) |
| December | 0 | Shigella(2) | 0 | None | 0 | None |
| January | 1 | Shigella(1) | 4 | None | 3 | Salmonella(1) Shigella(1) |
| February | 0 | Salmonella(1) | 0 | Salmonella(1) | 0 | Salmonella(1) |
| **TOTAL** | **9** | **(4 %)*** ** | **14** | **(2 %)** | **21** | **(14 %)** |

*** Number of samples with 10 or more fecal coliforms/100 ml water.

** Enteric pathogen isolated and the number of tanks from which the pathogen was isolated.

*** Averaged percent of samples with enteric pathogen isolated of each month for 7 months sampling period.

present in the sample thus, indicating that the water may contain some pathogenic agents and any isolation of these pathogens in the rainwater would accurately support the assumption that there are health risks associated with its consumption.

The possible disease causing organisms in Thailand are numerous. Therefore, Thailand's provincial health records were consulted to determine the major health problems that may be due to water-borne disease transmission. Tables 2.5 through 2.7 show the occurrence by month and age of the major water sanitation related diseases in Khon Kaen Province for the years 1982, and October, 1983 through September, 1984. These tables showed that the major health problem was acute diarrhea with 7409 cases in the years 1983 through 1984, and 5227 cases in 1982. The other health problems were; dysentery with 878 cases in 1982, and 842 cases occurring from 1983 through 1984; and bacillary dysentery with 589 cases occurring between the years 1983 through 1984. All the other counts were less than 100 cases per year.

The other trends evident from this data were that:

1) The major occurrences of acute diarrhea were during the months of January through July (generally coinciding with the cool and dry season) and decreasing in August (one to two months after the rainy season had begun).

2) The cases of dysentery and bacillary dysentery also appeared to be greater from February through June during the dry season and early rainy season.

3) The major occurrences of diarrhea occurred in infants under three years of age with the highest occurrence between the ages of 1 to 11 months. This trend was also true for dysentery and baciliary dysentery.

While these results indicate the magnitude of the problem they do not reveal the etiological background of acute diarrhea. Therefore, the pathogen(s) responsible for the high morbidity of acute diarrhea remain unknown.

This information was derived from reviewing the results of diarrheal research studies conducted at various hospitals throughout Thailand.

It is the intention of the present study to isolate the common pathogens present in rainwater that may be responsible for this high acute diarrheal morbidity. However, the study's results must be applied carefully. The presence of pathogens in rainwater is not conclusive proof that its consumption is responsible for the high morbidity of diarrheal diseases. This is particularly true as knowledge of infective doses is as of yet uncertain, especially considering the following:

1) Malnourishment may lower the required infective dose to induce disease.

2) The populace may develop an acquired immunity for any disease endemic to an area, thus increasing its infective dose.

It is also necessary to recognize that all of the diarrheal diseases considered here can be spread by a more direct fecal-oral route via poor sanitation and/or poor personal hygiene. Any attempt to pinpoint the most common or most critical transmission route would require an integrated study considering many more aspects than what was analysed in this study.

**Table 2.5 Occurrence by Month of the Major Water and Sanitation Related Diseases in Khon Kaen Province, 1982**

| Disease | Months | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | JAN | FEB | MAR | APP | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | TOTAL |
| Acute Diarrhea | 649 | 434 | 444 | 581 | 612 | 595 | 426 | 255 | 194 | 340 | 324 | 373 | 5227 |
| Cholera | | | | | | 1 | | | | | | | 1 |
| Dysentery | 61 | 96 | 105 | 88 | 53 | 101 | 77 | 61 | 74 | 94 | 83 | 65 | 878 |
| Enteric fever | 2 | 7 | 9 | 5 | 4 | - | 10 | 2 | 4 | 7 | 4 | 4 | 58 |
| Hepatitis | 13 | 16 | 10 | 16 | 20 | 10 | 21 | 28 | 10 | 21 | 11 | 9 | 185 |
| Poliomyelitis | 1 | 1 | 1 | 1 | | 1 | 2 | 1 | 2 | | 1 | | 10 |

**Table 2.6 Occurrence by Month of the Major Water and Sanitation Related Diseases in Khon Kaen Province, October, 1983 through September, 1984.**

| Disease | Months | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | TOTAL |
| Diarrhea | 1034 | 995 | 912 | 896 | 893 | 1027 | 697 | 561 | 213 | 95 | 96 | 86 | 7409 |
| Dysentery | 47 | 76 | 126 | 125 | 98 | 103 | 56 | 60 | 40 | 46 | 33 | 32 | 842 |
| Bacillary-Dysentery | 25 | 37 | 53 | 102 | 71 | 79 | 79 | 60 | 17 | 21 | 25 | 20 | 589 |

**Table 2.7 Occurrence of Water-Borne and Sanitation Related Disease in Khon Kaen Province (October, 1983 - September,1984)**

| Age | Number of Cases | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Diarrhea | Dysentery | Cholera | Bacillary Dysentary | Hepatitus A | Poliomyelitis | Typhoid | Enteric fever | Amoebic Dysentary |
| 0-27 days | 66 | - | - | - | - | - | - | - | - |
| -11 months | 1364 | 83 | | 63 | - | 1 | - | - | 2 |
| 1- | 984 | 82 | | 45 | - | 5 | - | - | 8 |
| 2- | 442 | 61 | | 52 | - | 3 | - | - | 3 |
| 3- | 212 | 32 | | 33 | - | 1 | 1 | - | 2 |
| 4- | 134 | 23 | | 18 | - | 1 | 1 | 2 | - |
| 5- | 97 | 13 | | 10 | 3 | - | - | - | 1 |
| 6- | 105 | 11 | | 10 | 2 | - | 2 | 4 | 1 |
| 7-9 | 272 | 24 | | 26 | 7 | 1 | 2 | 5 | 3 |
| 10-14 | 355 | 41 | | 31 | 7 | 1 | 8 | 13 | - |
| 15-24 | 783 | 96 | | 53 | 34 | - | 15 | 21 | 7 |
| 25-34 | 684 | 93 | 1 | 64 | 9 | - | 3 | 17 | 10 |
| 35-44 | 528 | 91 | 1 | 48 | 4 | - | 2 | 11 | 5 |
| 45-54 | 485 | 80 | | 47 | 1 | - | - | 7 | 2 |
| 55-64 | 441 | 67 | | 41 | 1 | - | 3 | 3 | 6 |
| 65 | 446 | 45 | 1 | 28 | - | - | - | - | 5 |
| **Total** | **7409** | **842** | **3** | **589** | **68** | **13** | **37** | **83** | **55** |

## 2.4 Previous Physical/Chemical Studies and their Implications

The following studies involving heavy metal analysis and rainwater collection systems have shown that some heavy metals may be present in cistern water in concentrations exceeding the United States Environmental Protection Agency's (USEPA) and WHO's Standards for drinking water. The metals of prime importance are: Lead (Pb), Zinc (Zn), and Cadmium (Cd). The possible sources for these metals may be the corrosion of zinc coatings on galvanized iron roofs (which frequently contain Pb and Cd as impurities) being washed into the storage containers, metal fixtures releasing heavy metals into the water, and cistern sediment containing high concentrations of settled heavy metals being disturbed and mixing with the upper layers.

A study by Gumbs and Dierberg (1984), supported the latter theory as no cistern water samples taken from the upper undisturbed layers of water contained Zn, Cd, or Pb concentrations in excess of USEPA Standards where rainwater taken from the bottom layers did.

These bottom layer samples had concentrations in excess of USEPA Standards in 22% of the cases for Zn, 39% of the cases for Pb, 6.5% of the cases for Cr, and 11% of the cases for Cd. Gumbs and Dierberg noted that any method used to withdraw the water sample which disturbed the bottom layer of sediment in cisterns could release hazardous levels of toxic heavy metals into the upper layers of rainwater.

The samples in this study taken from kitchen taps had concentrations in excess of the standards for Pb in 6.5% of the cases, and for Cd in 2.2% of the cases, indicating that the distribution system (metal fixtures) was another possible source of heavy metal contamination as previously suggested.

A study by Waller, et.al. (1984), noted higher Zn concentrations in downspout samples compared to precipitation samples, but no conclusive source was determined for this happening. Metal concentrations were higher in tap water samples for Cu, Pb, and Zn than in cistern water samples, again indicating that the distribution system was the source of contamination.

A study of 12 cistern water systems in the Virgin Islands (Lee and Jones, 1982) revealed that cistern water generally did not exceed USEPA Standards for Zn, Cu, Pb, Cr, Ni, Cd, Fe, and Mn.

Sharpe and Young (1982), analysed water samples from 40 roof catchment cistern systems in rural areas. Most of the cistern water samples did not exceed the USEPA Standards for Pb, Cu, and Cd. However, during 3 sampling periods Pb did exceed the maximum permissible standard; 55% during the first period, 42% during the second period, and 59% during the third testing period. Sharpe and Young also revealed that at times, sediment water samples greatly exceeded the standards for Pb and Cd.

Other analytical results of the physical/chemical and bacteriological quality of drinking water was obtained by the Department of Health (DOH) in 1984 and is given in Table 2.2. Rainwater exhibited the highest physical/chemical quality with 83.7% of the samples having good quality, as defined by WHO's Drinking Water Standards (1971). This compared better than shallow well water, water from tubewells, and public wells, in which water did not meet the physical/chemical quality standards. These results were supported by the Thai-Australia Village Water Supply study (1985), where 90% of the rainwater samples passed WHO Standards (Table 2.1).

An additional study conducted by the Department of Health (1984) analysed water from various sources in Kalasin Province, approximately 70 Km from Khon Kaen. The results are shown in Table 2.3.

The most prominent problem encountered with all of the water sources was an excess of copper and lead. According to the DOH results, the copper concentrations were unacceptable and ranged from a low of 1.73 mg/l to a high of 12.3 mg/l, while the lead concentrations varied from a low of 0.28 mg/l to a high of 0.73 mg/l, also an unacceptable concentration. Another heavy metal present in a high concentration was iron, but this was only reported in water samples from deep wells. One deep well also had a high manganese and turbidity level, while two others had a high chloride and turbidity level, respectively.

Another study conducted by Bunyaratpan and Sinsupan (1984) studied the effect of the type of collection surface (roofing material), and the age of the storage tanks on the quality of stored rainwater. Partial results from the studies are given in Table 2.8. The Table lists only those parameters which did not meet WHO Standards (1971). Three types of roofs were considered in the study: thatch, asbestos cement, and galvanized iron. The type of the roof collection system appeared to have little effect on the quality of water from roof runoff, although iron was higher in runoff from asbestos cement roofs (it may be noted that in only 6% of the cases were the iron concentrations above the maximum permissible limit of 1.0 mg/l). The reason for this difference in iron levels remains unclear, although Bunyaratpan and Sinsupan suggested that it may be due to dirt collecting on the roof surface and hence, being washed into the storage tanks and therefore, not due to the type of roofing material itself.

Table 2.8, reveals that the major problems with roof runoff and the stored rainwater were the undesirable high manganese and iron concentrations, and the undesirable pH levels.

High manganese concentrations were a problem in 14% of the samples and the pH values were lower than the recommended values, but not out of the range expected for rainfall. Bunyaratpan and Sinsupan, did not make any suggestions as to why the manganese levels were escalated. No source was suggested.

A small percentage of the samples had iron values above the maximum recommended limit. Values much higher than this limit would not necessarily present a health hazard, but would make the water unpleasant in taste. A greater concern was the source of this iron. If the high iron concentration was due to corrosion of the collection surfaces or other metal fixtures in the system it may be assumed that other detrimental heavy metals such as Pb, Cr, and/or Cd may be concomitantly leached from the system as well, causing additional health problems. This corrosion is observed in conjunction with water having a low pH.

**Table 2.8 Effects of Type of Collection System and Type and Age of Storage Container on the Quality of Stored Rainwater (after Bunyaratapan and Sinsupan, 1984)**

**a) Roof-Collection System**

| Type of Roof | No. of Samples | Sampling Period | pH | Mn (mg/l) | Fe (mg/l) |
|---|---|---|---|---|---|
| 1. Asbestos cement | 14 | Feb. 82-June 82 | 4.8-6.3 | 0-0.96 | 0-1.4 |
| 2. Asbestos cement | 7 | April 82-May 82 | 5.5-6.0 | 0-0.6 | 0.01-1.24 |
| | | | (5.7) | (0.15) | (0.21) |

**b) Old Storage Tanks**

| Source | No.of Samples | Sampling Period | Mn (mg/l) | pH |
|---|---|---|---|---|
| 1. Mortar Jar | 11 | July 82-Nov. 82 | 0-0.13 | 5.7-8.2 |
| | | | (0.03) | (7.3) |
| 2. Mortar Jar | 6 | July 82-Oct 82 | 0-0.13 | 6.0-6.7 |
| | | | (0.03) | (6.3) |
| 3. Mortar Jar | 8 | Aug. 82-Oct. 82 | - | - |
| 4. Reinforced Concrete | 12 | June 82-Nov. 82 | - | 5.9-7.4 |
| | | | | (6.7) |
| 5. Bamboo Reinforced | 10 | Aug. 82-Dec. 82 | - | - |

*** numbers indicate range of results; average result in parentheses

**Table 2.8 (cont'd)**

**c) New Storge Tanks**

| Type of tank | No. of Samples | Sampling Period | pH | Fe(mg/l) |
|---|---|---|---|---|
| 1. Brick Tank | 11 | July 83-March 84 | 8.5-11.5 (10.2) | 0.0-0.24 (0.07) |
| 2. Brick Tank | 11 | June 83-Feb 84 | 9.2-11.2 (10.5) | 0.04-2.40 (0.40) |
| 3. Brick Tank | 11 | July 83-May 84 | 7.9-10.2 (9.5) | 0.04-0.72 (0.24) |
| 4. Brick Tank | 8 | June 83-Dec 83 | 8.9-10.4 (9.5) | 0.02-0.26 (0.10) |
| 5. Ferrocement | 11 | June 83-Feb 84 | 8.5-10.6 (9.8) | 0.04-0.42 (0.15) |
| 6. Ferrocement | 14 | July 83-May 84 | 8.7-10.5 (9.8) | 0.01-0.56 (0.19) |
| 7. Ferrocement | 14 | June 83-May 84 | 6.9-10.2 (8.7) | 0.02-1.60 (0.37) |

A comparison was drawn between samples taken from old storage tanks, (containers which included mortar jars, reinforced concrete, and bamboo reinforced tanks) and new storage tanks (which were built out of cement bricks or ferrocement). The analyses' results for water from old storage tanks demonstrated that pH and Mn levels did not always meet WHO Standards. The table showed that the pH values were again within the normal range expected for rainfall (5.3-5.8). However, they were still below WHO's recommended limit of 6.5. All of the samples from old storage tanks had acceptable Mn concentrations below the value of 0.01 mg/l and only 6% of the samples had Mn concentrations higher than 0.01 mg/l.

All of the new storage tanks had pH values above the maximum permissible limit of 9.2, regardless of the type of new tank sampled, be it brick of ferrocement. Although this elevated pH trend was displayed more strongly in some tanks than others, there was a general decrease of pH to acceptable limits in all of the tanks over a period of time. Thus, the initial high pH values were probably due to the stored rainwater leaching alkaline materials from the tank. Thus, the pH would gradually decrease as these materials were depleted from the tank itself. This was supported by the low pH values reported in water samples from old storage tanks.

Iron was occasionally higher in the new storage tanks as well, but only in four cases (5%) was it greater than the maximum permissible limit.

The results from this study revealed that the stored rainwater was contaminated with some chemicals which caused an increase in some heavy metal concentrations (iron and manganese) and an undesirable pH level. Even so, the failure to meet the pH standard was not critical as pH is an aesthetic standard and not strictly detrimental to health. Any values above or below the recommended standards do not render water unfit for human consumption. A high pH does not render water unpalatable either as villagers used the water which possessed high pH values from the new tanks for drinking purposes.

The major problem associated with water possessing a low pH is its corrosive nature. The potential for corrosion is highest from the roof and gutter systems made of galvanized iron, thus leading to heavy metal contamination.

Two aspects of the Bunyaratpan and Sinsupan study was recommended for further investigation:

1) Bacteriological quality, and

2) The possible contamination source of heavy metals being from corroded collection surfaces.

## 2.5 Heavy Metals

Cadmium (Cd), is a biologically nonessential and nonbeneficial element. It is potentially highly toxic and has been implicated in cardiovascular disease, particularly hypertension. There is a cumulative retention of Cd in hepatic (liver) and renal (kidney) tissues and it has been associated with Itai Itai disease. A disease which causes gradual bone disintegration. The standard for Cd is a strict health standard and has been set at 0.010 mg/l (NAS, 1972).

Copper (Cu), is an essential and beneficial element in human metabolism. Its presence can impart an astringent taste to water and cause some discoloration. The limit for Cu is 1.0 mg/l and is considered an aesthetic limit rather than one of health (NAS, 1972).

Lead (Pb), is toxic in both acute and chronic exposures. Acute lead toxicity is characterized by a burning sensation in the mouth, severe thirst, inflammation of the gastro-intestinal tract, with vomiting and diarrhea. Chronic toxicity produces anorexia, nausea, vomiting, severe abdominal pain, paralysis, mental confusion, visual disturbances, anemia, and convulsions. The standard for Pb is based on its toxicity and is set at 0.05 mg/l (NAS,1972).

Iron (Fe), is an essential element in human nutrition. It is contained in a number of biologically significant proteins. However, the presence of iron in drinking water supplies is objectionable for a number of reasons unrelated to health. Water containing insoluble ferric salts often tastes unpalatable and its rust color stains laundry and plumbing fixtures. Fe, also promotes the growth of bacteria which then produce a slimy coating on metal piping. Therefore, the guidelines for drinking water have been recommended at 0.3 mg/l (WHO, 1984).

Manganese (Mn), is an essential element in animals and man. It is required as a co-factor in a number of enzyme systems. However, much like Fe, its presence in drinking water supplies may be objectionable for a number of reasons unrelated to health. Mn, concentrations exceeding 0.15 mg/l imparts an undesirable taste to water and stains laundry and plumbing fixtures. Mn, guidelines have been set at 0.1 mg/l (WHO,1984) based on these staining qualities.

Zinc (Zn), is also an essential and beneficial element in human metabolism. Its presence in water may cause an astringent taste, opalescence, and makes a sand- like deposit. Its limit is set at 5.0 mg/l (NAS, 1972 and WHO, 1971).

## 2.6 Secondary Contamination

Secondary contamination is the contamination which occurs between the point of withdrawing rainwater from a storage container and the point of the rainwater's consumption. One probable route of secondary contamination would be the use of unclean carrying vessels to transport rainwater from the storage tank container to the in-house storage container which would cause a significant deterioration of rainwater quality.

As discussed in section 2.4, secondary contamination may also be responsible for high pH levels where chemicals from the rainwater container itself had leached into the stored rainwater (Bunyaratpan and Sinsupan, 1984). This was supported by the fact that the pH levels decreased to acceptable limits as the chemicals were depleted from the storage container over time.

There was also an elevation of heavy metal concentrations due to secondary contamination as discussed in section 2.4 (Gumbs and Dierberg, 1984). This occurred when sediment containing heavy metals was disturbed allowing the metals to be released into the upper layers of the stored rainwater.

The sources of secondary contamination was observed and analysed in this study.

# III. METHODOLOGY

## 3.1 Selection of the Sampling Station Villages

Khon Kaen province is composed of 1600 villages. Most of the villages are generally recognized as rural villages. The physical environment such as; housing, toilet, water sources, and the behavioral practices of the villagers (Sanitation and water handling practices) in all the villages are quite similar. Therefore, for sampling convenience and to satisfy statistical analysis in terms of data replication, three villages with similar conditions were chosen for sampling.

Three days were spent surveying the villages for sampling station selection. A village meeting was conducted at the same time as the village survey. The scope and purpose of this project was explained to and discussed with the village head masters and village committees. The villagers' willingness to cooperate with the research team was also considered to be of vital importance in the selection of the villages.

Three villages which were not far from Khon Kaen University, Ban Kok-Phan-Pong, Ban Dang-Noi, and Ban Non-Tun, were chosen for this study (Figure 3.1). All of three of these villages were easily accessible by dirt road and no village was more than 5 kilometers from a health station. Six to seven households in each village were selected as sampling stations. The selection of these households was based on the following criteria:

1) The storage tanks at the selected households contained enough water to last one year for sampling.

2) The storage tanks and collection facilities were available for investigating the effects of type of rainwater storage on rainwater quality, and

3) The cooperativeness of the household members.

A survey of the alternative drinking water sources was also included in this investigation to allow a comparison of alternative sources'quality to the quality of the stored rainwater. Thus, adding weight to the assumption that rainwater is the most viable source of drinking water in the village.

## 3.2 Equipment

The equipment in this study included the following:

1) An atomic absorption spectrophotometer (AA). It was used for heavy metal analysis.

2) A composite automatic roof and gutter water sampler was specifically designed with the capability of collecting rainwater samples from roof and gutter systems at varied time intervals. The sampler was composed of 3 cylinderical containers connected in a vertical series (Figure 3.2). This sampler was then connected to the bypass of a storage container that so when it rained, water from the roof and gutter were collected at three different time intervals. The first few minutes of rainfall was collected in the bottom container, the middle container collected rainfall after another few minutes had passed, and the top container collected the last time interval.

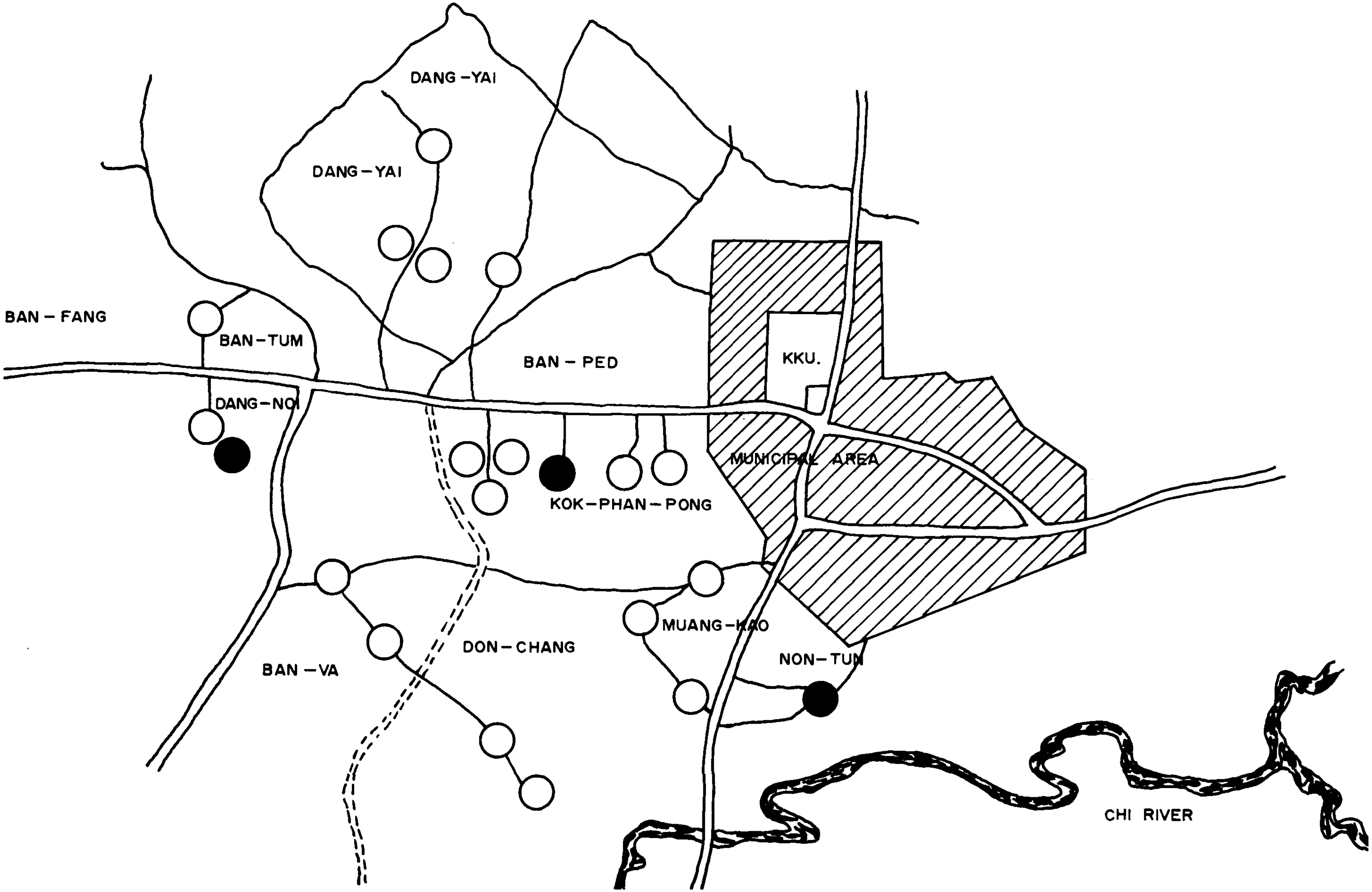



Figure 3.1 Location of the Villages Selected as Sampling Station.

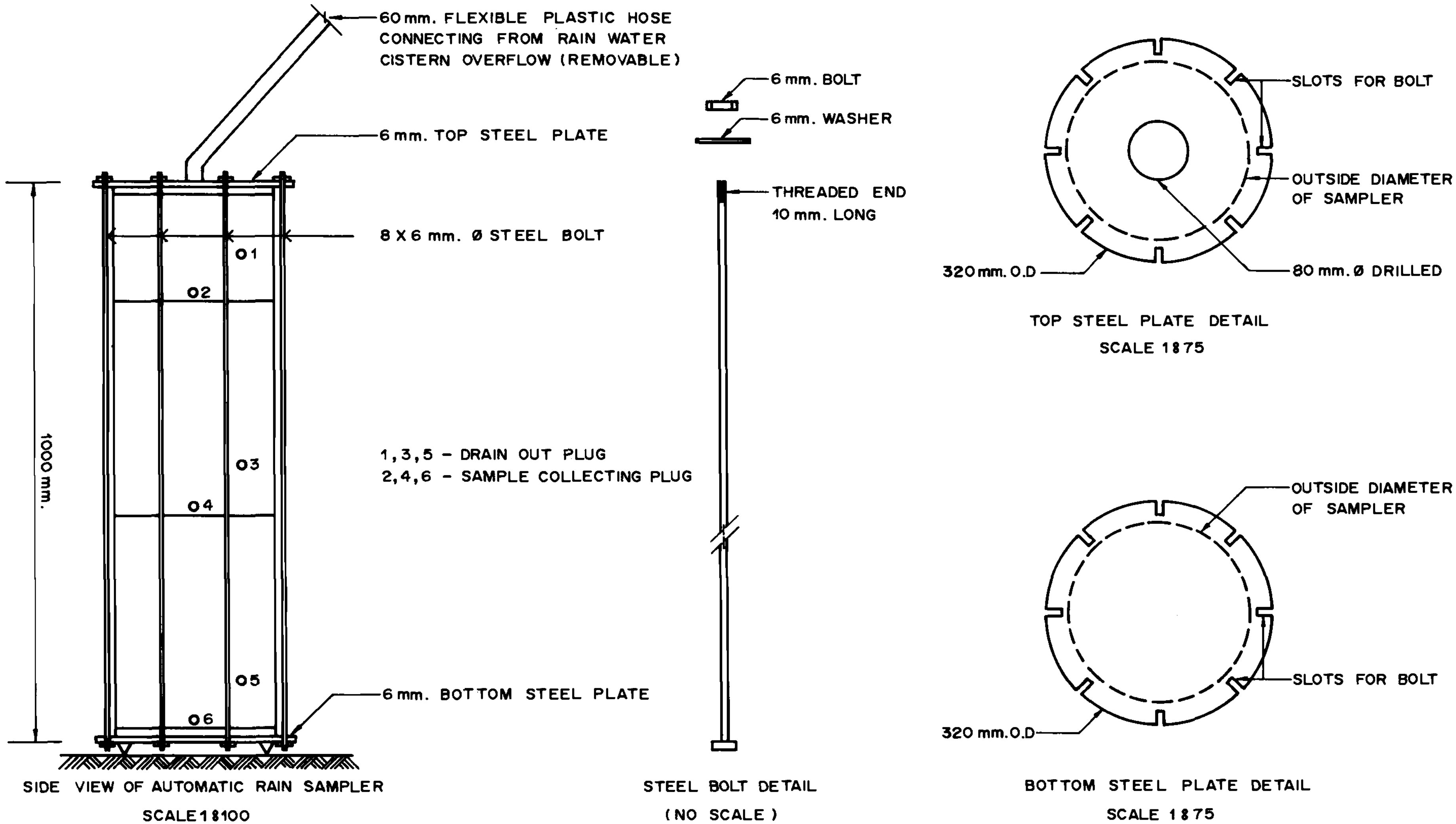
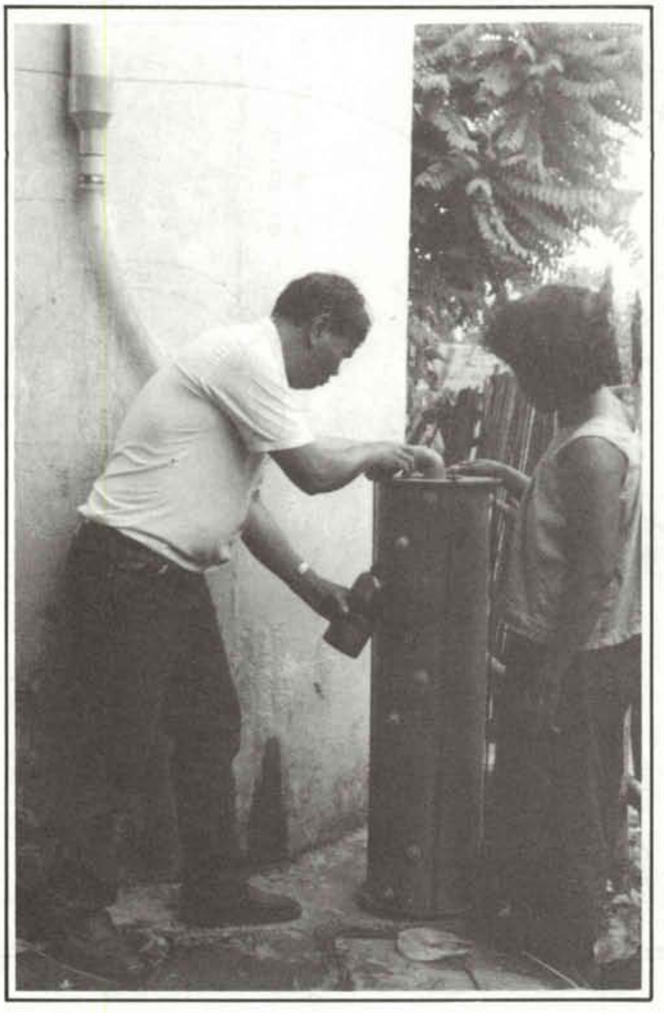
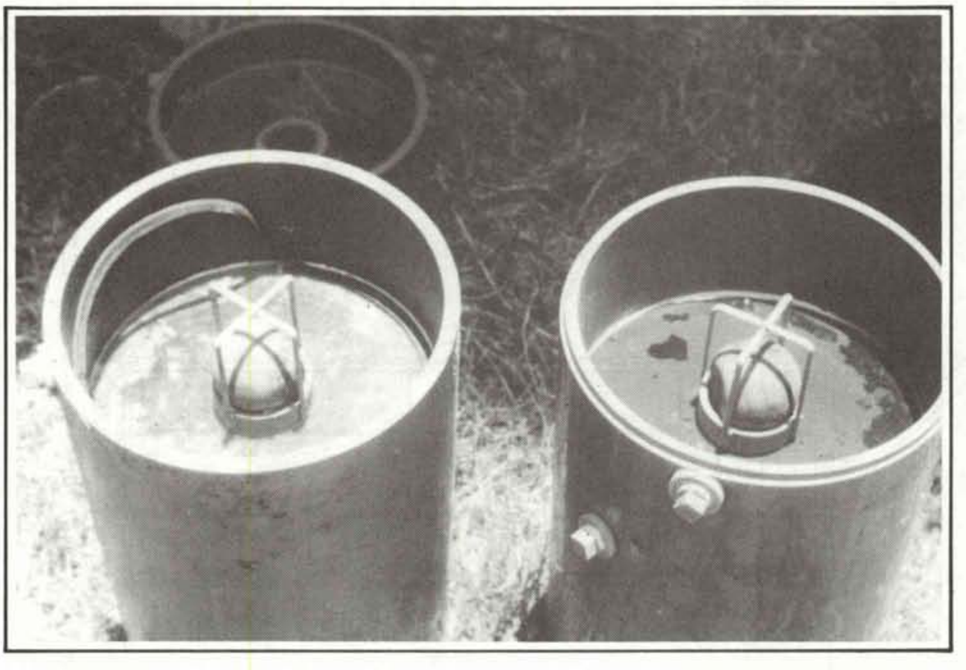



**Figure 3.2 Composite Automatic Roof and Gutter Water Sampler.**



**Picture 1 Composite Automatic Roof and Gutter Water Sampler.**



**Picture 2 Details Structure of Composite Automatic Roof and Gutter Water Sampler.**

3) An atmospheric rainwater sampler (Figure 3.3). This sampler was made from a 50 litre PVC water bottle with a funnel formed by cutting the top half and inverting it onto itself with a PVC pipe connecting the funnel (top half) with the bottom.

## 3.3 Water Sample Collection

An attempt was made to collect atmospheric rainwater to provide a baseline for a rainwater quality comparison. It was assumed that atmospheric rainwater is free of any organisms and does not exceed the heavy metal concentration standards established by WHO in 1971.

Evaluating the route of rainwater contamination in terms of pathogens and heavy metals required that all of the possible sources of contamination from the roof to the storage container be investigated. The possible points of contamination included:

1) Roofing materials causing heavy metal contamination, as well as decaying leaves and excreta on the roof tops causing bacteriological contamination,

2) Gutters causing heavy metal contamination,

3) Storage containers, or the manner in which the water was stored (i.e. jars with or without taps) causing pathogenic contamination, and

4) Storage containers in the home as a site of secondary contamination.

There were several types of storage containers used in this study; three were concrete tanks, and another three were rainwater jars. Five samples were taken from each of the selected households. For instance, three samples were taken from roofs with gutters, one sample from a storage container, and one sample from a container located in the home. Another four samples were collected from outside of the households. Two samples were collected from the atmosphere, and one to two samples were collected from shallow wells, as they were used as an alternative drinking water source. The sampling design is shown in Figures 3.4 and 3.5. The sampling and the number of collected samples are summarized in Table 3.1.

All of the collected sample types were analysed for bacteriological and heavy metal contamination. There were five types of samples collected. They included:

1) Atmospheric Rainwater – Two samples were collected from each village using an atmospheric rainwater sampler, to provide a quality baseline for atmospheric rainwater. This type of collection required the household owners to participate in the sample collection. Each owner was instructed in how to properly procure the rainwater sample by demonstration by the research team. However, it was found that this method of instruction and collection was not sufficient to insure good quality sample collection and many of the samples were obviously contaminated. Therefore, all of the atmospheric rainwater samples were disregarded and an ideal baseline of atmospheric rainwater being free from any bacteria and lower in heavy metal concentration than the standards established by WHO was used.

2) Roof and Gutter Rainwater – Three composite samples were taken from each of the selected households' roof and gutter systems. The materials used for the roofing included asbestos cement and galvanized iron, but only galvanized iron was used for the gutters.

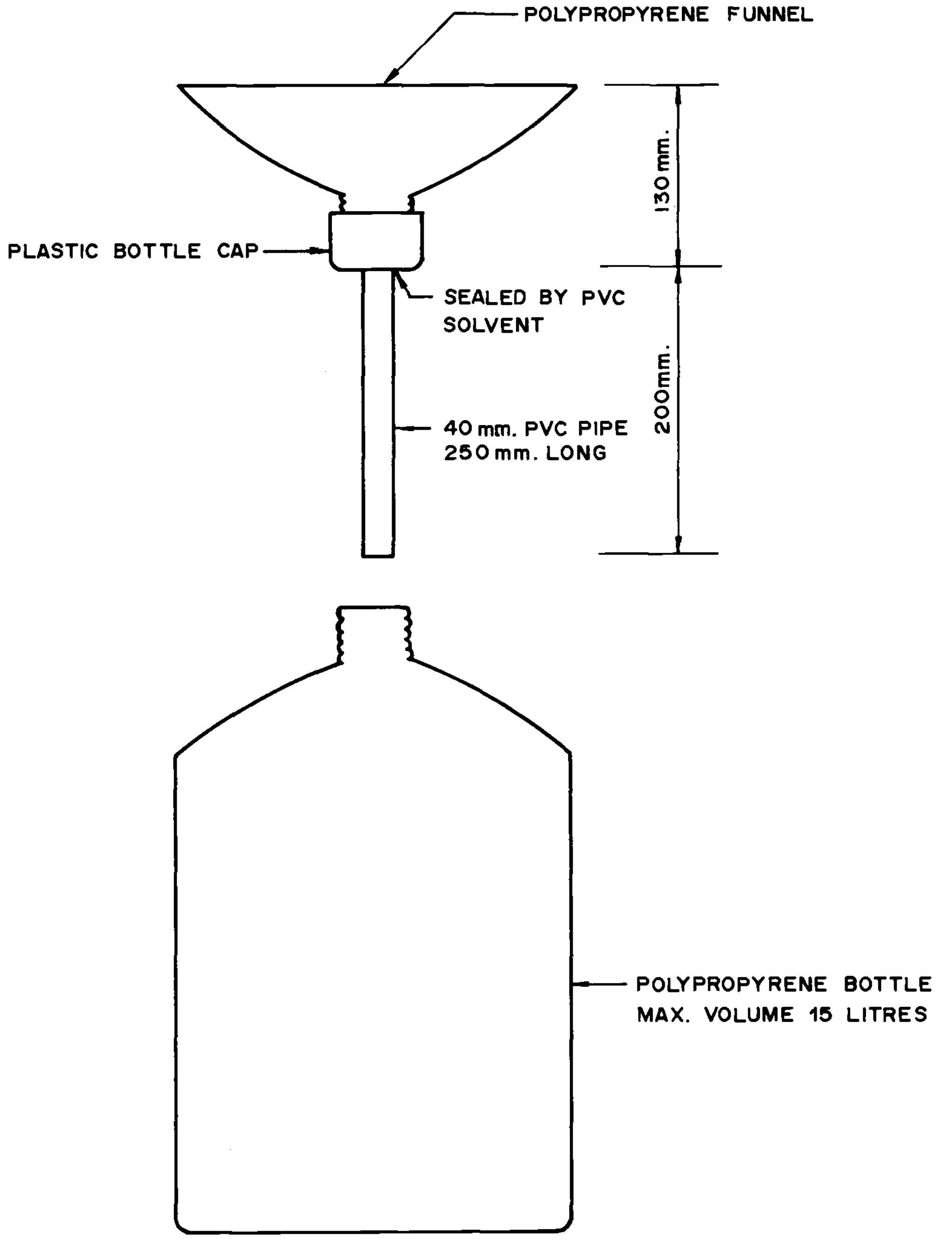
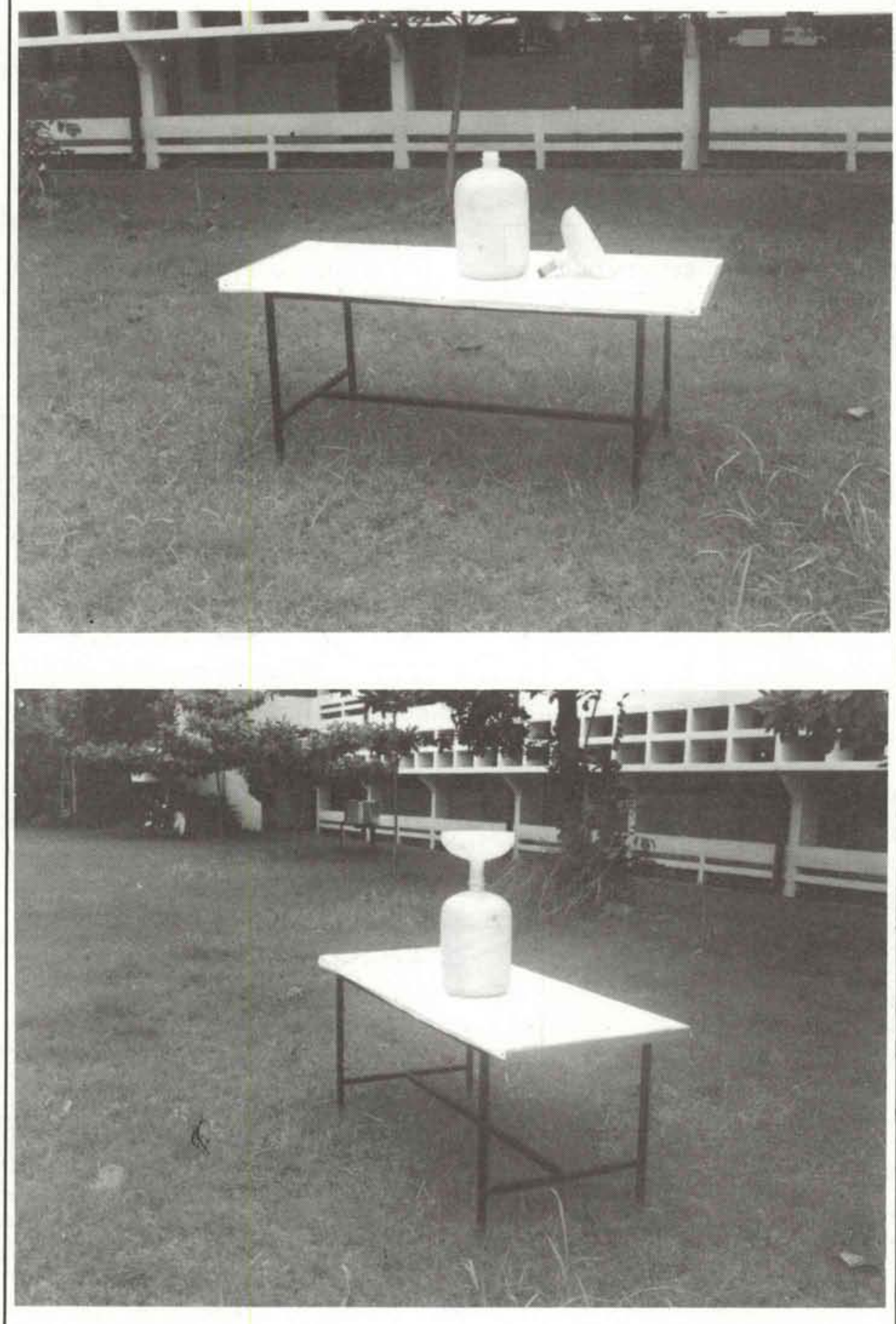



**Figure 3.3 Atmospheric Rainwater Sampler. (Scale 1 : 5)**



**Picture 3 Atmospheric Rainwater Sampler.**

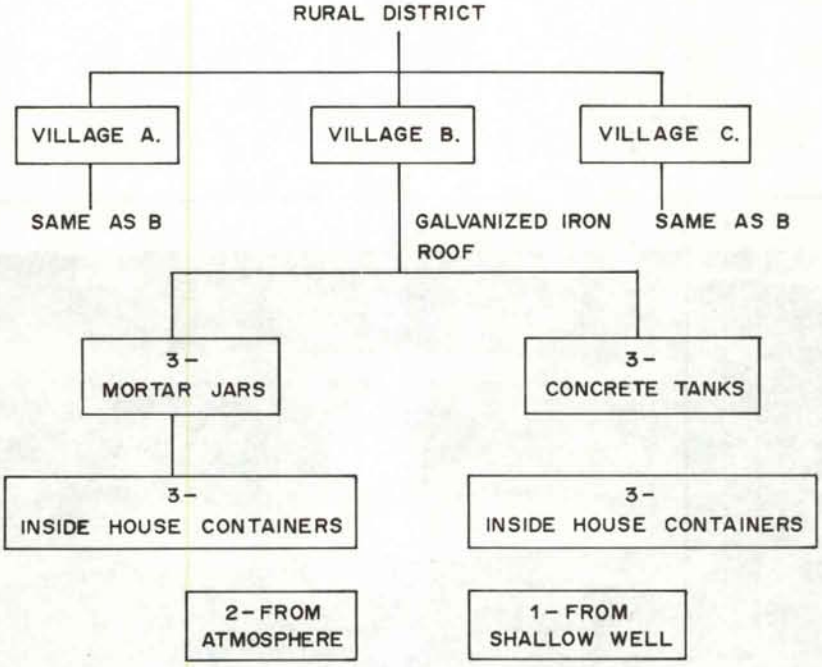



**Figure 3.4 Research Design for Field Water Sample Collection.**

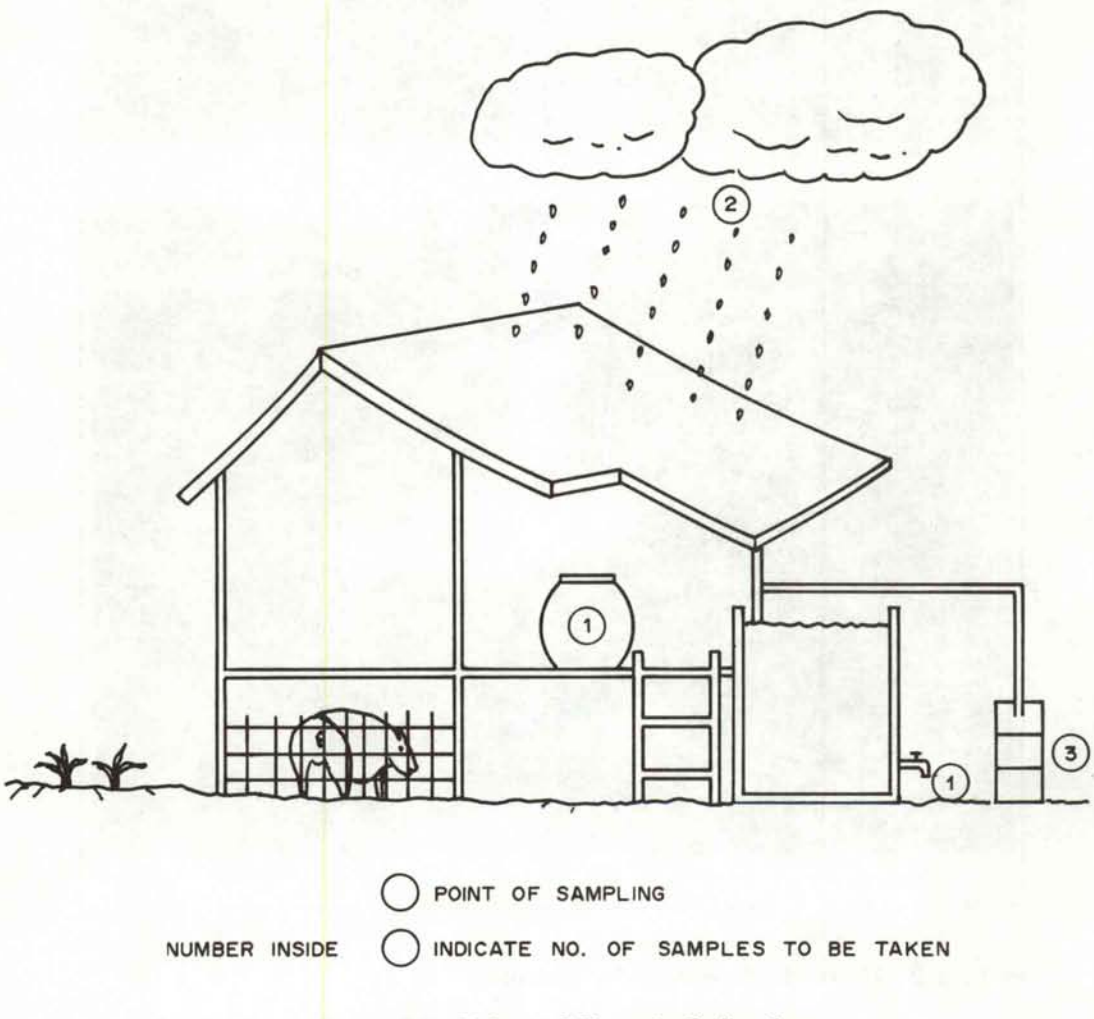



**Figure 3.5 Points of Sample Collection.**

**Table 3.1 Sampling Points and Number of Samples**

| Sampling Points | Village 1 Kok-Phan-Pong | Village 2 Dang-Noi | Village 3 Non-Tun |
|---|---|---|---|
| Roof and Gutter* | | | |
| - Bottom | 7 | 6 | 6 |
| - Middle | 7 | 6 | 6 |
| - Top | 7 | 6 | 6 |
| Storage Container | | | |
| - Tank | 3 | 3 | 3 |
| - Jar | 4 | 3 | 3 |
| Inhouse Container | 3 | 6 | 1 |
| Shallow Well | 1 | 1 | 1 |

* Rainwater samples from roof and gutter were collected in 3-vertical-connected-containers of the automatic sampler. Bottom, middle, and top, represent the position of the 3 containers which collected the first rainfall in the bottom container and the following few minutes of rainfall in the middle and top containers. These are presented in all following tables.

An asbestos cement roof is more costly than a galvanized iron roof and were encountered rarely in the selected villages. Therefore, samples were only taken from the galvanized iron roof and gutter systems using the composite automatic sampler as discussed in section 3.2.

3) Rainwater Storage Containers – Rainwater containers were divided into two types, tanks and jars. The cement tanks were 10 to 12 cubic meters in volume and the mortar jars were approximately 2 cubic meter in volume. Only the containers that were two years old were selected for sampling. Thus, the effect of the containers' age on rainwater quality was eliminated.

4) In-house Rainwater Containers – Secondary contamination was investigated by taking samples from containers in the home, observation of sanitary practices, and by completing a questionaire. Most of the containers were small pots made of clay which were used as drinking water vessels. Water from collection tanks must be transported to these clay in-house containers by carrying vessels. This was considered one of the possible routes of secondary contamination as well as a poor sanitary technique on the part of the home owner.

5) Shallow Well Water – Samples were also taken from shallow wells, which are sometimes used for drinking water, and analyzed for comparison studies against rainwater quality.

### 3.4 Laboratory Analysis

Two sample bottles were taken from each sampling point, be it from the roof and gutter systems or from the in-house storage container. One bottle, that was approximately one-liter in volume was used for heavy metal analysis, and another bottle that was approximately 500ml in volume, was used for bacteriological analysis.

The bacteriological analysis bottles were sterilized prior to collecting the water samples and all of the sample bottles were kept at 4° C by storing them in an icebox while in the village. These samples were analysed as soon as they arrived back in the lab (within six hours of collection). The heavy metal samples were stored in a refrigerator at 2° - 8° C with 2 ml of nitric acid added to keep the metals from adhering to the bottles' sidewalls. These samples could be stored in this manner for up to six months.

The rainwater analysis was performed in the Environmental Engineering Laboratory, Faculty of Engineering, and the Microbiology laboratory, Faculty of Medicine, at Khon Kaen University.

The Environmental Engineering Laboratory was responsible for heavy metal analysis, while the Microbiology Laboratory was responsible for bacteriological analysis.

The heavy metals that were analysed in this study included: Zn, Cu, Cd, Cr, Fe, Pb, and Mn, to determine whether their concentrations posed any health hazards. It was previously noted that sediments in the bottom of the rainwater storage containers could be a possible source of contamination and any withdrawal method which would disturb this bottom layer could introduce dangerous levels of these metals into the upper layers of rainwater as well as the bacteria settled there. Therefore, both jars with and without taps were sampled to determine the effect of the withdrawal methods utilized upon the water quality. A tap eliminated the possiblity of disturbing the sediment layer focusing attention on the possibility of corrosion of the galvanized iron roofs being another possible source of the high heavy metal concentrations in rainwater.

This study will highlight both of these aspects of heavy metal contamination.

The bacteriological study determined if the following indicator organisms and pathogens could be isolated:

| | |
|---|---|
| Indicator Organisms: | Total bacterial count |
| | Total coliform |
| | Fecal coliform |
| | *Eschericia coliform* (*E. coli*) |
| | Fecal streptococci |
| Pathogens: | *Salmonella* |
| | *Shigella*. |
| | *Aeromonas* |
| | *Vibrio* |

The pathogens were analysed using methods from both "The Manual of the Laboratoratory Diagnosis of Bacterial Food Poisoning", (Ohashi, M., et.al., 1978), and the "Microbiological Methods for Monitoring the Environment, Water and Wastes", (Bordner,et.al., 1978).

### 3.5 Sanitary Practices

Rainwater contamination does not only arise during the course of collection (i.e. from the roof and gutter system to the container), but also through poor water handling and rainwater usage practices of the villagers. The research assistants spent one complete week in the village studying the effect of these practices, both by conversing with the villagers directly and by visual observation. A questionaire was developed for this specific topic and included some of the following questions:

- Was the storage tank cleaned before it was used to collect rainwater ?
- Was there any mixing of the collected rainwater with water from another source such as shallow wells ?
- What kind of vessels were used to transport rainwater from the storage container to the in-house storage container ?
- What were their toilet habits ?

The details of the questionaire used are shown in Appendix A. The information obtained from the survey allowed an assessment of the possible pathways of secondary contamination via improper sanitary practices, and dirty or corroded roof and gutter systems.

# IV. DISCUSSION

## 4.1 Bacteriological Quality of Rainwater Versus Water Quality Standards

The bacteriological quality of rainwater collected from various sampling points were compared to the standards of drinking water quality recommended by WHO in 1971 (Table 4.1). The standard bacteriological parameters included:

A) Total bacterial count, not to be higher than 500 cells/ ml,
B) Most Probable Number (MPN) of coliform, not to be higher than 2.2 cells/ 100 ml,
C) Most Probable Number (MPN) of fecal coliform, not to be present, and
D) *E. coli*, not to be present.

Table 4.1 shows in detail that all of the rainwater samples taken from the four sampling points; roof and gutter, tank and jar storage containers, and in-house storage containers, did not meet the drinking water standards. The total bacteriological counts were unacceptable in 60% of the cases and over for all of the rainwater samples, 34% of the cases and over for all of the total coliform counts, 43% of the cases and over for all of the fecal coliform analyses, and 10% of the cases and over for all of the *E.coli* analyses. This indicated that all of the sampling points were bacteriologically contaminated.

## 4.2 The Effect of Storage Containers on Bacteriological Quality

The storage containers observed in this study were tanks, jars, and in-house containers. Among these three, in-house containers had the highest percentage of samples that did not meet the WHO standards in every bacteriological parameter (Figure 4.1). When the bacteriological counts of the in-house containers were recorded, it was found that they did not meet the WHO standards in 88% of the total bacteria counts, 78% of the total coliform counts, 78% of the fecal coliform counts, and 33% of the *E. coli* counts (Table 4.2). This high percentage of bacterial contamination in in-house containers was considered to be due mainly to the unhygienic practices of the villagers. The details of these practices will be discussed in the Sanitary Practices Section 4.6 of this report.

It is shown in Figure 4.1 that the percentage of tanks not meeting WHO standards is higher than that of jars in every bacteriological parameter. The conclusion that has been drawn from this fact is that the jars being of a smaller size than the tanks, make them easier for the villagers to clean. Thus, their storage jars are kept cleaner than their large storage tanks. This, of course, would make the water stored in the jars much cleaner than the water stored in the tanks and a higher percentage of acceptable quality water samples would be expected from the jars.

According to the total bacterial count analysis of rainwater in Table 4.3, the percentage of acceptable quality rainwater is higher in rainwater storage containers, no matter the kind, when compared with the rainwater samples taken directly from the roof and gutter systems or with water from shallow wells. This may be due to the fact that water after being stored has less

**Table 4.1 Bacteriological Quality of Rainwater Versus Water Quality Standards**

| Sampling Points | Total Number of Samples | Results in % of Total Number of Samples | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Total Bacterial Count | | Total coliform | | Fecal coliform | | *E. coli* | |
| | | Meet Standard | Doesn't Meet Standard | Meet Standard | Doesn't Meet Standard | Meet Standard | Doesn't Meet Standard | Meet Standard | Doesn't Meet Standard |
| Roof and Gutter | 416 | 9 | 91 | 42 | 58 | 42 | 58 | 90 | 10 |
| Tank and Jar Storage Container | 189 | 40 | 60 | 66 | 34 | 57 | 43 | 88 | 12 |
| In-house Container | 100 | 12 | 88 | 22 | 78 | 22 | 78 | 67 | 33 |

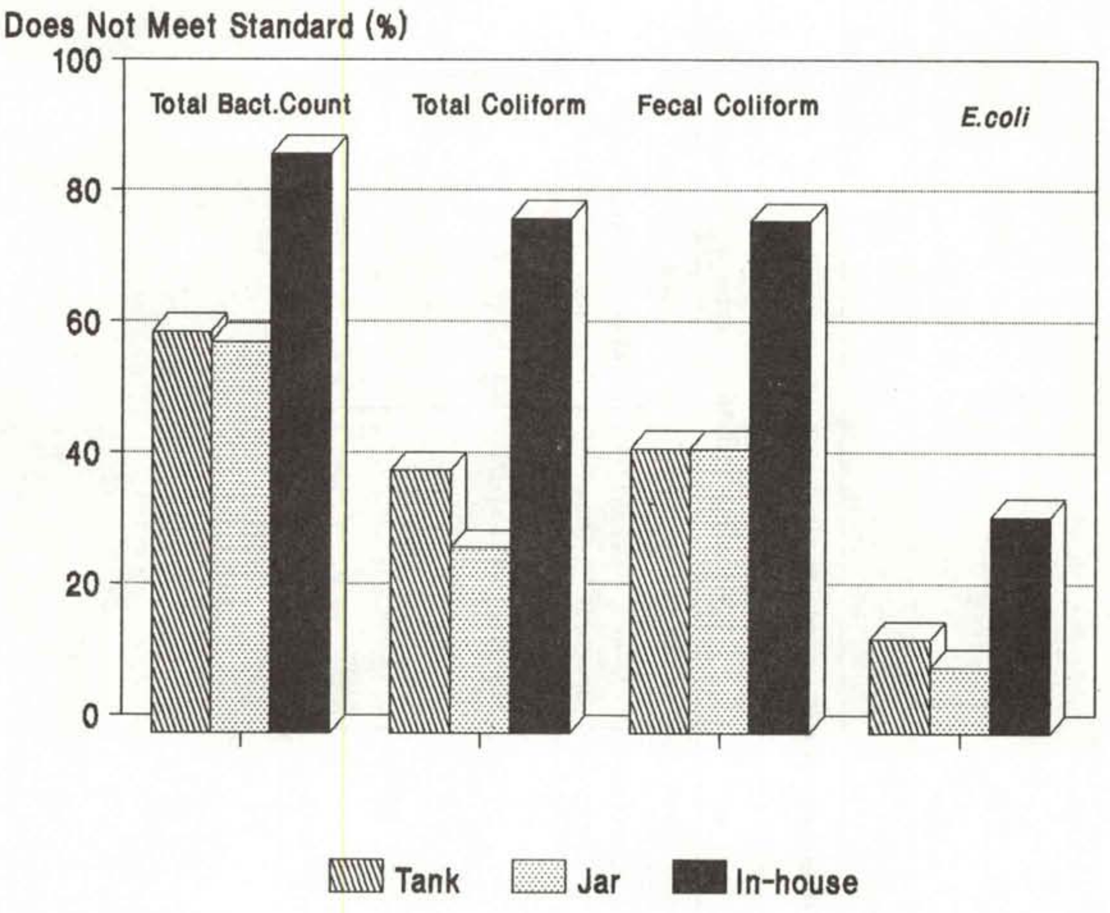



**Figure 4.1 A Comparison of the Bacteriological Quality Results in Storage Container.**

**Table 4.2 Analysis of Bacteriological Quality of Rainwater in Various Storage Contaniers**

| Type of Storage Containers | Total Number of Samples | Results in % of Total Number of Samples | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Total Bacterial Count | | Total coliform (MPN) | | Fecal coliform | | *E. coli* | |
| | | Meet Standard | Doesn't Meet Standard | Meet Standard | Doesn't Meet Standard | Meet Standard | Doesn't Meet Standard | Meet Standard | Doesn't Meet Standard |
| Tank | 90 | 39 | 61 | 60.0 | 40.0 | 57 | 43 | 86 | 14 |
| Jar | 99 | 40.0 | 60 | 72 | 28 | 57 | 43 | 90 | 10 |
| In-house Container | 100 | 12 | 88 | 22 | 78 | 22 | 78 | 67 | 33 |

**Table 4.3 Analysis of Bacteriological Quality of Rainwater from Various Sampling Points**

| Sampling Points | Total Number of Samples | Results in % of Total Number of Samples | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Total Bacterial Count | | Total coliform | | Fecal coliform | | *E. coli* | |
| | | Meet Standard | Doesn't Meet Standard | Meet Standard | Doesn't Meet Standard | Meet Standard | Doesn't Meet Standard | Meet Standard | Doesn't Meet Standard |
| Roof and Gutter | 416 | 9 | 91 | 42 | 58 | 42 | 58 | 90 | 10 |
| Tank and Jar Storage Container | 189 | 40 | 60 | 66 | 34 | 57 | 43 | 88 | 12 |
| In-house Container | 100 | 12 | 88 | 22 | 78 | 22 | 78 | 67 | 33 |
| Shallow Well | 22 | 14 | 86 | 0 | 100 | 0 | 100 | 68 | 32 |

of a chance of becoming contaminated than water left standing in an open system such as in uncovered shallow wells and unenclosed roof and gutter systems.

The more specific bacteriological parameters, such as *E. coli* analysis, give a stronger indication as to where secondary contamination originates, for example, Table 4.3 points out that the percentage of samples contaminated by *E. coli* is nearly the same for roof and gutter systems at 10% as it is for storage tank and jar containers at 12%. While the in-house storage container, in comparison showed a marked increase in percentage at 33%. Therefore, it may be concluded that rainwater in in-house storage containers have a higher rate of secondary contamination. *E. coli*, even with its rapid die-off rate, still increased in concentration from the number encountered in both roof and gutter systems, and samples collected from tank and jar storage containers.

### 4.2.1 The Route of Bacteriological Contamination

To determine the route of rainwater's bacteriological contamination the averages of the bacteriological counts for each sampling point, or source, were analysed and presented in Table 4.4. The numbers from the total bacterial count show the risk of contamination from the surrounding environment. It can be seen that the average number from the roof and gutter systems as well as from the shallow wells, are higher than the average number from the storage containers (jars, tanks, and in-house storage containers). The highest average number was observed in water from shallow wells with a count of 3,412,769 cells/ml and the lowest average number was observed in storage tanks with 6,871 cells/ml. This supports the assumption that water from shallow wells has the highest risk of contamination from the immediate environment and that water stored in tanks has the lowest risk of contact with bacteria in the surrounding environment as shallow wells are uncovered where tanks have lids giving them much more protection.

The average number of total coliform and fecal coliform could also indicate secondary contamination. Table 4.4 reveals a different trend than the total bacterial count, where water from in-house storage container had a higher average number of total coliform and fecal coliform than water from roof and gutter, tank and jar storage containers. The results from total coliform and fecal coliform indicators show that secondary contamination occurred at the in-house containers, thus supporting the assumption that sanitary practices were responsible for this contamination.

In order to discuss the route of contamination further, the water handling routes were classified into 2 types according to the observed practices of Thai villagers. The two types are:

1) Handling Route 1 Rainwater from roofs and gutters pass through the system and flows directly into a storage container which is the rainwater's last point of storage before consumption.

2) Handling Route 2 Rainwater passes through the same route as above, but then is transferred from the storage container to the in-house storage container before it is consumed.

Figure 4.2 displays the quality of rainwater in terms of the average numbers of specific bacterial indicators (total coliform, fecal coliform, and *E.coli*). It can be seen that contamination in

**Table 4.4 Average Number of Rainwater Contamination Bacteriological Parameters**

| Sampling points | Average number of Total bacterial Count (Cells/ml) | Average number of Total coliform (MPN/100 ml) | Average number of Fecal coliform (MPN/100 ml) | Average number of *E. coli* (MPN/100 ml) |
|---|---|---|---|---|
| Roof and Gutter | 2,100,542 | 300 | 186 | 2 |
| Storage Container | | | | |
| Tank | 6,871 | 39 | 19 | 1 |
| Jar | 689,375 | 38 | 33 | 1 |
| In-house Container | 233,547 | 361 | 204 | 2 |
| Shallow Well | 3,412,769 | 711 | 711 | 8 |

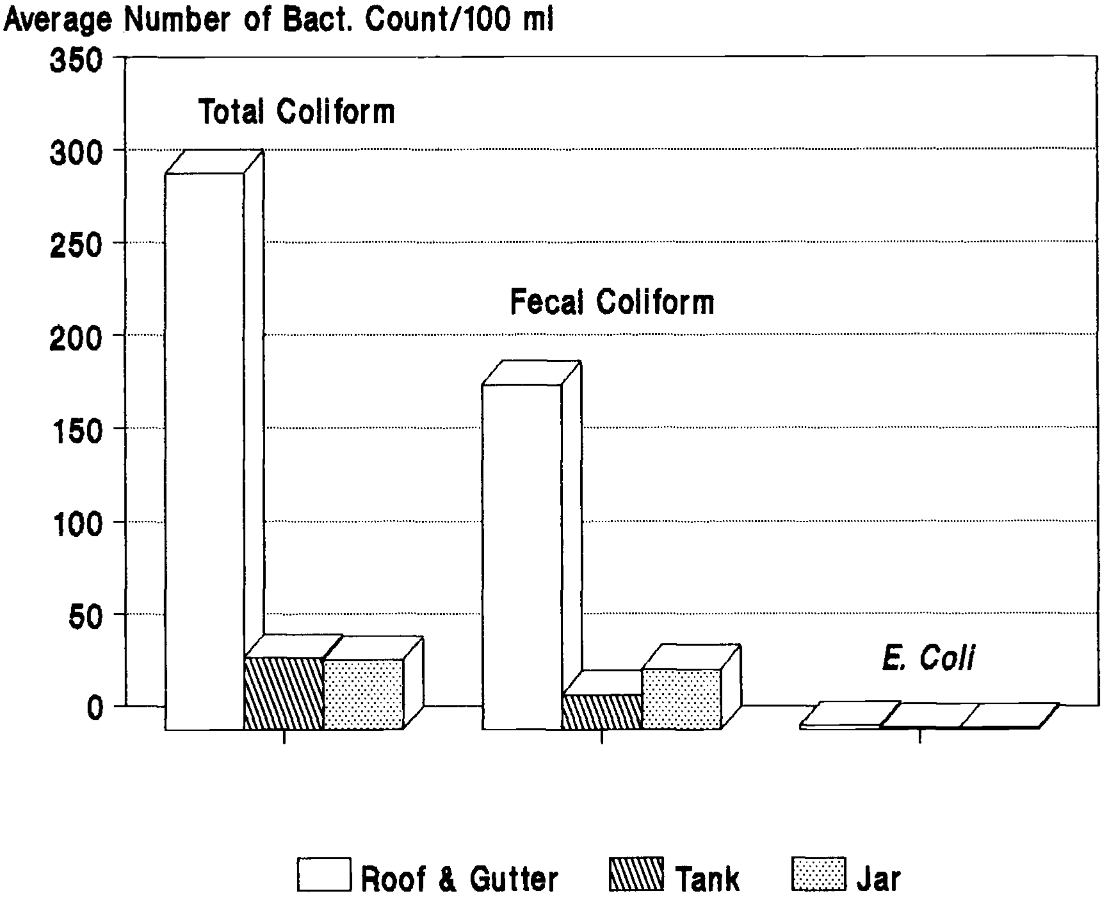



**Figure 4.2 Quality of Rainwater from Handling Route 1 in Terms of the Average Numb of Specific Bacterialiological Indicators.**

handling route 1 originated from the roof and gutter systems and that with proper flushing of these systems before the collection of rainwater the amount of contamination would be reduced.

Handling route 2 shows that rainwater was contaminated not only by the dirty roof and gutter systems, but also by the method used to transport water from the storage tanks and jars to the in-house storage containers via a fetching vessel. As shown in Figure 4.3, the average number of total coliform and fecal coliform indicators isolated from the water samples taken from in-house storage containers were higher than that of samples taken from roof and gutter systems. This indicates that secondary contamination occurred not only during the transfer of water, but also from the unhygienic practices observed in the households (i.e. dipping unclean hands and fetching vessels in stored rainwater tanks and jars). As these indicators, in an ideal atmospheric sample would not be present, therefore the indicators must be directly transmitted to the stored rainwater, via human or animal contact.

To prevent stored rainwater contamination, roof and gutter systems, as well as hands and handling containers must be cleaned before being used. This practice could be increased greatly by personal hygiene awareness on the part of the villagers. Village health seminars could be held at the local health stations to help educate the villagers in these areas of personal hygiene and safe home practices.

### 4.2.2 The Sources of Rainwater Contamination

Fecal streptococci was also used as an indicator organism. The ratio of fecal coliform to fecal streptococci (FC : FS) was used to determine whether the original source of the fecal contamination was from human and/or from animal excreta. A FC:FS ratio greater than 2-4 indicates that the contamination was from human rather than animal origin, while a ratio of less than 1 indicates that the contamination was of animal origin. A ratio of 1-2 indicates that the fecal contamination source originated from either human or animal origin and a distinction can not be drawn.

The FC : FS ratios are summarized in Table 4.5. The Table 4.5 shows that in 79% - 84% of the samples collected from roof and gutter systems, storage rainwater tanks and jars, had FC : FS ratios of less than 1, indicating that the source of contamination was from animal rather than human origin.

The FC : FS ratios revealed that only two sampling points had a ratio greater than 4. The points being from in-house storage containers and shallow wells indicating that their contamination was of human origin also. Therefore, it can be concluded that contamination from humans occurred mostly during the handling of rainwater to and from in-house storage containers and during the collection of water from shallow wells where unclean buckets that have been sitting on the ground have been dipped into the well to retrieve the water. Also the practice of bathing near the mouths of the open shallow wells may lead to contamination as bathing water may run into the open well.

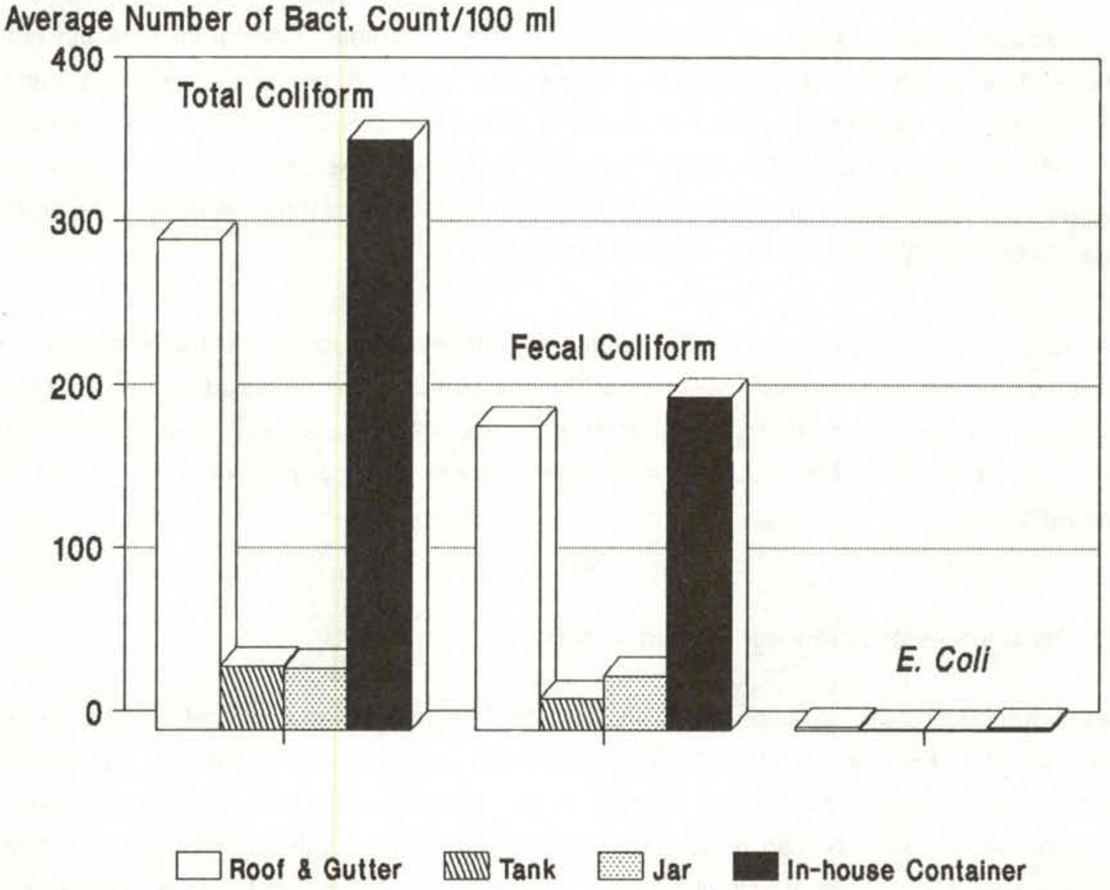



**Figure 4.3 Quality of Rainwater from Handling Route 2 in Terms of the Average Numb of Specific Bacterialiological Indicators.**

**Table 4.5 Ratio of Fecal Coliform to Fecal Streptococci (FC:FS) from Various Sampling Points**

| Sampling Points | Number of Samples | Results in % of Samples FC:FS | | | |
|---|---|---|---|---|---|
| | | >4 | >2 | 1–2 | <1 |
| Roof and Gutter | 405 | 8 | 4 | 9 | 79 |
| Storage Container | | | | | |
| Tank | 92 | 8 | 4 | 8 | 80 |
| Jar | 95 | 9 | 3 | 4 | 84 |
| In-house Container | 100 | 47 | 7 | 7 | 39 |
| Shallow Well | 21 | 43 | 19 | 5 | 33 |

Since most of the bacterial contamination in the rainwater samples from roof and gutter systems, and rainwater tanks and jars, were of animal origin, it has been concluded that rainwater remains the better source of drinking water as opposed to shallow well water when secondary contamination via unsanitary practices, unclean roof and gutter systems, and storage containers have been eliminated by proper cleaning and handling techniques. These findings support the previous studies discussed in the introduction of this paper (Thai-Australia Village Water Supply Project, 1984) where rainwater was found to be the most suitable supply source of drinking water.

### 4.3 Pathogenic Contamination

This study evaluated the bacteriological quality of rainwater in terms of both indicator organisms and pathogens that were isolated from the samples. Table 4.6 shows the results from the pathogenic isolation of rainwater. Theoretically, pathogens in water are rarely found because of the pathogens' short life span. However, pathogenic contamination was found in samples taken from roof and gutter systems, samples from storage tanks, and sample from in-house storage container. No pathogens were isolated from the jars. This may be due to the less frequently cleaned large storage tanks (Section 4.2) being a much more suitable environmental for bacteria to survive in than in clean jars.

The pathogens that were isolated in this study included: *Salmonella group E*, *Salmonella group C*, *Aeromonas sp.*, *Vibrio parahaemolyticus*, and *Aeromonas hydrophila*.

*Salmonella group E*, was isolated from roof and gutter systems and *Salmonella group C*, was isolated from storage tanks. This kind of bacteriological contamination usually occurs in unhygienic environments like the households keeping unconstrained livestock, as *Salmonella* is commonly found in the intestines of animals, especially pigs, cows, goats, sheep, rodents, and fowl. It is capable of surviving under dry conditions as well. So it is also found in products processed for long periods of storage such as powdered or dried eggs, or bone meal fertilizers (Monica Cheesbrough, 1984).

*Aeromonas sp.*, and *Aeromonas hydrophila*, were isolated from tank and shallow well samples. *Aeromonas* is commonly found in soil and water. Therefore, this type of pathogenic contamination was unsurprising as these pathogens could easily be introduced to a water supply by the unhygienic practice of dipping dirty fetching vessels into stored rainwater for retrieval or for the simple fact that shallow wells are dug into the earth.

*Vibrio parahaemolyticus* was isolated from in-house storage containers. This pathogen is an enteropathic strain which can be found in fresh and brackish water and is transmitted via inadequate sanitation and lack of personal hygiene (Monica Cheesbrough, 1984). This fact indicates that the in-house storage containers were a site of secondary contamination.

All of the above pathogens may cause diarrheal diseases in humans. The WHO standards dictate that drinking water must be free of any pathogens. However this study has shown that

**Table 4.6 Analysis of Pathogenic Contamination in Water Collected from Various Sampling Points**

| Sampling Points | Total Number of Samples | Number of Samples Contaminated by Pathogen (s) | % of Pathogenic Contamination | Name of Pathogens |
|---|---|---|---|---|
| Roof and Gutter | 395 | 1 | 0.2 | *Salmonella group E* |
| Storage Container | | | | |
| Tank | 89 | 2 | 2.2 | *Aeromonas sp.,Salmonella group C* |
| Jar | 97 | 0 | 0.0 | |
| In-house Contanier | 99 | 1 | 1.0 | *Vibrio parahaemolyticus* |
| Shallow well | 24 | 1 | 4.2 | *Aromonas hydrophila* |

the percentage of pathogenic contamination in rainwater remains quite lower than that of shallow well water (Figure 4.4), the next source of drinking water. This indicates that rainwater remains the drinking water supply of choice. Table 4.6 reveals that the percentage of pathogenic contamination in samples from roof and gutter systems was 0.2%, storage tanks was 2.2%, storage jars was 0%, and in-house containers was a mere 1.0%, while shallow well water samples had a much higher contamination rate of 4.2%. Therefore, it remains clear that although rainwater is not free from pathogenic contamination entirely it is still a better source than shallow well water.

Of course, it is also necessary to improve the hygienic practices of the villagers in order to further reduce the risk of bacterial contamination of drinking water, thus making it more fit for human consumption.

## 4.4 Heavy Metal Analysis Results

### 4.4.1 Heavy Metal Concentrations versus Water Quality Standards

The heavy metals analysed in this study included: Cadmium (Cd), Chromium (Cr), Lead (Pb), Copper (Cu), Iron (Fe), Manganese (Mn), and Zinc (Zn). The drinking water standards established by WHO in 1971, classified Cd, Cr, and Pb as inorganic constituents that significantly affect health while Cu, Fe, Mn, and Zn are classified as inorganic constituents that affect the aesthetic quality of drinking water only. The standard values of these parameters are listed in Appendix B. All of the analysed data concerning heavy metal concentrations are presented in Appendix C.

Overall, most of the heavy metal concentrations of the samples collected from various sampling points compared favorably with the WHO Standards for drinking water. The two exceptions were Mn and Zn (Table 4.7 and Figure 4.5). However, the percentage of Mn and Zn concentrations exceeding the WHO standards were hot critically high since these two parameters are considered to effect the aesthetic water quality only and are not considered significant health risks.

The total number of samples tested for Mn concentrations from each point (roof and gutter systems, and in-house storage containers) exceeded the standard in 9% - 20% of the roof and gutter systems, and 2% of the in- house storage containers.

The Zn samples collected from the roof and gutter systems exceeded the standard also. The percent of the total number of samples exceeding the standard ranged from 4% - 26%.

### 4.4.2 The Source and Route of Heavy Metal Contamination

The maximum concentration of heavy metals in the samples collected from roof and gutter collection systems, storage containers (tanks and jars), and in-house storage containers is displayed in Table 4.8 and Figure 4.6. When the concentrations of Cd, Cr, Pb, Fe, and Cu from the various sampling points were compared they were not found to be significantly different.

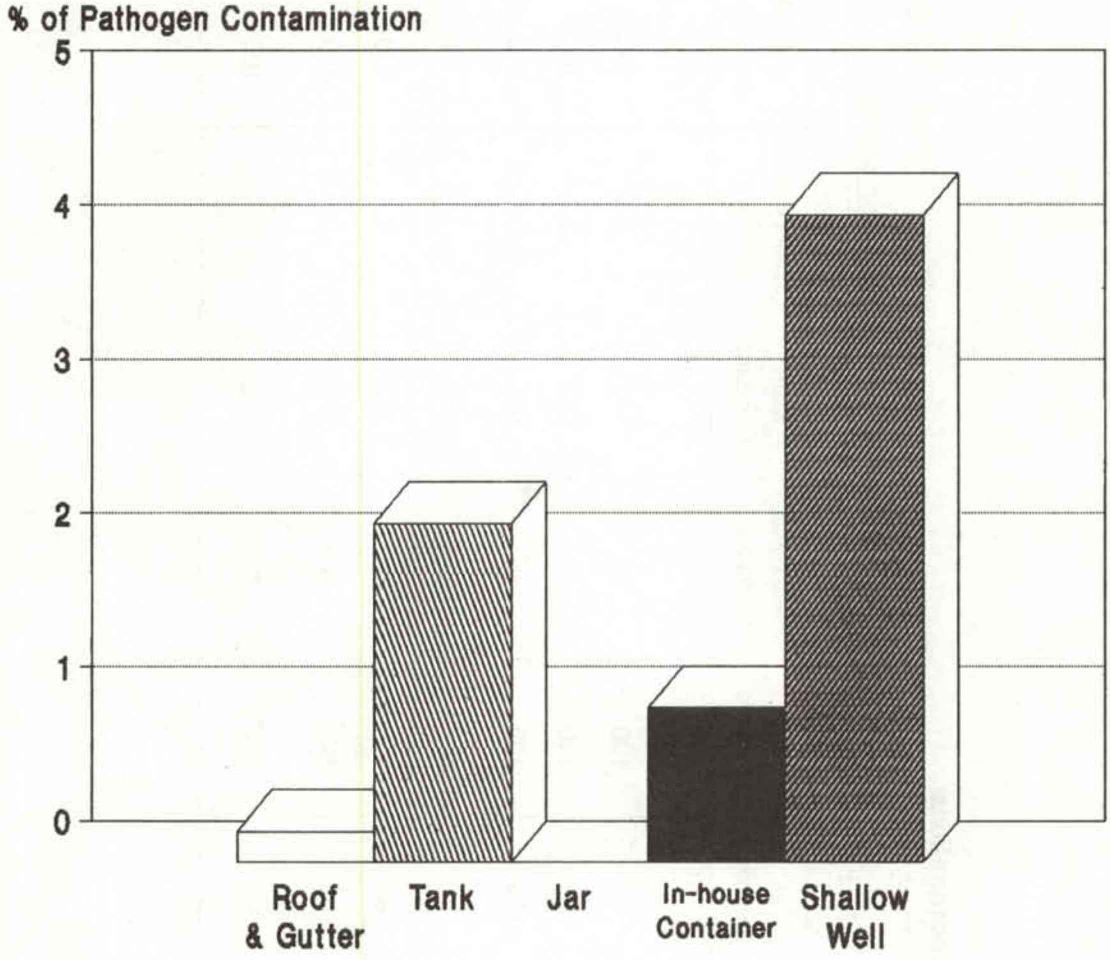



Figure 4.4 Percentage of Pathogenic Contamination in Various Samples of Rainwater and in Shallow Wells.

**Table 4.7 Analytical Results of Heavy Metal Concentrations**

| Sampling Points | Total Number of Samples | Results in % of Total Number of Samples | | | | | |
|---|---|---|---|---|---|---|---|
| | | Cd | | Cr | | Pb | |
| | | Meet Standard | Doesn't Meet Standard | Meet Standard | Doesn't Meet Standard | Meet Standard | Doesn't Meet Standard |
| Roof and Gutter | | | | | | | |
| - Bottom | 93 | 100 | 0 | 100 | 0 | 100 | 0 |
| - Middle | 125 | 100 | 0 | 100 | 0 | 100 | 0 |
| - Top | 100 | 100 | 0 | 100 | 0 | 100 | 0 |
| Storage Container | | | | | | | |
| - Tank | 86 | 100 | 0 | 100 | 0 | 100 | 0 |
| - Jar | 96 | 100 | 0 | 100 | 0 | 100 | 0 |
| In-house Container | 90 | 100 | 0 | 100 | 0 | 100 | 0 |

Table 4.7 Analytical Results of Heavy Metal Concentration (Cont'd)

| Sampling Points | Total Number of Samples | Results in % of Total Number of Samples | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Cu | | Fe | | Mn | | Zn | |
| | | Meet Standard | Doesn't Meet Standard | Meet Standard | Doesn't Meet Standard | Meet Standard | Doesn't Meet Standard | Meet Standard | Doesn't Meet Standard |
| Roof and Gutter | | | | | | | | | |
| - Bottom | 93 | 100 | 0 | 100 | 0 | 98 | 20 | 74.20 | 26 |
| - Middle | 125 | 100 | 0 | 100 | 0 | 91 | 9 | 94 | 6 |
| - Top | 100 | 100 | 0 | 100 | 0 | 91 | 9 | 96 | 4 |
| Storage Container | | | | | | | | | |
| - Tank | 86 | 100 | 0 | 100 | 0 | 100 | 0 | 100 | 0 |
| - Jar | 96 | 100 | 0 | 100 | 0 | 100 | 0 | 100 | 0 |
| In-house Container | 90 | 100 | 0 | 100 | 0 | 98 | 2 | 100 | 0 |

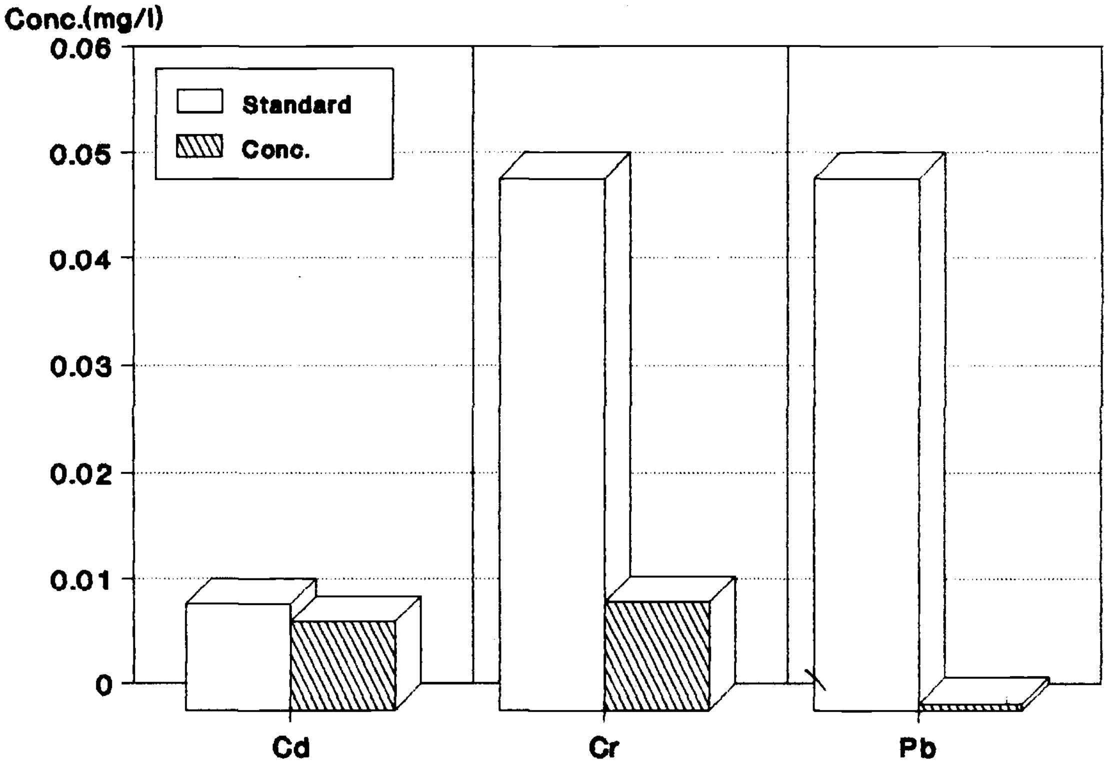
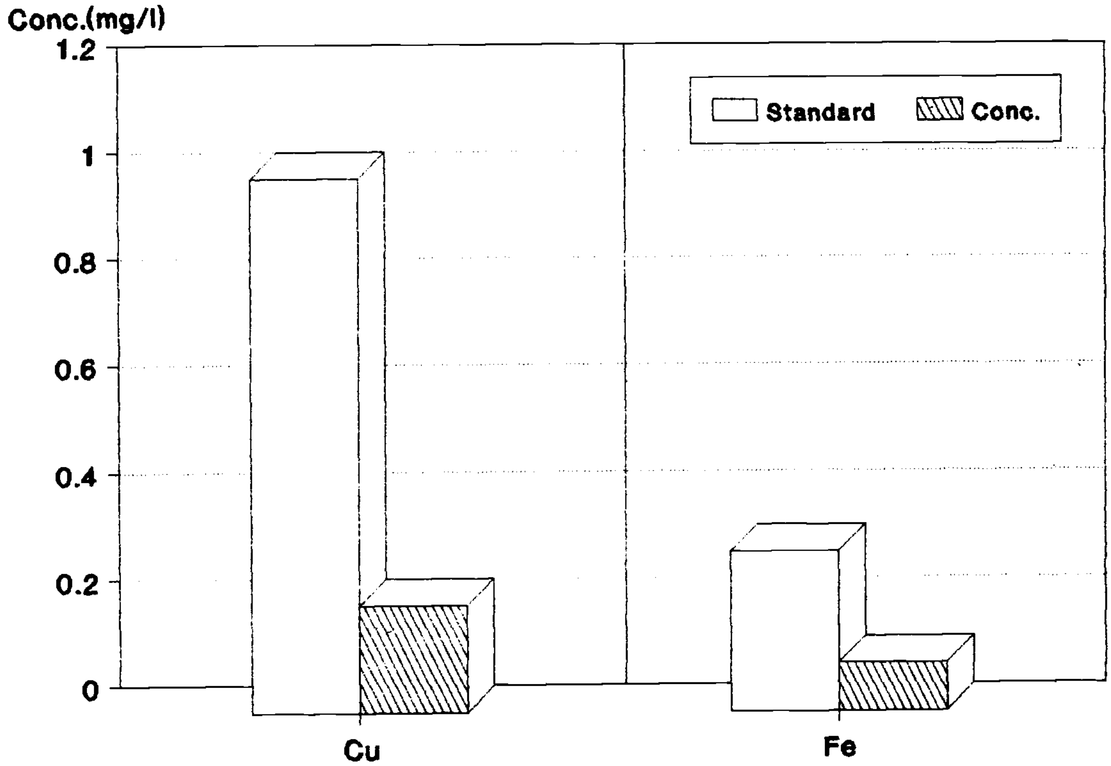



**Figure 4.5 Heavy Metal Concentrations Compared with WHO Standards.**



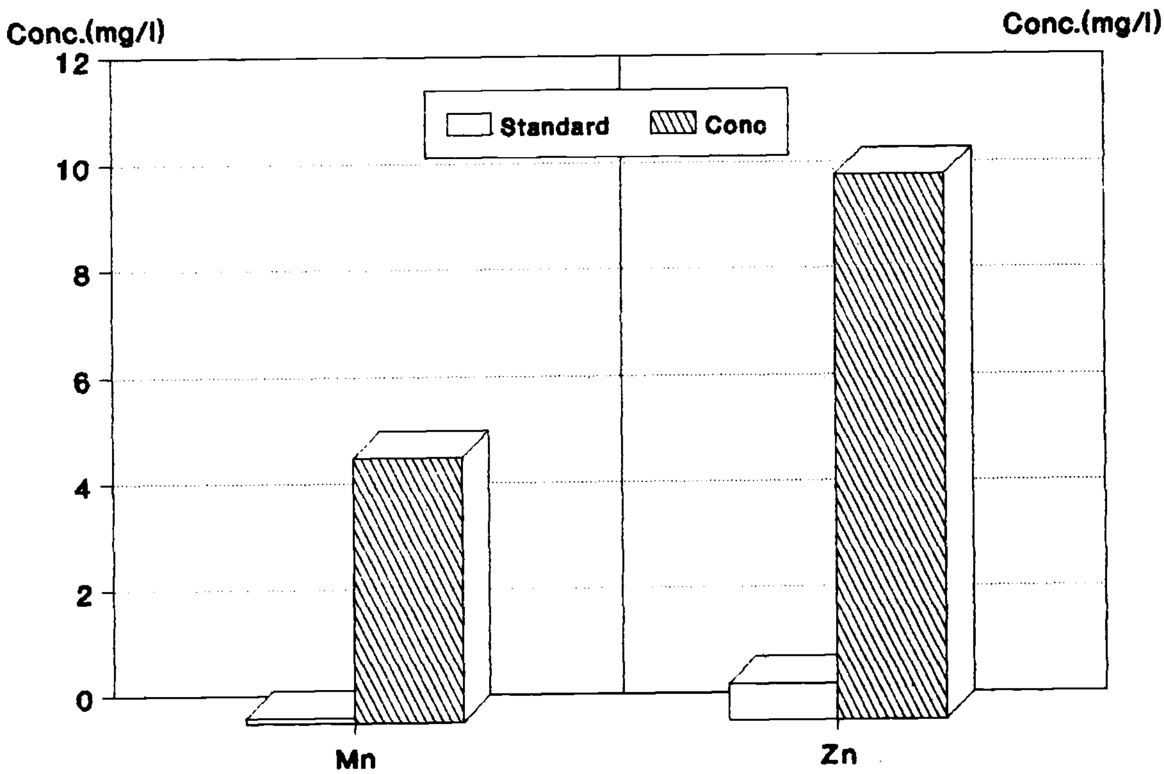




Figure 4.5 (Cont'd)

**Table 4.8 Source and Route of Heavy Metal Contamination**

| Sampling Points | Maximum Concentration, mg/l | | | | | | |
|---|---|---|---|---|---|---|---|
| | Cd | Cr | Pb | Cu | Fe | Mn | Zn |
| Roof and Gutter | | | | | | | |
| - Bottom | 0.0083 | 0.0061 | 0.0005 | 0.0640 | 0.0592 | 0.5860 | 10.2700 |
| - Middle | 0.0060 | 0.0052 | 0.0005 | 0.0810 | 0.0759 | 0.6530 | 6.3400 |
| - Top | 0.0028 | 0.0034 | 0.0005 | 0.0510 | 0.0523 | 0.6890 | 9.6520 |
| Storage Container | | | | | | | |
| - Tank | 0.0024 | 0.0029 | 0.0005 | 0.2010 | 0.0658 | 0.0750 | 1.5100 |
| - Jar | 0.0022 | 0.0040 | 0.0005 | 0.1700 | 0.0634 | 0.0740 | 1.1100 |
| In-house Container | 0.0041 | 0.0102 | 0.0006 | 0.1300 | 0.0901 | 0.1340 | 1.0990 |

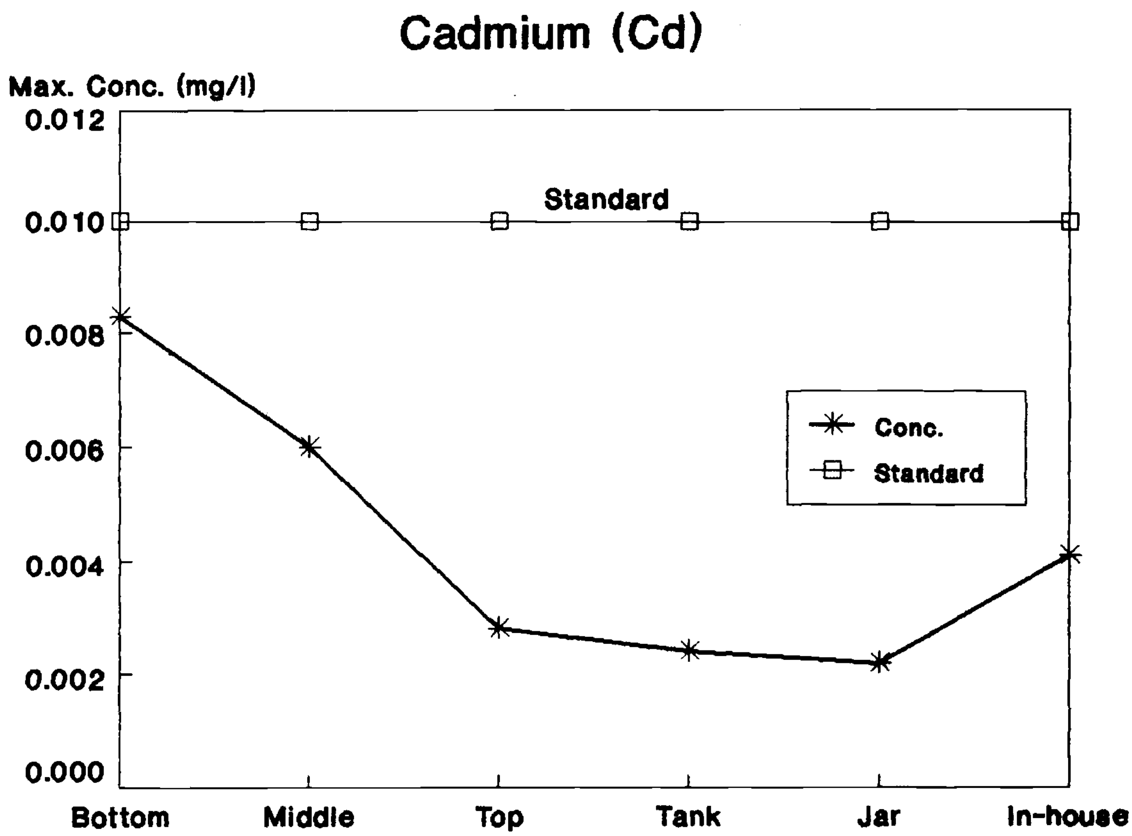
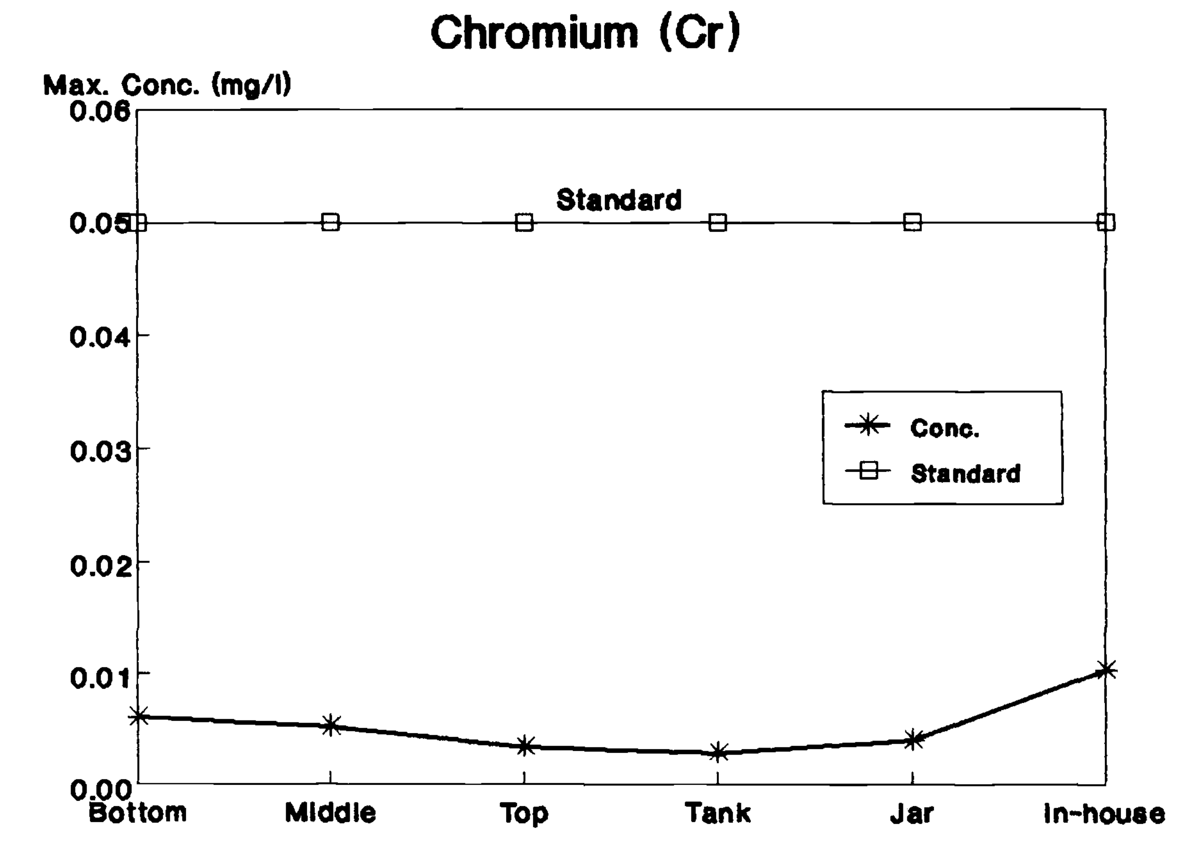



**Figure 4.6 Maximum Concentration of Heavy Metal vs WHO Standard Values.**



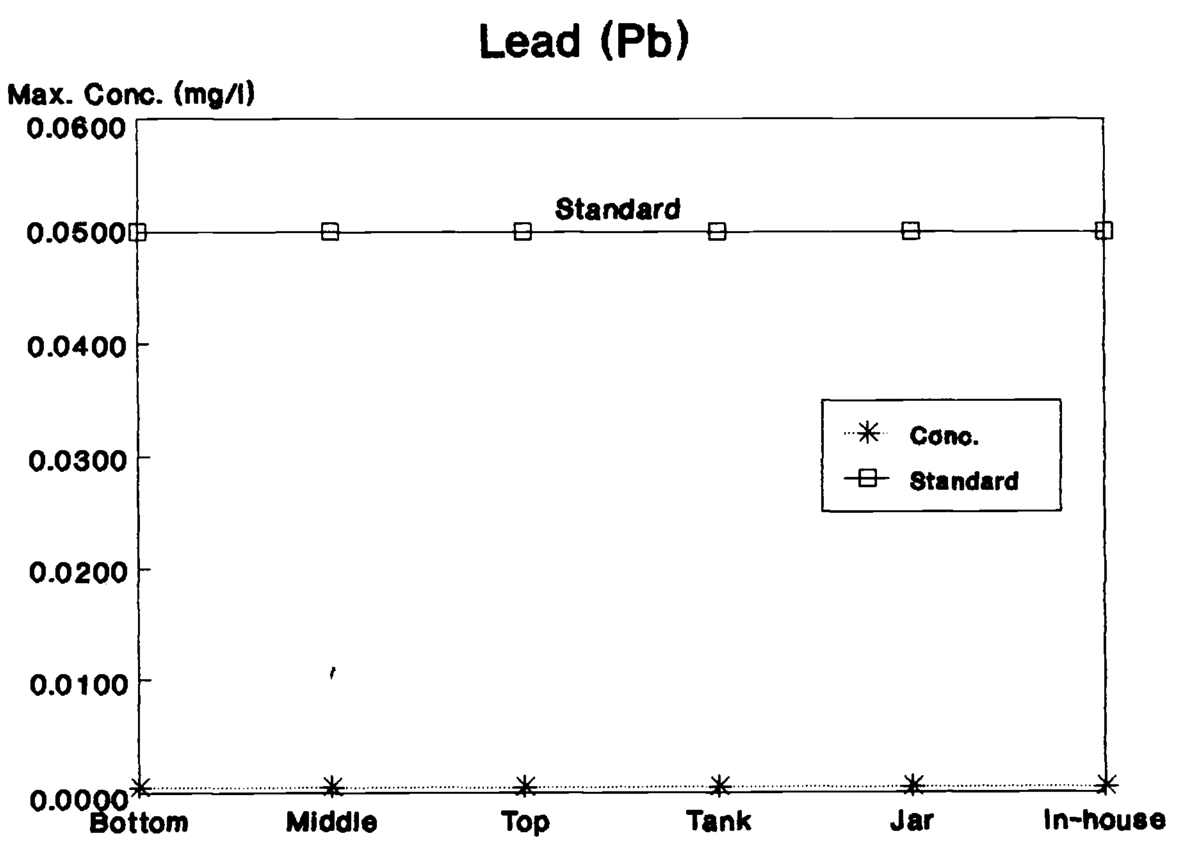
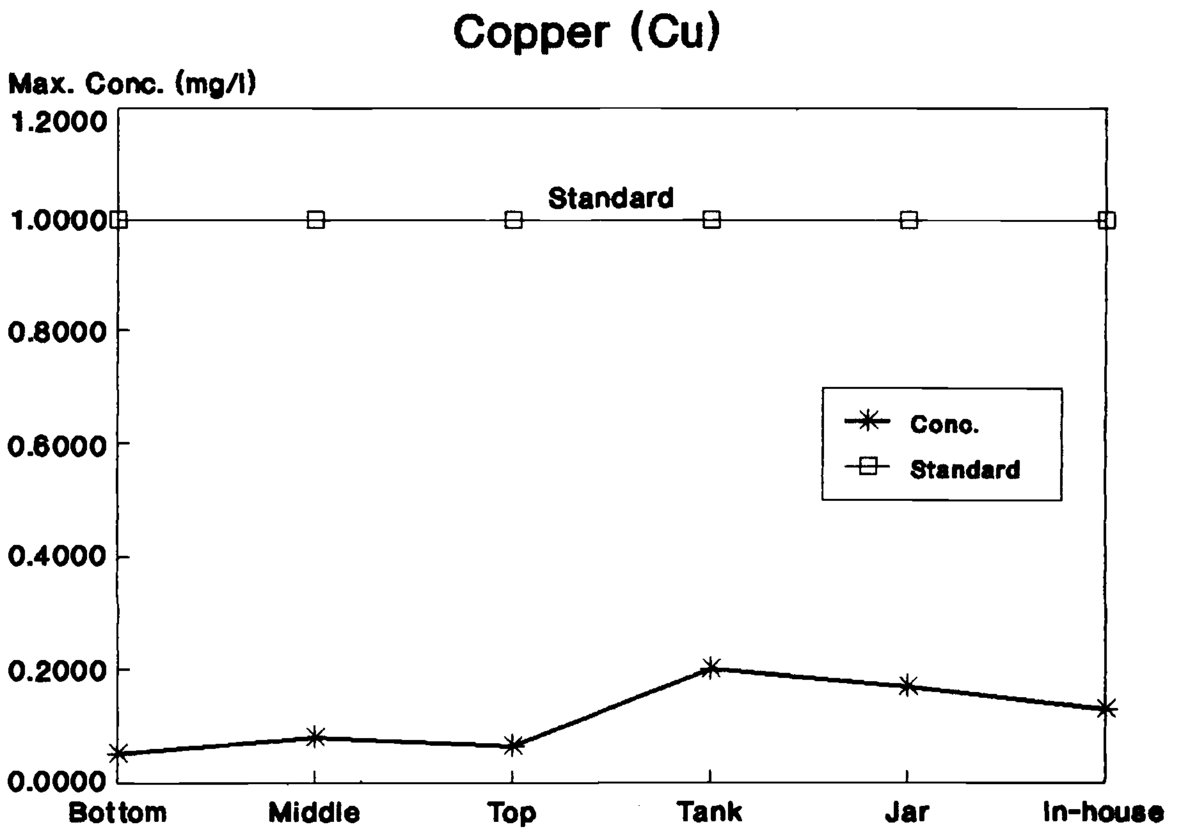




Figure 4.6 (Cont'd)



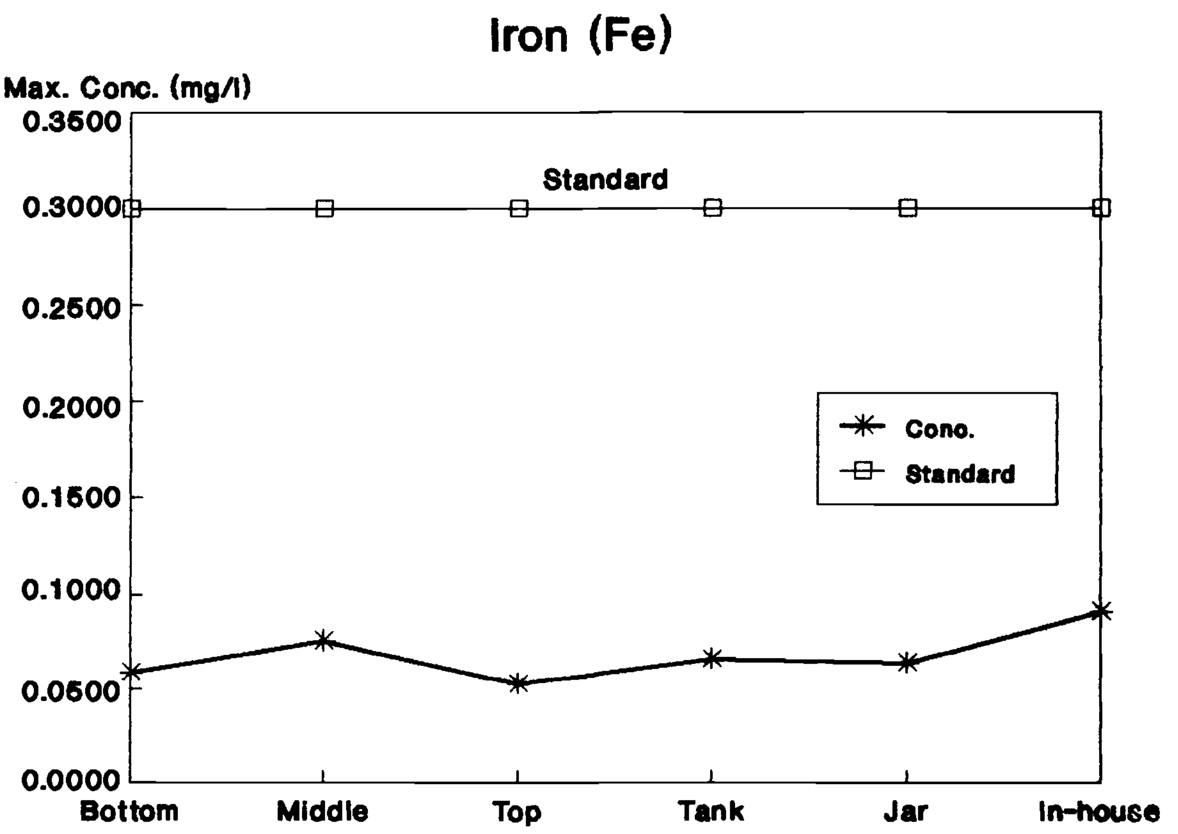
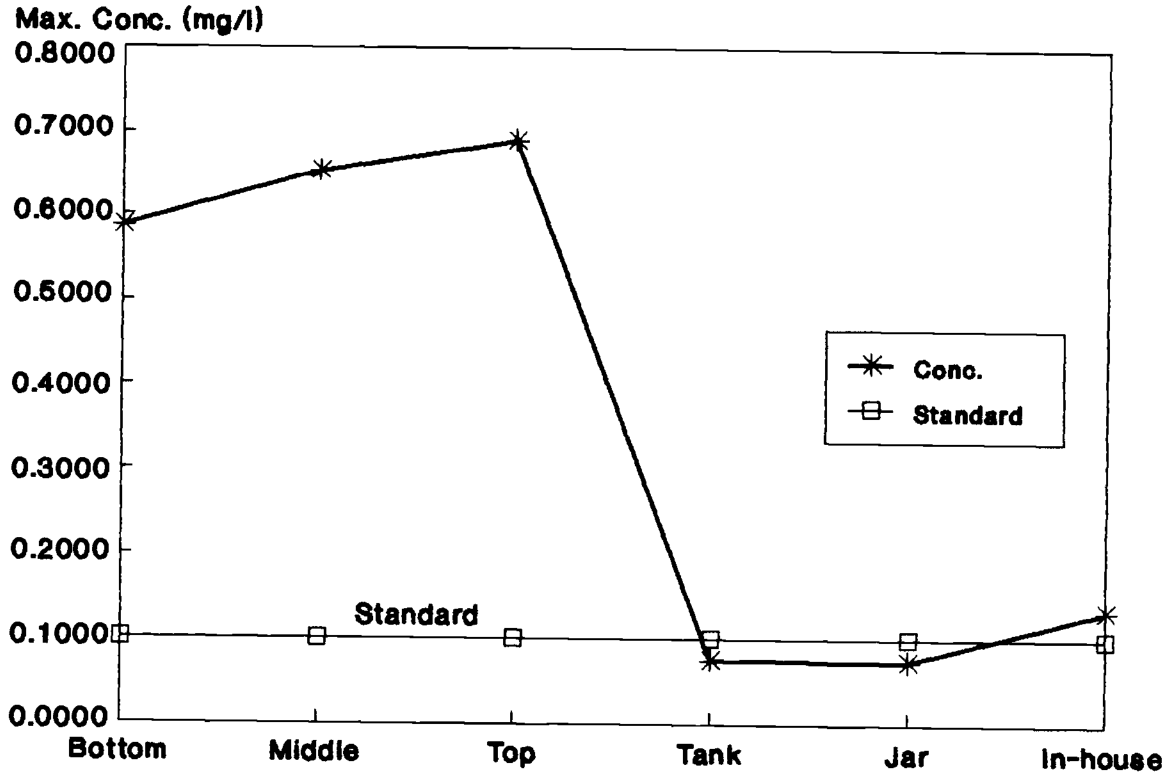




Figure 4.6 (Cont'd)

## Manganese (Mn)




## Zinc (Zn)

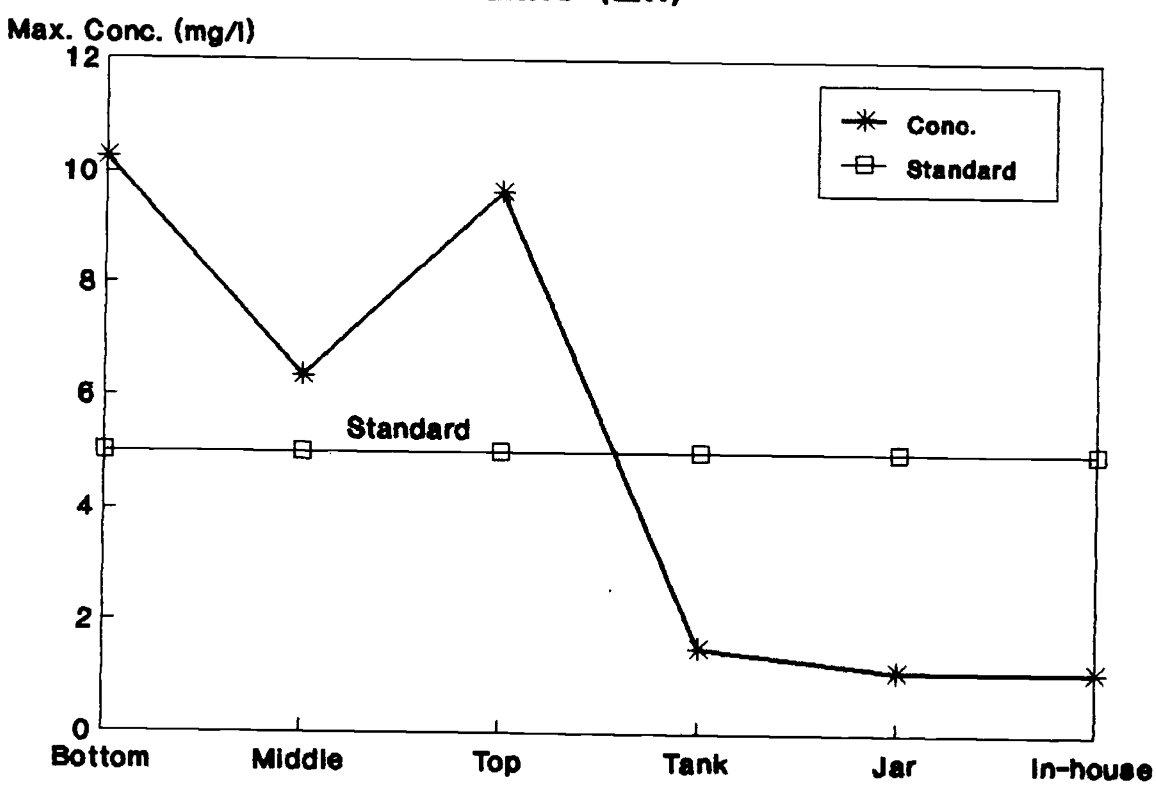



Figure 4.6 (Cont'd)

The concentrations did not exceed the standard values. Therefore, the route of contamination could not be clearly derived from such small differences at these low concentrations.

The maximum Mn concentrations of the samples collected from the roof and gutter systems ranged from 0.5860 - 0.6890 mg/l, the range for the storage containers was 0.0740 - 0.0750 mg/l, and the maximum concentration for the in-house containers was 0.1340 mg/l. Therefore, the samples collected from the roof and gutter systems and in-house storage containers exceeded the acceptable standard for Mn (0.1 mg/l). A similar trend was found in the Zn concentrations where the roof and gutter systems were found to have the highest concentrations ranging from 6.34 - 9.65 mg/l, followed by the storage tanks and jars with a range of 1.11 - 1.51 mg/l, and last of all the in-house storage containers with a concentration of 1.10 mg/l. This trend may be due to Zn being leached from the galvanized roofing material and metal fittings containing Zn. The Zn then settles to the bottom sediment layer of the storage containers, thus depleting the concentration of Zn in the upper layers of stored water in the tanks, jars, and in-house storage containers. This type of leaching was discussed in the study completed by Bunyaratpan and Sinsupan in 1984 as was mentioned in the literature review.

Mn is another impurity found in the galvanized iron roofing material. It may be present in both dissolved and suspended forms. Therefore,it is reasoned that the higher concentrations from the roof and gutter systems compared to the storage containers and in-house containers is for similar reasons. Dissolved Mn reactes with oxygen to form a precipitate of manganese dioxide which then settles to the bottom of a storage container.

In addition, pH may affect the dissolution of heavy metals. Naturally, the pH of atmospheric rainwater is within the acidic range because of $CO_2$ becoming carbonic acid when it reacts with rainwater. The reaction is described as follows: $H_2O + CO_2 \rightleftarrows H_2CO_3$. The low pH, or acidic rainwater, may then corrode the galvanized iron roofs causing Zn and Mn to be washed into the storage containers causing heavy metal contamination as described above. The pH of the samples collected from the roof and gutter systems ranged from 6.35 - 7.80, the pH of the storage containers ranged from 9.1 - 9.2, and the pH of the in-house containers was 8.2 (Table 4.9).

The higher pH values found in the rainwater collected from the storage containers in this study is thought to be due to the storage container material itself which is made from concrete (a mixture of cement, and sand aggregate) and cement (a mixture of lime, silica, alumina, and iron oxide) being leached from the container as with the heavy metals. This high pH, thus causes the dissolved form of the heavy metals to combine with hydroxide to form an insoluble metal precipitate $\{M^{++} + 2(OH)^- \rightleftarrows M(OH)_2\}$ which settles to the bottom of the containers contributing to the sediment layer. Therefore, the heavy metal concentrations in the stored rainwater itself were reduced.

### 4.4.3 The Effect of Rain on Heavy Metal Concentration

The concentrations of Mn and Zn in samples collected from the roof and gutter systems at various time intervals were compared in terms of the percentage of samples exceeding the

**Table 4.9 pH of Rainwater Collected from Various Sampling Points**

| Sampling Points | pH |
|---|---|
| Roof and Gutter | |
| - Bottom | 7.80 |
| - Middle | 7.55 |
| - Top | 7.65 |
| Storage Container | |
| - Tank | 9.10 |
| - Jar | 9.20 |
| In-house Container | 8.20 |

**Table 4.10 Effect of Rain on Heavy Metal Concentration**

| Sampling Points | Doesn't Meet WHO Standard (%) | |
|---|---|---|
| | Mn | Zn |
| Roof and Gutter | | |
| - Bottom | 20 | 26 |
| - Middle | 9 | 6 |
| - Top | 9 | 4 |
| Storage Container | | |
| - Tank | 0 | 0 |
| - Jar | 0 | 0 |
| In-house Container | 2 | 0 |

WHO standard (Table 4.10). As mentioned earlier, the collection of the roof and gutter samples was accomplished by using a special automatic sampler that allowed rainwater to be collected at three different time intervals. The sample in the bottom of the collection sampler contained rain from the first few minutes of rainfall, the middle section, and the top section contained rainwater from a later sequential time interval.

These samples that were collected at separate time intervals during a period of rainfall showed that the bottom collection sample had higher heavy metal concentrations for both Mn and Zn, 20% and 26%, respectively. The later sequential time intervals, middle and top (collected a few minutes after the first bottom sample had been taken) had much lower heavy metal concentrations. The concentration for Mn was only 9% for the middle sample and 6% for the top sample, while the concentration for Zn was 9% and 4%, respectively. This suggests that during the first few minutes of rainfall most of the heavy metal material from the roof and gutter system as well as collected dust and debris that has settled on the roof top is washed into the storage containers and therefore is not so highly concentrated during the following minutes of rainfall. Thus, there were lower concentrations found in the middle and top rainfall samples.

## 4.5 Sanitary Practices

### 4.5.1 Household Structure

It was observed from this study's survey that most of the houses were made of wood with galvanized iron roofs and were built on stilts to prevent flooding during the rainy season. The economic status of all three villages were adequate. Even the households earning a meager income of less than 25,000 Baht/year (66%) had the added benefit of owning their own land in 60% of the cases and nearly all of the village families owned their own houses (Table 4.11).

### 4.5.2 Drinking Water Sources

The households used rainwater as their source of drinking water year round in 63.4% of the cases. The rest used shallow well water and piped water from the village water supply as their drinking water source. During the rainy season the percentage of homes using rainwater increased to 97.4% while decreasing to 38.2% during the dry season. 54.2% of the village households used shallow well water as their drinking water source during the dry season instead of rainwater. Table 4.12 also shows that 81.7% of the villagers preferred rainwater as their drinking water source while 16.4% preferred shallow well water, 1.7% preferred piped water, and 0.2% preferred pond water. This finding supports the Thai-Australia study (1984) where rain water was deemed the best water supply option as it was socially acceptable to Thai villagers.

### 4.5.3 Effect of Collection Systems on Rainwater Quality

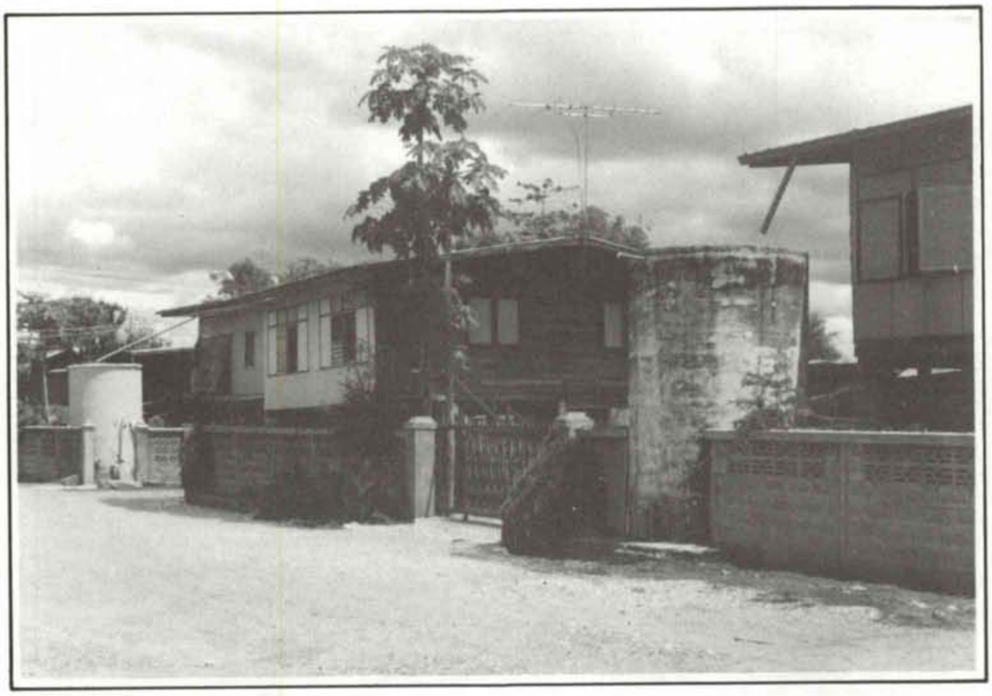
Another area of observation was the effect ofcollection systems on the quality of rainwater. All of the roof and gutter collection systems were made of galvanized iron. It was found that

**Table 4.11 Economic Status of the Survey Villages (survey of 421 households)**

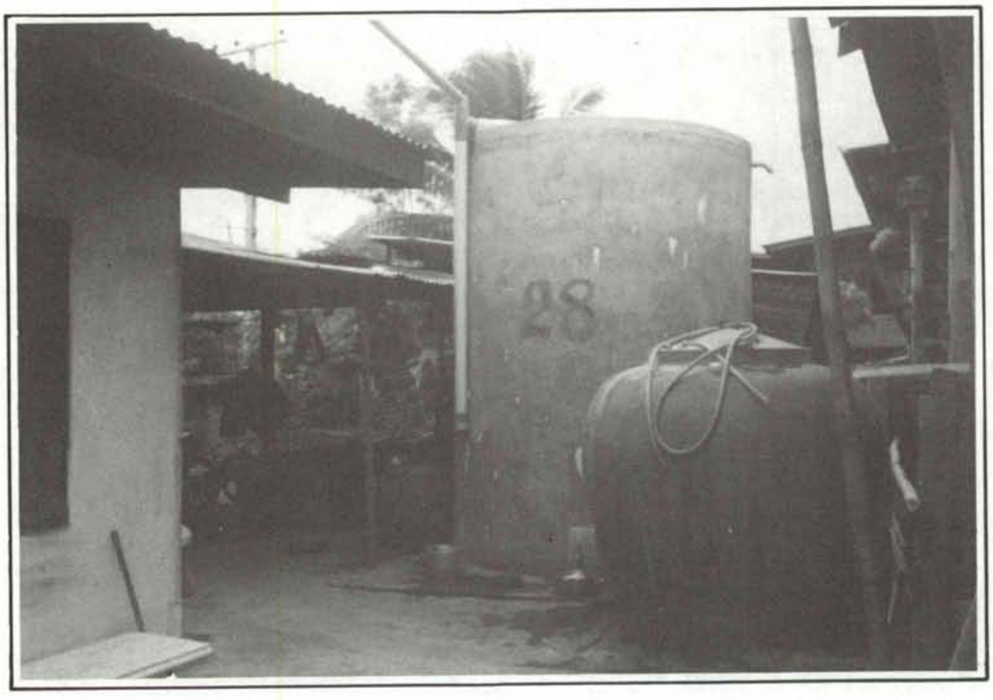
| Income Level (Baht/year) | Number of Households | % |
|---|---|---|
| 00,001 - 25,000 | 276 | 66 |
| 25,001 - 50,000 | 98 | 23 |
| 50,001 - 100,000 | 39 | 9 |
| > 100,000 | 8 | 2 |

**Table 4.12 Preferred Sources of Drinking Water (survey of 421 households)**

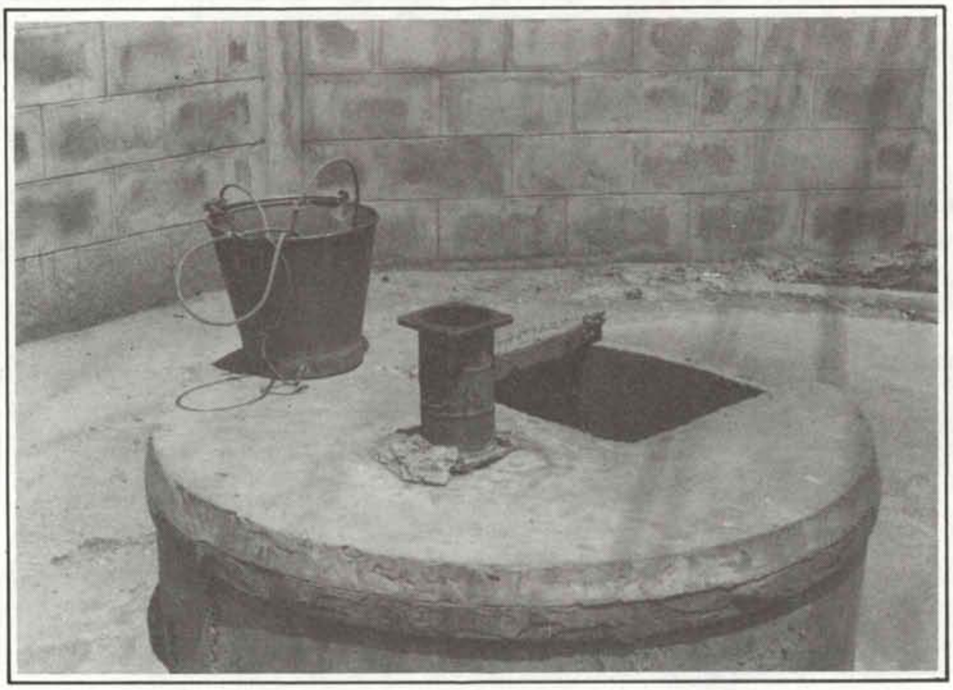
| Sources | Piped Water | | Rainwater | | Dug well | | Shallow well with pump | | Pond | |
|---|---|---|---|---|---|---|---|---|---|---|
| Preference | No. | % | No. | % | No. | % | No. | % | No. | % |
| Whole year | 22 | 5.2 | 267 | 63.4 | 131 | 31.1 | 1 | 0.2 | 0 | 0 |
| Rainy Season | 7 | 1.7 | 410 | 97.4 | 3 | 0.7 | 1 | 0.2 | 0 | 0 |
| Dry Season | 30 | 7.1 | 161 | 38.2 | 228 | 54.2 | 1 | 0.2 | 1 | 0.2 |
| Most Preferred | 7 | 1.7 | 344 | 81.7 | 69 | 16.4 | 0 | 0 | 1 | 0.2 |
| Considered best quality by villagers | 23 | 5.5 | 390 | 92.6 | 8 | 1.9 | 0 | 0 | 0 | 0 |



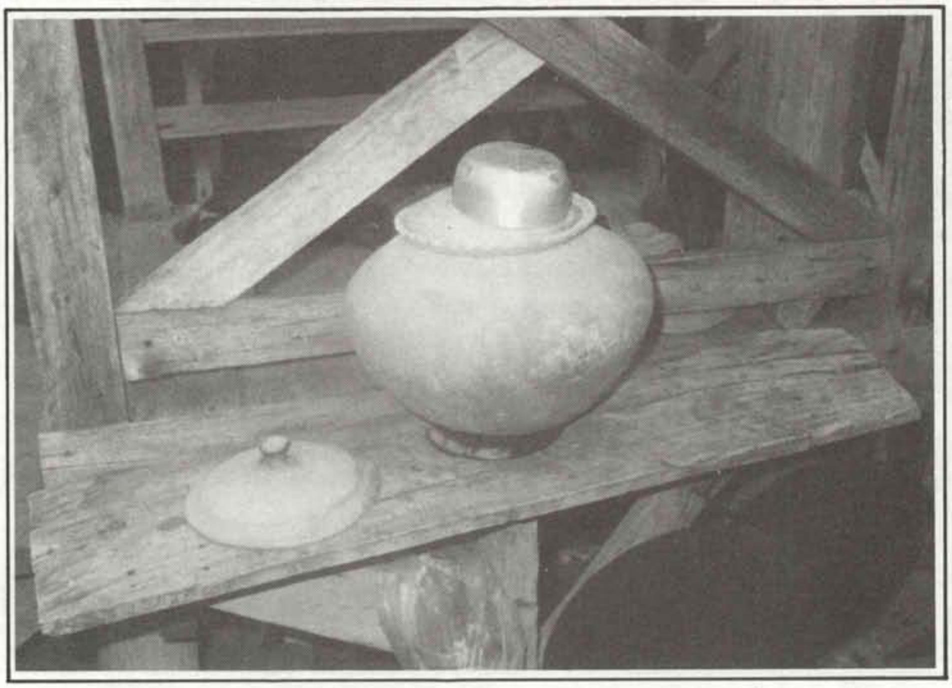
**Picture 4 Household Structure.**




**Picture 5 Rainwater Storage Container.**



**Picture 6 Shallow Well Water.**



**Picture 7 In-house Storage Container.**

79.6% of the village households had a properly designed collection system (Table 4.13). This being one that fits snuggly to the edge of the roof and using storage tanks that are lower than the roof. It was also observed that 70.5% of the homes had permanent gutters, 24% had non-permanent gutters, and another 5.5% had no gutters at all and collected their rain directly from the atmosphere by placing the collection containers in the open. All of the permanent gutters were made of galvanized iron, and 23.5% out of the 24% of the non-permanent gutters were made out of galvanized iron also. 0.5% of the gutters were made of bamboo (Table 4.14).

The sanitary condition of 54% of these roofs and gutters were found to be clean without rust or debris while another 46% were found to be dirty and corroded (Table 4.15).

The storage tanks and jars were used to collect rainwater directly from the roof and gutter systems. The water was then transferred to other storage containers including the in-house storage containers. 92% of the village households owned their own jars, but only 19% had their own tanks (Table 4.16) due to the higher cost of the tanks. The expense of rainwater tanks is inconsequential when compared to the tank's size.

According to the survey, no sanitary jars (jars with taps, drainage plugs, lids, and screens) were found in the villages. The jars always lacked at least one of the following features ; a tap, a drainage plug, a screen or a proper lid. Table 4.17 shows that 78.9% of the jars had two major features, a tap and a lid. This demonstrated that secondary contamination may have occurred through a very direct route, from the environment itself.

The withdrawal method of water from the storage tanks and jars varied. 89% of the withdrawal methods used taps, while 7% of the withdrawal methods used both the tap and a dipping vessel to fetch water. Sometimes plastic tubes were run out of the top of the storage containers to siphon water from the tanks and jars (Table 4.18).

The questionnaire also revealed that 61.3% of the households cleaned their storage containers only once a year, 33.5% cleaned their storage containers more than once a year, and 5.2% of the households had never cleaned their storage containers at all (Table 4.19).

The shallow well water that is sometimes used to supplement a dwelling water supply during the dry season is kept in a seperate container than the rainwater in 79.6% of the cases (Table 4.20). The water is fetched from the shallow well by emmersing buckets, which have been set on the ground, into the well thereby contaminating the water (Table 4.21).

#### 4.5.4 Solid Waste Disposal

According to this study's survey done in 1988, the environmental conditions of Thai villages have improved. Villagers pay more attention to the disposal of excreta, solid waste, and also animal manure. It was observed that 91.7% of the households had their own toilet and most of them used their toilet for excreta disposal (Table 4.22). The toilets were usually seperated from the house, but within the yard around the house perimeter. The homeowners without toilet facilities used that of their neighbors (Table 4.23).

**Table 4.13 Characteristics of Collection Systems (survey of 421 households)**

| Characteristics | Number of Households | % |
|---|---|---|
| Proper design | 335 | 79.6 |
| Improper design | 86 | 20.4 |

**Table 4.14 Characteristics of Gutters (survey of 421 households)**

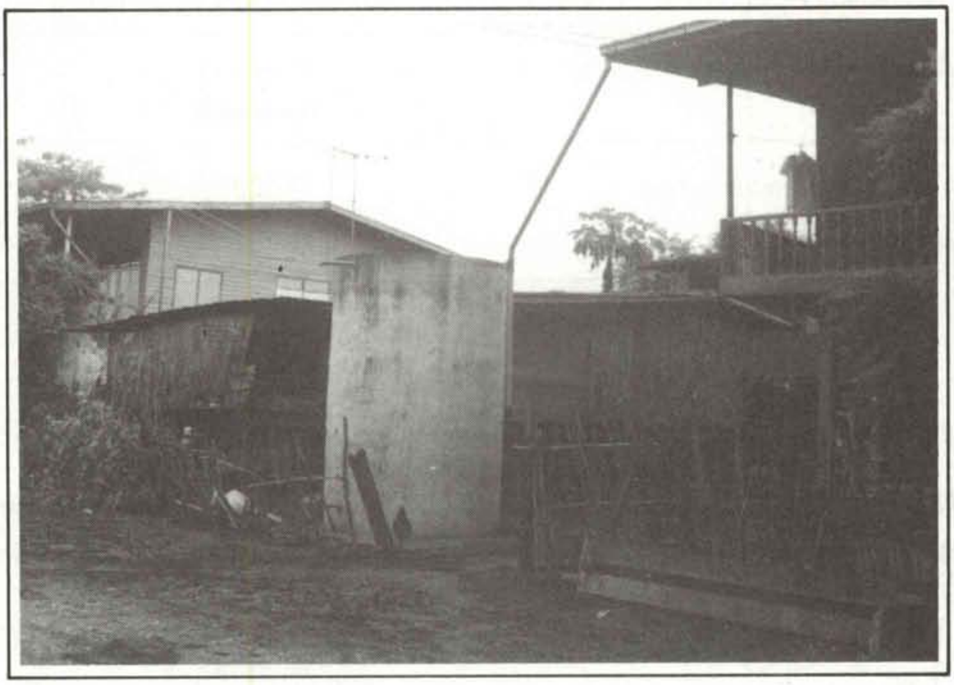
| Characteristics | Number of Households | % |
|---|---|---|
| With Permanent gutter | 297 | 70.5 |
| Non permanent gutter made of bamboo | 2 | 0.5 |
| Non permanent gutter made of galvanized iron | 99 | 23.5 |
| Without gutter | 23 | 5.5 |

**Table 4.15 Sanitary Conditions of Roof and Gutter (survey of 421 households)**

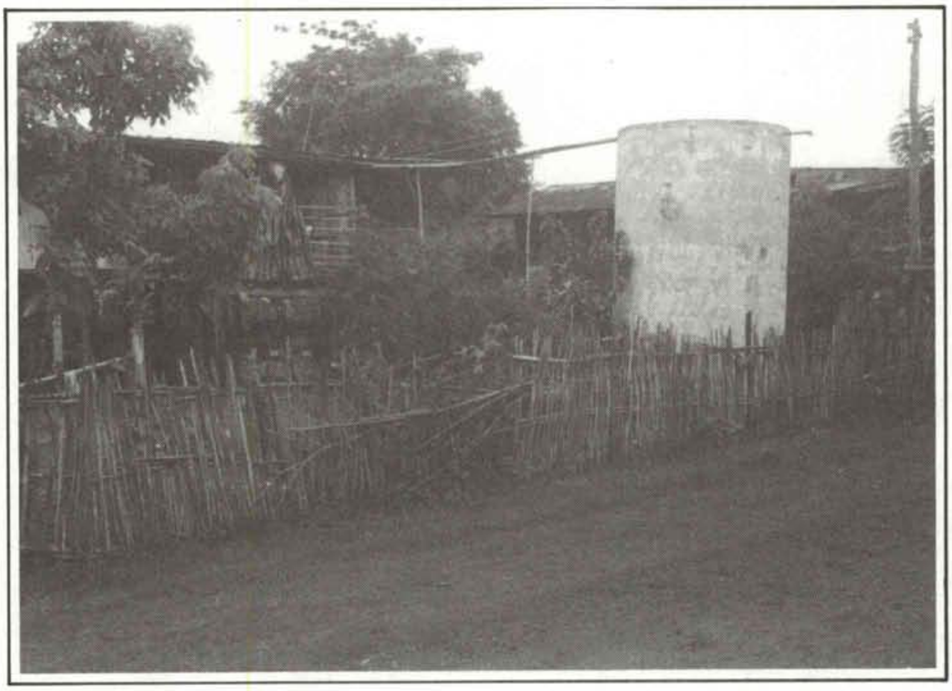
| Cleanliness | Number of Households | % |
|---|---|---|
| Clean without rust and/or leaves | 229 | 54.4 |
| Unclean with rust and/or leaves | 192 | 45.6 |

**Table 4.16 Percent of Owned Storage Containers (survey of 421 households)**

| Type of Storage Containers | Owned (%) | Dont have their own(%) |
|---|---|---|
| Jar | 92.2 | 7.8 |
| Tank | 19.0 | 65.0 |



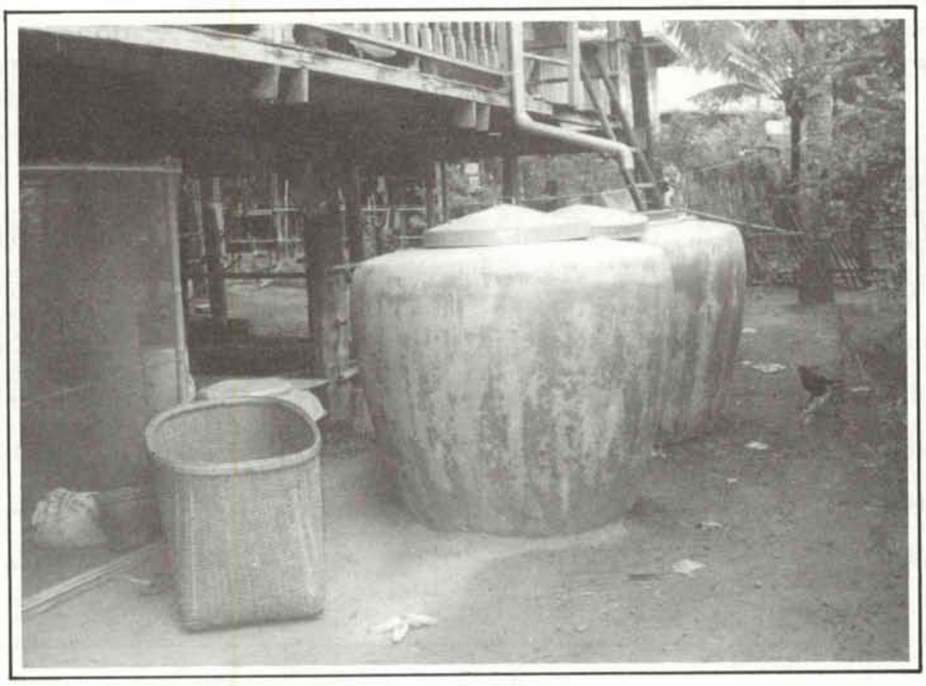
**Picture 8 Proper Design of Collection System.**



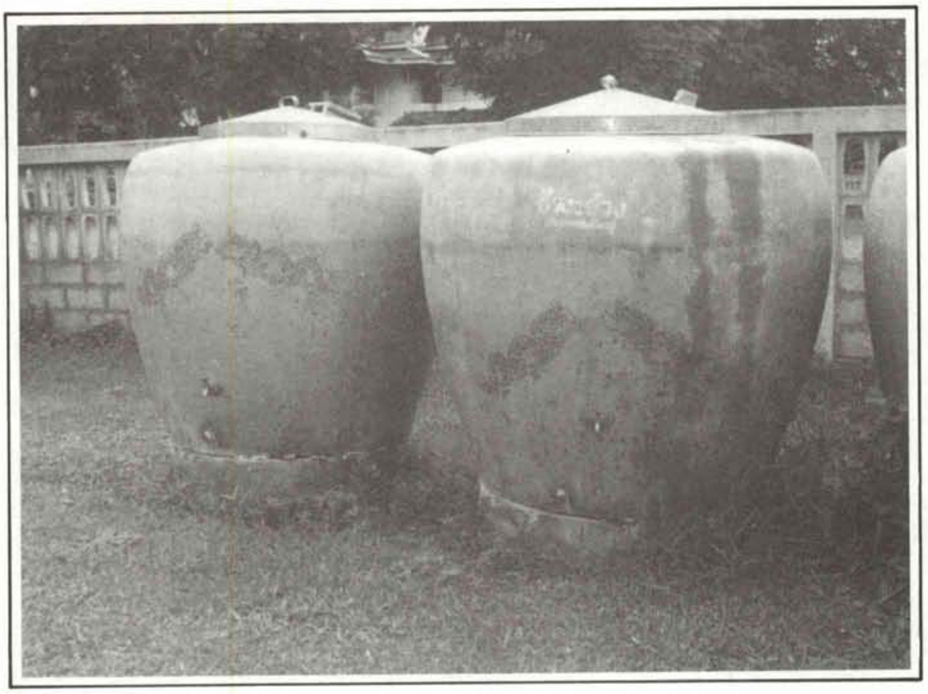
**Picture 9 Improper Design of Collection System.**

**Table 4.17 Characteristics of Rainwater Jars**

| Characteristics | Number of Jar Samples | Percentage |
|---|---|---|
| with tap, drainage plug, lid and screen | 0 | 0 |
| with tap, drainage plug, lid | 32 | 6.8 |
| with tap and lid | 371 | 78.9 |
| with tap, drainage plug, and screen | 1 | 0.2 |
| with tap, lid, and screen | 3 | 0.6 |
| with tap, and drainage plug | 5 | 1.1 |
| with lid only | 29 | 6.2 |
| with tap only | 24 | 5.1 |
| with tap and screen | 5 | 1.1 |
| **Total** | **470** | **100** |



**Picture 10 Common Rainwater Jars.**



**Picture 11 Sanitary Rainwater Jars.**

**Table 4.18 Withdrawal Practices from Storage Containers**

| Type of Storage containers | Withdrawal Practices Used | Number of Container Samples | % |
|---|---|---|---|
| with tap (85%) | 1. Only used tap | 357 | 89.0 |
| | 2. Used tap and/or dipping vessels | 29 | 7.2 |
| | 3. Used tap, dipping vessels and/or plastic tube | 2 | 0.5 |
| | 4. Used tap or plastic tube | 11 | 2.8 |
| | 5. Used dipping vessels and/or plastic tube | 2 | 0.5 |
| | **Total** | **401** | **100** |
| without tap or with broken tap (15%) | 1. Only used dipping vessels | 39 | 56.5 |
| | 2. Dipping and plastic tube | 9 | 13.1 |
| | 3. Only used plastic tube | 21 | 30.4 |
| | **Total** | **69** | **100** |

**Table 4.19 Cleaning Practices of Rainwater Storage Containers**

| Practices | Frequency | Number of Container Samples | % |
|---|---|---|---|
| Cleaned | - annually | 258 | 61.3 |
| | - more than 1 time per year | 141 | 33.5 |
| Never cleaned | - | 22 | 5.2 |
| | **Total** | **421** | **100** |

**Table 4.20 Drinking Water from Shallow Wells Storage Practices**

| Storage Practices | Number of Samples | % |
|---|---|---|
| Kept in rainwater jar | 47 | 18.8 |
| Kept in separate storage jar | 199 | 79.6 |
| Kept in plastic bottle | 4 | 1.6 |
| **Total** | **250** | **100** |

**Table 4.21 Dipping Vessels used to Fetch Water from Shallow Wells**

| Type of Dipping Vessels | Number of Samples | % |
|---|---|---|
| Common bucket | 0 | 0 |
| Personal bucket | 250 | 100 |
| **Total** | **250** | **100** |

**Table 4.22 Excreta Disposal Facilities**

| Excreta Disposal Facilities | Number of Households | % |
|---|---|---|
| Have their own toilets | 386 | 91.7 |
| Don't have their own toilets | 35 | 8.3 |
| **Total** | **421** | **100.0** |

**Table 4.23 Excreta Disposal Sites for Households Without Toilets**

| Disposal Sites | Number of Samples | % |
|---|---|---|
| Fields | 4 | 11.4 |
| Neighbour's toilet | 31 | 88.6 |
| **Total** | **35** | **100.0** |

A proper waste collection system was counted in 38.7% of the households system (a rubbish bin was used to keep wastes until the time of their proper removal via burning or burying). However, more than 60% still had an irregular solid waste disposal system where waste was simply thrown in the yard surrounding the house leading to the spread of disease via pathogens present in the exposed excreta (Table 4.24). The households used a disposal by burning method in 84.2% of the households, 13.6% directly disposed of the waste in their fields which again could lead to disease transmission, and only 2% of the households buried their solid waste in the yards around their homes (Table 4.25). These solid waste management methods remain unhygienic in nature. Some possible mitigation measures would be supplying the villages with proper incinerators for burning waste, or instructing village health volunteers on how to properly compost or make landfills of the solid waste for disposal.

### 4.5.5 Area Arrangement of Livestock

Most of the Thai villages still feed their livestock within the yards surrounding their homes. The observation of these three villages revealed that 38.9% of the households that fed their livestock kept them in separate cages, and 58.7% kept their livestock under the house unconstrained (Table 4.26). This last practice also promotes bacterial contamination of the surrounding area by the livestock stirring up dirt and their excreta. Encouraging villagers to cage the animals that live within the household grounds would help considerably in keeping the immediate living quarters and home environment cleaner and therefore healthier.

### 4.5.6 Personal Hygiene Practices

One of the personal hygiene practices which was associated with the contamination of rainwater was the use of unwashed hands or unclean fetching bowls to withdraw water from storage containers. It was found that 68.4% of the villagers used good personal hygiene methods as they washed their hands every time after using the latrine. Another 31.6% of the villagers used improper methods such as never washing their hands after using the latrine or before preparing food (Table 4.27). Some households do not even make it a practice to use soap while washing their hands. This of course, increases the risk of fecal - oral transmission of disease via contaminated drinking water.

Unclean hands may also contaminate the fetching bowls used in withdrawing water from the storage containers. These same bowls may also increase the risk of disease transmission. According to Table 4.28, up to 98% of the households used a common bowl for a drinking vessel between household members and up to 76% of the vessels don't have handles (Table 4.29). This, of course, is another route of infection. Encouraging the use of fetching bowls with handles and keeping enough bowls for each family member's personal use would help erradicate this form of contamination.

According to the sanitary practices' survey, it can be seen that the route of bacteriological contamination of rainwater is not only from unhygienic practices during storage and transfer, but also from unsanitary surroundings where there is improper solid waste disposal and an

**Table 4.24 Solid Waste Storage Systems**

| Systems | Number of Households | % |
|---|---|---|
| No storage | 1 | 0.2 |
| *Permanent storage | 163 | 38.7 |
| **Irregular storage | 257 | 61.1 |
| **Total** | **421** | **100.0** |

* Permanent storage – rubbish bin used to store wastes

** Irregular storage – sometimes without rubbish bin to store wastes

**Table 4.25 Solid Waste Disposal Methods**

| Disposal Methods | Number of Samples | % |
|---|---|---|
| Buried | 10 | 2.2 |
| Burned | 389 | 84.2 |
| Directly disposed of in field | 63 | 13.6 |
| Composted | 0 | 0 |
| **Total** | **462** | **100.0** |

**Table 4.26 Area Arrangement for Keeping Livestock**

| Area Arrangement | Number of Samples | % |
|---|---|---|
| Kept in separate cages | 101 | 38.9 |
| Kept around household area without cages | 6 | 2.4 |
| Kept under the house without cages | 152 | 58.7 |
| **Total** | **259** | **100.0** |

**Table 4.27 Personal Hygiene Practices after Using Latrine**

| Frequency of Washing Hands After Using Latrine | Number of People Questioned | % |
|---|---|---|
| Every time (with soap & water) | 288 | 68.4 |
| Sometimes (with soap & water) | 90 | 21.4 |
| Sometimes (with water only) | 27 | 6.4 |
| Never | 16 | 3.8 |
| **Total** | **421** | **100.0** |

**Table 4.28 Usage of Fetching Bowls**

| Type of Bowl | Number of People Questioned | % |
|---|---|---|
| *Common bowl | 331 | 98.2 |
| **Separate bowl | 6 | 1.8 |
| **Total** | **337** | **100.0** |

* Common bowl – Everyone uses the same bowl for fetching and drinking, water.
** Seperate bowl – Everyone uses their own bowl for fetching and drinking, water.

**Table 4.29 Characteristics of Fetching Bowls**

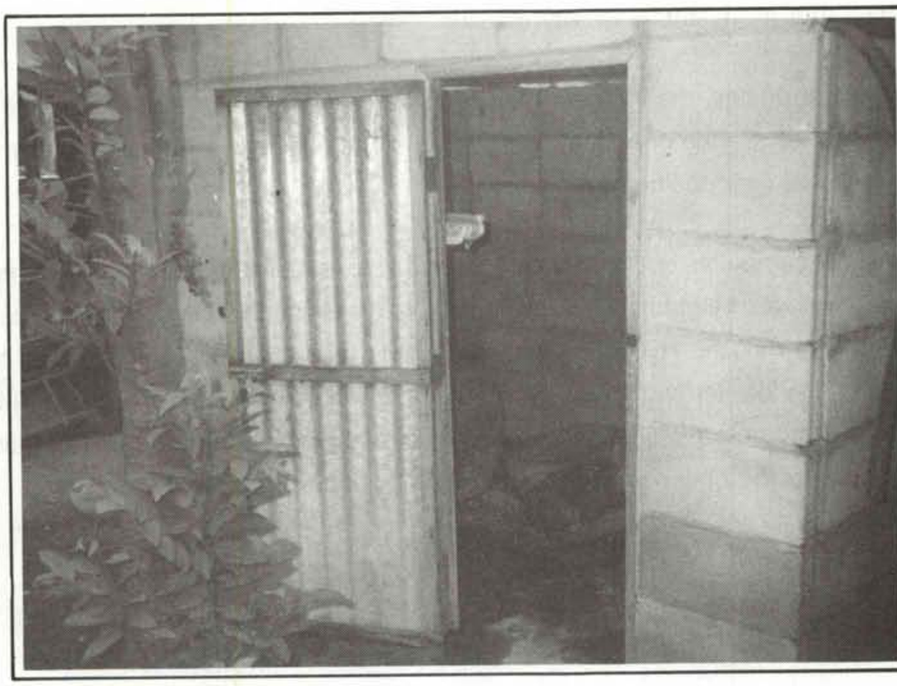
| Characteristics | Number Observed | % |
|---|---|---|
| with handles | 92 | 24.2 |
| without handles | 288 | 75.8 |
| **Total** | **380** | **100.0** |

unhygienic area arrangement of livestock.

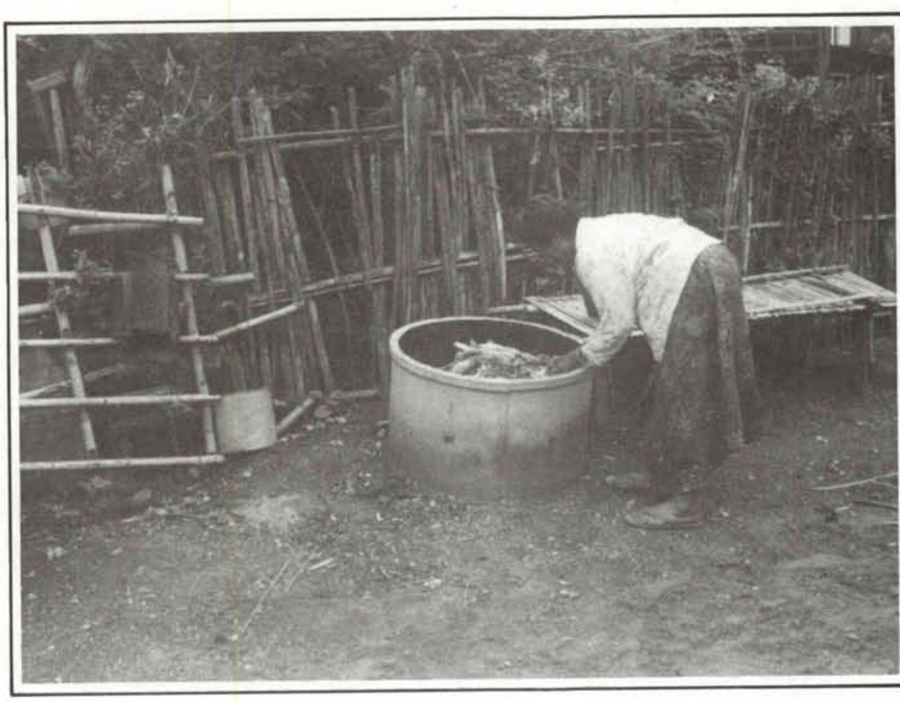
As for the source of heavy metal contamination, this study has shown that it originates mainly from the galvanized iron roofing material. However, this study has also pointed out that this contamination may not necessarily have a harmful affect on health as Mn and Zn are not considered a risk, but an aesthetic quality measure only.

To improve rainwater quality, the villagers themselves are a very important factor in the mitigation proceedings since they are the ones that must improve the hygienic conditions of their immediate surroundings and also their sanitary practices.

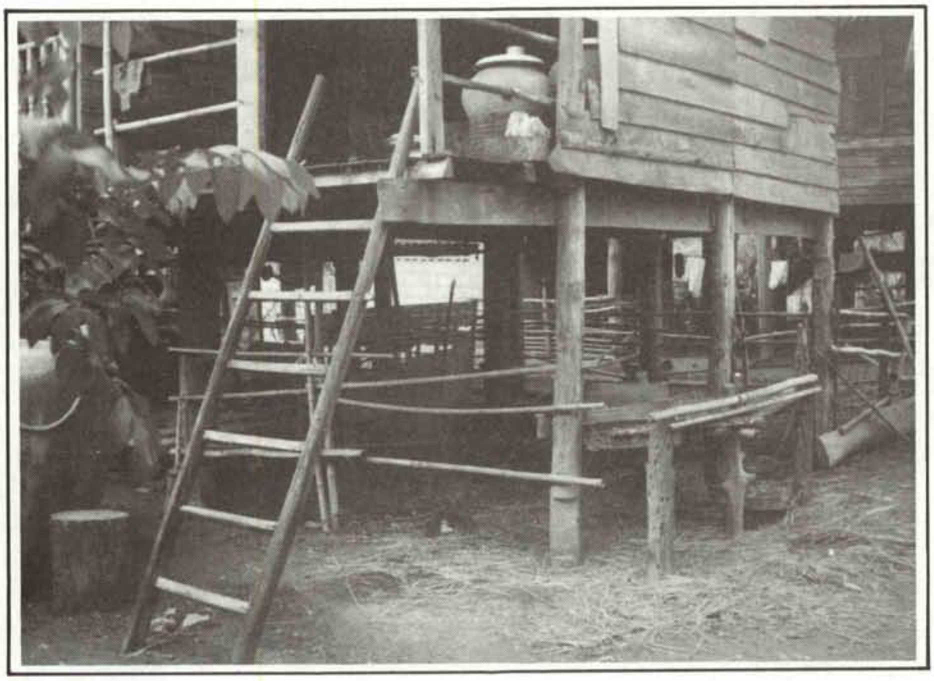
A health education campaign could motivate villagers to change their habits and reduce their malpractices as well as heighten their hygienic awareness thus, improving the condition of their lives. In the long run, this mitigation measure would be the most successful way to improve rainwater quality. A short term method would be through rainwater disinfection. This method could be used and promoted while at the same time changing the attitude and practices of the villagers thus doubling the chances of a successful mitigation process.



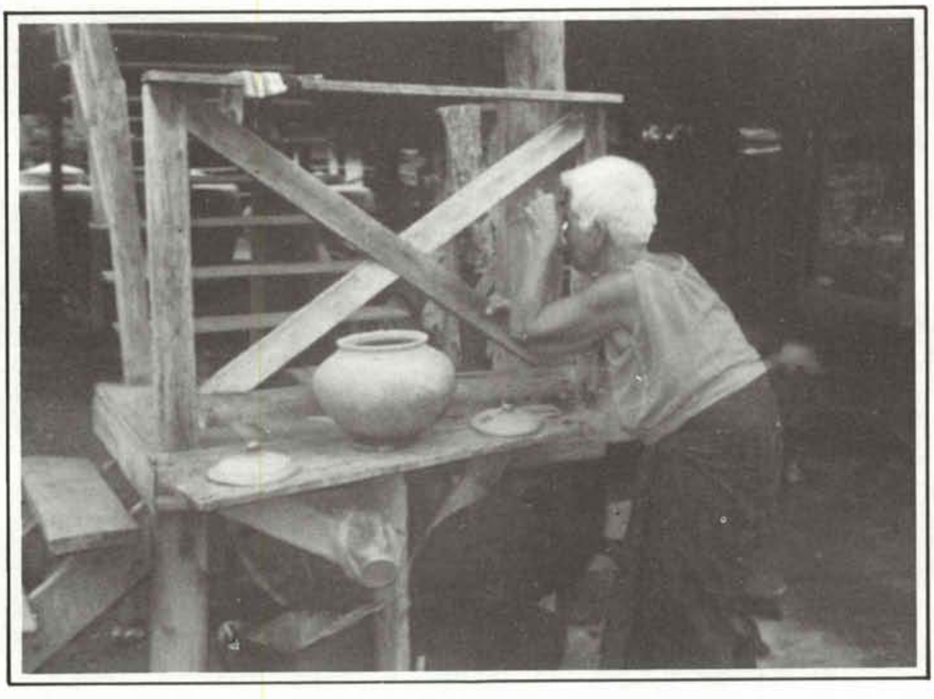
**Picture 12 Toilet Facilities.**



**Picture 13 Solid Waste Storage System.**



**Picture 14 Area Arrangement of livestock.**



**Picture 15 Personal Hygiene Practice (Usage of Bowl).**

# V. SUMMARY AND CONCLUSION

The work reported herein has provided the analysis results of rainwater quality in terms of its bacteriological and heavy metal contamination. It has also included the effect of storage systems on the quality of the collected rainwater, the route of contamination via rainwater collection systems, and the effect of water handling, usage, and sanitary practices on the level of secondary contamination.

The conclusions presented in this section include some recommendations for proper mitigation measures drawn from this study's findings.

## 5.1 Evaluation of the Bacteriological Quality of Rainwater

### 5.1.1 Bacteriological Contamination of Rainwater

The evaluation of whether there was indeed bacteriological contamination in stored rainwater required the collection and testing of samples from various sampling points. The results from this analysis was then compared with the drinking water standards established by WHO in 1971, for accepted total bacterial counts, total coliform, fecal coliform, and *E.coli* analyses.

Rainwater samples collected from all of the various sampling points; roof and gutter systems, tank and jar storage containers, and in-house storage containers, failed to meet those standards. It was found that 60% of the various samples and over, had total bacterial counts which exceeded standards, 34% of the samples and over exceeded the total coliform standard, 43% of the samples and over exceeded the fecal coliform standard, and 10% of the samples and over exceeded the WHO drinking water standard for *E.coli.* The conclusions drawn from these results are summarized below.

All of the samplings points were bacteriologically contaminated. However, the highest percentage of contamination encountered in samples were from in-house storage containers followed by samples from roof and gutter systems and lastly, storage containers.

The contamination occuring at the roof and gutter systems was most likely due to dirt, debris, decaying leaves, and excreta from birds and reptiles being washed off the roof with the first rains and into the storage containers. This was concluded due to the fact that the contamination from this sampling point was of animal origin, where the contamination occuring at the in-house storage container was of both animal and human origin (this was based on FC : FS ratios that will be discussed in section 5.1.2). This made the water handling and usage practices of the villagers another probable source of contamination. These poor practices, of course, would also account for the higher percentage of contamination in the in-house storage containers.

The percentage of samples collected from tanks not meeting WHO standards is higher than that for jars in almost every bacteriological parameter, save for fecal coliform. They are as follows: 61% compared to 60% for total bacterial counts, 40% compared to 28% for total coliform, and 14% compared to 10% for *E. coli*. This was considered to be due to the cleaning practices observed in the selected villages. The jars being much easier to manipulate and wash were cleaned much more regularly than the large storage tanks and therefore, had lower contamination levels.

### 5.1.2 The Source of Bacterial Contamination

The source of bacterial contamination was evaluated using FC : FS ratios. About 79% of the samples collected from roof and gutter systems and 84% of the samples collected from rainwater storage tanks and jars had FC : FS ratios of less than 1, indicating that the source of contamination for these samples were of animal rather than human origin. Approximately 39% of the samples collected from the in-house storage containers had FC : FS ratios of less than 1 and 47% had FC : FS ratios of greater than 4, indicating that the contamination was from both animal and human origin. Therefore, it was concluded that the human contamination occurred due to unhygienic water handling and usage practices.

### 5.1.3 Pathogenic Contamination

The pathogenic contamination was found in samples taken from roof and gutter systems, samples from storage tanks, and from in-house storage containers. No pathogens were isolated from storage jars. The isolated pathogens from these samples were *Salmonella group E*, *Salmonella group C*, *Aeromonas sp.*, *Vibrio parahaemolyticus*, and *Aeromonas hydrophila*. These pathogens are known to cause diarrheal diseases in humans. However, the pathogens were isolated in only about 0.6% of the samples collected.

The findings above have allowed some recommendations to be drawn. The recommendations for the mitigation of stored rainwater contamination are as follows:

1) Cleaning roof and gutter systems by letting the first rain wash off the the collected debris present of its surface before collecting rainwater for consumption.

2) Cleaning storage containers before collecting rainwater.

3) Using hygienic practices when handling and using rainwater to prevent secondary contamination, and

4) Disinfecting stored rainwater when necessary.

## 5.2 Bacteriological Contamination of Shallow Well Water

The bacteriological quality of shallow well water was also investigated so that a comparison to the quality of rainwater could be drawn. It was found that the bacterial contamination of shallow well water was higher than that of rainwater in every bacteriological parameter.

The FC : FS results of shallow well water were similar to the results from the in-house storage container samples, as approximately 33% of the shallow well samples had a FC : FS ratio of less than 1 and 43% of the samples had a FC : FS ratio of greater than 4, indicating that the source of contamination was of both animal and human origin.

A pathogens was also isolated from the shallow well samples. The isolated pathogen was *Aeromonas hydrophila*. The pathogenic contamination occurred in approximately 4% of the samples which is a higher rate of occurrence than for any of the rainwater samples, regardless of the rainwater sample that was taken. Therefore, it may be concluded that rainwater is still a better source of drinking water than shallow well water.

### 5.3 Heavy Metal Contamination of Rainwater

The heavy metals analysed in this study included Cd, Cr, Pb, Cu, Fe, Mn, and Zn. Most of the heavy metal concentrations did not exceed WHO standards for drinking water (1971) with the exception of Mn and Zn. However, both Mn and Zn are considered to affect aesthetic quality of water only and are not considered to be significant healthwise.

There was a range of 9 - 20% of the roof and gutter system samples which failed the WHO standards for Mn and 4 - 26% of the samples failed for Zn. Only 2% of the samples taken from the in-house storage containers failed WHO standards for Mn. No samples taken from the storage tanks or jars exceeded the standards in any of the analysed parameters. This indicated that the initial route of contamination originated at the roof and gutter systems and was then recontaminated at the site of the in-house storage container. However, it may be noted that the roof and gutter systems were considered the major source of contamination. It was also found that the first rainfall samples contained higher concentrations of Mn and Zn than the following rainfall samples, suggesting that Mn and Zn were leached initially from the galvanized iron roofing material and then washed into the storage containers. The lower concentration of heavy metals in the upper layers of stored rainwater could be due to the metals settling to the bottom sediment layers of the storage containers via either adsorption (e.g. Zn) or precepitation (e.g. Mn). A high pH of stored rainwater may also cause the dissolved form of heavy metals to become insoluble and therefore, deplete the stored rainwater's heavy metal concentration.

The recommendations for preventing heavy metal contamination are as follows:

1) Discard the first rainfall, and
2) Do not use the rainwater near the bottom sediment layer of a storage container for consumption.

### 5.4 Sanitary Practices

The sanitary practices investigated in this study included: The household structure itself, drinking water sources, characteristics of collection systems, characteristics of storage containers, water handling and usage practices, cleaning practices, excreta disposal facilities, solid waste disposal, and personal hygiene practices.

The investigating methods included a questionnaire and visual observation. A group of 5 research assistants spent one week in each village collecting this data.

It was concluded that the sanitary practices played an important role in the bacterial contamination of stored rainwater. Not only did unhygienic practices during collection, storage, and transfer of rainwater affect the bacteriological contamination, but also the unsanitary surroundings of the household itself affected the bacteriological quality of the rainwater.

Consequently, the major factor being considered for rainwater quality improvement is the hygienic sanitary practices of the villagers. This can be done by a hygienic education campaign via an implementing agency especially the Ministry of Public Health.

Rainwater is potentially the safest and the most economical source of drinking water with the improvement of hygienic collection procedures, storage, and sanitary practices.

# VI. RECOMMENDATIONS

Two recommendations were drawn from this study. They include recommended methods for the reduction of contamination and a recommendation for further research.

The recommended methods for the reduction of contamination are as follows:

1) Making improvements in the hygienic collection practices used in rainwater collection systems, such as cleaning roof and gutter systems, and storage containers.
2) Improving water handling and usage practices.
3) Improving sanitary practices.
4) Improving the sanitary conditions of the household and the surrounding yard.
5) Using rainwater disinfection techniques when necessary to improve the quality of the drinking water.

The recommedation for further research include investigating proper mitigation measures for the reduction of rainwater contamination and could be best continued in the following manner:

1) Through a health education training project.
2) Through an evaluation of appropriate rainwater disinfection techniques, and
3) Through evaluating modifications of existing collection systems.

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# APPENDICES

# APPENDIX A

# QUESTIONNAIRE AND SANITARY PRACTICES OBSERVATION

## I Questionnaire

**Direction :** This questionnaire is divided into 5 parts. Part I is about the socio-economic condition of the village community. Part II deals with the condition of drinking water in the village and traditional water usage and storage. Part III is about excreta disposal. Part IV deals with solid waste, animal manure, and wastewater disposal. Part V deals with food sanitation.

### Part I : Socio - Economic Conditions

1. House no. : ..........................................................................................................................

   Village no. :.................................................Name of village.........................................................................

   Subdistrict :............................................District :..........................................Province :.........................................

2. Status of interviewed person

   ( ) head of the family ( ) wife

   ( ) daughter / son / relatives

3. Sex

   ( ) male age.............................. ( ) female age...........................

4. Religion

   ( ) Buddhism ( ) Christian

   ( ) Islam ( ) Other (specify)...........................

5. Education

   ( ) Primary school ( ) Secondary school

   ( ) High school ( ) Further education

6. Number of people in the household :..........................................................................................................

7. Who is the rightful owner of your house ?

   ( ) own house ( ) rented

   ( ) stay with relative ( ) other (specify)...........................

8. Total amount of land under your ownership : ...........................rai (1 rai = 1600 $m^2$)

9. Occupation and family 's average income per annum

| Occupation | Product (thung)* | Cost/unit product (bath) | Total income (bath) |
|---|---|---|---|
| Working in paddy field | ........................ | ........................................ | ........................................ |
| Working on plantation | ........................ | ........................................ | ........................................ |
| Working as labourers | ........................ | ........................................ | ........................................ |
| Merchandizing | ........................ | ........................................ | ........................................ |
| Raising animals | ........................ | ........................................ | ........................................ |
| Working in civil service | ........................ | ........................................ | ........................................ |
| Others (specify)...................... | ........................ | ........................................ | ........................................ |
| | | **Total** | ........................................ |

* 1 thung = 16 kilograms

10. In your opinion, this family's income, is ..................

( ) adequate ( ) inadequate

( ) adequate with some saving

( ) other (specify) ......................

11. Distance from village to district/province ........................................................................ km.

Distance from village to market ........................................................................ km.

Distance from village to health center ........................................................................ km.

12. Are there any training sessions about personal hygiene in your village ?

( ) No

( ) Yes (specify) ........................

**Part II : Condition of drinking water in the village and traditional for water usage and storage**

1. Please write ( / ) in the space provided the drinking water source that you use during the following periods and which drinking water source is the best and most accessible for you.

| **Usage characteristics** | **Piped water** | **Rainwater** | **Wells with pump** | **Shallow well** | **Pond** | **Other (specify)** |
|---|---|---|---|---|---|---|
| 1. Drink during most of the year | | | | | | |
| 2. Drink mostly in the rainy season | | | | | | |
| 3. Drink mostly in the dry season | | | | | | |
| 4. Prefer most | | | | | | |
| 5. In your opinion which source is the best for drinking | | | | | | |
| 6. Which is the most accessible source ? | | | | | | |

2. Structure of roof and gutter system

2.1 Roofing meterial

( ) sunbaked clay tile (color........................................ condition....................................................)

( ) galvanized iron (color......................................., condition....................................................)

( ) thatch (condition................................)

( ) other (specify.................................)

(color........................................... condition.........................................)

2.2 The height between the gutter and the storage containers is.........................

( ) proper

( ) improper

2.3 Characteristic of roof and gutter system

( ) permanent gutter properly fixed to the roof

( ) non - permanent gutter made of bamboo

( ) non - permanent gutter made of galvanized iron

( ) other (specify)...........................

2.4 How do you store water during the rainy season ?

( ) stored immediately after rain

( ) stored after it rains 2 or 3 times

( ) other (specify)...........................

3. Storage containers

3.1 Do you have jar (s) in your house ?

( ) Yes, How many ? number.....................

How many are used to store rainwater ? number...........................

( ) No.

3.2 Size and characteristic of jars.

| Size of jar | Number of jars | | | | | |
|---|---|---|---|---|---|---|
| | with cover | without cover | with tap | without tap | with screen | without screen |
| Small jar (10-15 peep*) | | | | | | |
| Middle jar (25-30 peep) | | | | | | |
| Big jar (50-100 peep) | | | | | | |
| Other (specify...............) | | | | | | |

* 1 peep (kerosene can) = 20 litres

3.3 How do you withdraw water from the large jar (50 - 100 peep) ?

( ) using dipping vessels

( ) using a tap

( ) using a plastic tube

( ) other (specify)..................................

3.4 Do you have a rainwater tank in your house ?

( ) Yes (specify)..............................size..................................$m^3$

( ) No.

3.5 Do you have any other rainwater storage containers besides a rainwater jar or rainwater tank ?

( ) Yes (specify)..............................size..................................$m^3$

( ) No. Why ? ..............................................................................................................

3.6 Have you ever cleaned your rainwater storage jar and/or tank before storage ?

( ) No, never

( ) Yes (specify frequency).....................................

( ) Other (specify).....................................

3.7 Did you have enough rainwater for drinking purposes last year ?

( ) Yes

( ) No. Why ? ................................................

3.8 Please estimate the quantity of rainwater that would be adequate for one whole year of consumption..................................................

4. When do you use water from a dug well ?

( ) for drinking purposes the whole year

( ) for drinking purposes only in the dry season

( ) only for washing/bathing

( ) only for drinking

5. Did you treat the water from the dug well before drinking it ?

( ) No.

( ) Yes, (How ?) ..............................

6. Where did you store the water from the dug well that you used for drinking ?

( ) stored it mixed together with rainwater in a jar.

( ) stored it seperately from the rainwater in a jar.

( ) stored it in a plastic gallon container.

( ) other (specify) .................................

7. How do you withdraw water from the dug well for purposes ?

( ) by using a common bucket.

( ) by using your own bucket.

8. What container did you use to carry the water back to your home ?

( ) plastic gallon

( ) bucket or peep ( ) without a cover

( ) covered with a cloth

9. Have you ever drunk water from a deep well that has a hand pump ?

( ) Yes, and ( ) it is acceptable.

( ) it is not acceptable because....................................

10. Do you think water from deep wells with hand pumps is suitable to use as a drinking water source why, or why not ?

( ) Yes, (explain) ..................................................................

( ) No, (explain) ..................................................................

11. In your village, the villagers use water from deep well, for.................

( ) drinking

( ) domestic use

( ) agricultural use

**Part III : Excreta Disposal**

1. Do you have a toilet in your house ?

( ) Yes (give the distance between the toilet and the well that is used for drinking purposes..............................m.)

( ) No.

2. If no, where did you deposit you excreta ?

( ) in the field

( ) neighbour's toilet

( ) other (specify) ...................................

3. Does everyone in your family use the toilet ?

( ) Yes ( ) No (give reason) ....................................

4. How often does your family use the toilet ?

( ) everytime

( ) sometimes because.........................................

( ) never

5. What do you use to clean yourself after using the toilet ?

( ) water ( ) tissue paper

( ) paper or other meterials, such as sticks, newspaper, etc.

6. Do you wash your hands everytime after using a toilet ?

( ) yes (everytime wisth soap) ( ) yes (sometimes with soap)

( ) yes (only with water) ( ) No (never)

7. Do you have enough water to flush the toilet for a whole year ?

( ) Yes,

( ) No. We have solved this problem by ....................................

**Part IV : Solid Waste, Animal Manure, and Wastewater Disposal**

1. Do you have a solidwaste storage system ?

( ) No, if no is it ( ) disposed of on the ground around the house

or ( ) sometimes collected and disposed

( ) Yes (storage bin)

2. How do you dispose of your solid waste ?

( ) bury ( ) burn

( ) compost ( ) open dump

3. Where do you keep your animals ?

( ) separate partitions for animals (ie: cage, pen, etc.)

( ) under the house

( ) within the household area

( ) don't have animals.

4. How do you dispose of your animal manure ?

( ) compost for fertilizer

( ) compost for biogas

( ) sold as fertilizer/used as fertilizer

( ) never do anything

5. How do you dispose of your wastewater ?

( ) dispose through drainage system

( ) dispose within household area

( ) dispose of in the nearest water source (river, stream, etc.)

( ) other (specify) ....................................................................................

**Part V : Food Sanitation**

1. Where do you keep your food after cooking ?

   ( ) in a cupboard

   ( ) in a plate with a cover

   ( ) on the table without a cover.

2. Do you wash your hands before eating ?

   ( ) Yes

   ( ) No

   ( ) Sometimes

3. Characteristic of drinking utensils.

   Handle : ( ) with handle ( ) without handle

   Usage : ( ) for common use ( ) for personal use

## II. Sanitary Practices Observation

**Direction :** This form is used by interviewer to observe the sanitary practices of the villagers. It is divided into two parts. Part I is about the latrine condition. Part II is about food sanitation and eating and drinking habits.

### Part I : The Latrine's Condition

1. Is the latrine still usable ?

   ( ) Yes (and in good condition)

   ( ) No (give reason)..............................................

2. Is the ventilation good ?

   ( ) Yes ( ) No

3. The Latrine's floor is .....................................................

   ( ) in good condition ( ) cracking

4. Is the place where they squat good condition ?

   ( ) Yes ( ) No

5. Is there a cover on the rubbish bin in the latrine ?

   ( ) Yes ( ) No

6. Is there any soap for washing hands after using latrine ?

   ( ) Yes ( ) No

7. Is there any water in the latrine storage jar ?

   ( ) Yes ( ) No

8. What do you use the latrine space for ?

   ( ) excreta disposal and bathing

   ( ) excreta disposal only

9. If the latrine is also used for bathing, the water is

   ( ) stored separately from the bathing water

   ( ) stored in the same jar for both excreta flushing and bathing

### Part II : Food Sanitation and Habit of Eating and Drinking Habits

1. The kitchen's floor is ....................................

   ( ) clean ( ) dirty

2. The ceiling and walls are ......................................

   ( ) clean ( ) dirty

3. The ventilation is ......................................................

   ( ) good ( ) not good

4. The condition of the kitchen is ................................................. ..............

( ) tidy and clean ( ) untidy and dirty

5. The dishes are kept

( ) on a rack ( ) on the floor

6. The spoons and forks are kept with ............................... ............

( ) the handles up ( ) the handles down

7. They eat food

( ) with utensils ( ) with hands.

8. Drinking vessel is for ...............................................

( ) common use ( ) personal use only

9. The drinking vessel(s) are

) clean ( ) dirty

10. Dirty dishes are cleaned with ...............................................

( ) detergent/soap and water

( ) water only

# APPENDIX B

## STANDARDS FOR DRINKING WATER QUALITY (WHO, 1971)

1. Bacteriological quality

| Organism | Unit | Standard value |
|---|---|---|
| total coliforms | number/100 ml | 2.2 |
| fecal coliforms | number/100 ml | 0 |

2. Inorganic constituents of health significance

| Constituent | Unit | Standard value |
|---|---|---|
| cadmium | mg/l | 0.01 |
| chromium | mg/l | 0.05 |
| lead | mg/l | 1.00 |

3. Inorganic constituents of aesthetic quality

| Constituent | Unit | Standard value |
|---|---|---|
| copper | mg/l | 1.00 |
| iron | mg/l | 0.30 |
| manganese | mg/l | 0.10 |
| zinc | mg/l | 5.00 |
| pH | - | 6.5-8. |

# APPENDIX C

## STANDARD DEVIATION, MINIMA AND MAXIMA DATA *

Roof and Gutter System

- Bottom container of automatic sampler

| Variable | Number of sample | Deviation | Minimum | Maximum | WHO Standard ** |
|---|---|---|---|---|---|
| Cd | 114 | 0.0016 | 0.0001 | 0.0107 | 0.0100 |
| Cr | 116 | 0.0011 | 0.0000 | 0.0061 | 0.0500 |
| Pb | 116 | 0.0001 | 0.0000 | 0.0005 | 0.0500 |
| Cu | 117 | 0.0100 | 0.0000 | 0.0640 | 1.0000 |
| Fe | 117 | 0.0132 | 0.0002 | 0.0592 | 0.3000 |
| Mn | 93 | 0.1200 | 0.0010 | 0.5860 | 0.1000 |
| Zn | 116 | 2.3000 | 0.3530 | 10.2700 | 5.0000 |
| pH | 18 | 0.3600 | 6.3500 | 7.8000 | 6.8-8.5 |

- Middle container of automatic sampler

| Variable | Number of sample | Deviation | Minimum | Maximum | WHO Standard ** |
|---|---|---|---|---|---|
| Cd | 108 | 0.0008 | 0.0001 | 0.0060 | 0.0100 |
| Cr | 111 | 0.0010 | 0.0000 | 0.0052 | 0.0500 |
| Pb | 111 | 0.0001 | 0.0000 | 0.0005 | 0.0500 |
| Cu | 111 | 0.0100 | 0.0000 | 0.0810 | 1.0000 |
| Fe | 116 | 0.0116 | 0.0003 | 0.0759 | 0.3000 |
| Mn | 117 | 0.0700 | 0.0000 | 0.6530 | 0.1000 |
| Zn | 112 | 1.3500 | 0.0160 | 6.3400 | 5.0000 |
| pH | 18 | 0.1400 | 7.0000 | 7.5500 | 6.8-8.5 |

- Top container of automatic sampler

| Variable | Number of sample | Deviation | Minimum | Maximum | WHO Standard ** |
|---|---|---|---|---|---|
| Cd | 86 | 0.0005 | 0.0001 | 0.0028 | 0.0100 |
| Cr | 89 | 0.0009 | 0.0000 | 0.0034 | 0.0500 |
| Pb | 89 | 0.0001 | 0.0000 | 0.0005 | 0.0500 |
| Cu | 88 | 0.0100 | 0.0000 | 0.0510 | 1.0000 |
| Fe | 88 | 0.0096 | 0.0001 | 0.0523 | 0.3000 |
| Mn | 99 | 0.0800 | 0.0000 | 0.6890 | 0.1000 |
| Zn | 88 | 1.440 | 0.0600 | 9.6520 | 5.0000 |
| pH | 15 | 0.2300 | 6.9000 | 7.6500 | 6.8-8.5 |

# APPENDIX C (Cont'd)

Storage Container : Tank

| Variable | Number of sample | Deviation | Minimum | Maximum | WHO Standard ** |
|---|---|---|---|---|---|
| Cd | 87 | 0.0005 | 0.0000 | 0.0024 | 0.0100 |
| Cr | 83 | 0.0009 | 0.0000 | 0.0029 | 0.0500 |
| Pb | 86 | 0.0001 | 0.0000 | 0.0005 | 0.0500 |
| Cu | 85 | 0.0300 | 0.0000 | 0.2010 | 1.0000 |
| Fe | 73 | 0.0116 | 0.0002 | 0.0658 | 0.3000 |
| Mn | 86 | 0.0200 | 0.0000 | 0.0750 | 0.1000 |
| Zn | 87 | 0.220 | 0.0030 | 1.5100 | 5.0000 |
| pH | 9 | 0.3100 | 8.0000 | 9.1000 | 6.8-8.5 |

Storage Container : Jar

| Variable | Number of sample | Deviation | Minimum | Maximum | WHO Standard ** |
|---|---|---|---|---|---|
| Cd | 98 | 0.0006 | 0.0000 | 0.0022 | 0.0100 |
| Cr | 94 | 0.0011 | 0.0000 | 0.0040 | 0.0500 |
| Pb | 97 | 0.0001 | 0.0000 | 0.0005 | 0.0500 |
| Cu | 97 | 0.0300 | 0.0000 | 0.1700 | 1.0000 |
| Fe | 82 | 0.0117 | 0.0000 | 0.0634 | 0.3000 |
| Mn | 96 | 0.0200 | 0.0000 | 0.0740 | 0.1000 |
| Zn | 109 | 0.2200 | 0.0000 | 1.1100 | 5.0000 |
| pH | 9 | 0.4300 | 7.7500 | 9.2000 | 6.8-8.5 |

In house Container

| Variable | Number of sample | Deviation | Minimum | Maximum | WHO Standard ** |
|---|---|---|---|---|---|
| Cd | 92 | 0.0007 | 0.0000 | 0.0041 | 0.0100 |
| Cr | 85 | 0.0015 | 0.0000 | 0.0102 | 0.0500 |
| Pb | 91 | 0.0001 | 0.0000 | 0.0006 | 0.0500 |
| Cu | 90 | 0.0200 | 0.0000 | 0.1300 | 1.0000 |
| Fe | 82 | 0.0173 | 0.0000 | 0.0901 | 0.3000 |
| Mn | 90 | 0.0200 | 0.0000 | 0.1340 | 0.1000 |
| Zn | 80 | 0.2700 | 0.0000 | 1.0990 | 5.0000 |
| pH | 9 | 0.2700 | 7.4100 | 8.200 | 6.8-8.5 |

* Unless otherwise noted concentration are expressed in mg/l

** Standards for Drinking Water Quality (WHO, 1971)