Shallow Groundwater Quality Assessment in Muang District, Phayao

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Abstract

A shallow groundwater well is the important source of potable water for the remote area. This study aimed to improve the state of knowledge on the quality of shallow groundwater in Muang District, Phayao Province. Thirty five shallow groundwater wells were sampled for the water quality testing. Inorganic contents (NO_3, As, Cd, Cu, Pb, F, Fe, Mn and Zn) and microbiological contamination, using fecal coliform bacteria as indicators, were investigated. The shallow well maintenance and locations were also studied. Although, 3 of 8 analyzed metals (F, Fe and Zn) were detected in shallow groundwater, the concentrations of those metals were within the standard norms proposed by the Pollution Control Department of Thailand. In contrast to the metal content, the nitrate concentrations were higher than standard (> 45 mg/l). Water hardness was between 60.89-1656.50 mg/l, and twenty one from thirty five samples were considered hard water. Coliform bacteria were found in all samples. This indicated that shallow wells had been contaminated with the fecal material of human beings or other animals. The cause of contamination could be that shallow wells were located very close to septic tanks. Moreover, the shallow wells were poorly maintained. The buckets and robes used to draw water in some wells were seen lying on the ground between uses and some wells were not covered.
Keywords: Coliform bacteria, Shallow groundwater, Water quality

Introduction

The use of shallow ground water sources for drinking and other domestic purposes is a common feature of many low-income communities in developing countries (Pedley & Howard, 1997). The well is a hole, which has been dug, bored, driven or drilled into the ground less than 50 feet deep for the purpose of extracting water. The source of a well is an aquifer - an underground layer of permeable soil (such as sand or gravel) that contains water and allows the passage of water. Aquifers are replenished by rainfall or surface water seeping down through the soil. Because of the depth and structure of the shallow well, the contamination with organic and inorganic compounds is a major concern (Aelion & Conte, 2004). The high concentration of many chemical elements such as Pb, Cd, Fe, As, F, Cu and Mn can occur in such waters. After many years of using or drinking water contaminated by these metals, it has been recognized as a world-wide public health hazard. For example, after many years of drinking water from drilled wells in the Rift Valley, Ethiopia, dental and skeletal fluorosis has become a serious medical problem (Reimann et al., 2003). Fluorosis has been reported not only from Ethiopia but from several other parts of the world, e.g. China, India, Sri Lanka and even Thailand (Handy, 1975). The shallow groundwater quality is threatened with not only metal contamination but microbiological contamination also; for example, the bacteria *Escherichia coli* and *Pseudomonas putida* and the bacteriophage virus H40/1 (Reid et al., 2001).

A number of studies have been done on the assessment of groundwater quality in the central region surrounding Bangkok. Until now, little information on shallow groundwater in the countryside of Thailand has been available. As rural communities continue to rely on shallow groundwater, it is important to improve the state of knowledge on the quality of shallow groundwater in these rural areas. Therefore, this study was undertaken to investigate the quality of shallow groundwater in Muang District, Phayao Province, Thailand. Inorganic contents (NO_3, As, Cd, Cu, Pb, F, Fe, Mn and Zn) in shallow groundwater were investigated. The study also focused on a microbiological contamination using total coliform bacteria as indicator. The maintenance and location of shallow wells were also surveyed because improper location and maintenance could create a microbiological contamination.

Materials and Methods

Site description and sampling method

The studies were carried out in Muang District, Phayao Province in northern Thailand (Figure 1). It is located between north latitude 18-20 and east longitude 99-100. A total number of 35 shallow well sites of this study were randomly selected from several villages which could not access a tap water supply in Muang District. All samples were taken in May 2005. Three water samples from each well were obtained in accordance with the standard methods for the examination of water and wastewater (American Public Health Association, 1998). Each sample was kept in 2000-mL polypropylene bottles and stored at + 4 ^{o}C until shipped to a laboratory for analyses.

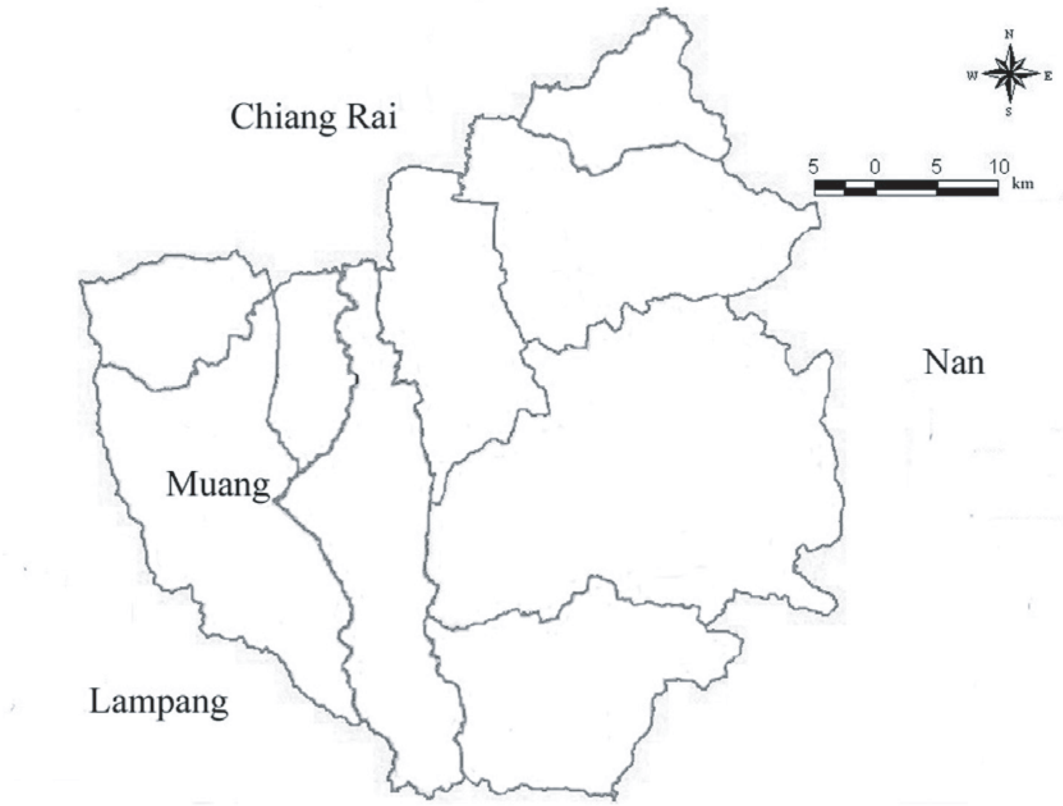

Figure 1 Location of Muang District, Phayao Province.

Laboratory analyses

For the metal analysis, water samples were digested with 5 ml of 65% nitric acid at 100 ^{o}C for 3 hours and filtrated through 0.45–µm cellulose acetate filter. The metal concentrations in digested samples were determined by the Perkin Elmer 2380 flame atomic absorption spectrophotometer. Nitrate determination was carried out according to the UV spectrophotometric screening method as described in the standard methods. Water hardness was measured by titrimetric method, which was described in the standard methods. For coliform bacteria measurement, the most probable number (MPN) method, which was expressed in the standard methods for the examination of water and wastewater, was used for the presumptive identification, confirmation, and enumeration of indicator bacteria, the total coliform bacteria. The information of shallow well location and maintenance was collected using a simplified questionnaire. This questionnaire involved identifying the distance between the shallow well and potential sources of microbiological contamination such as a septic tank or live stock yard. The questions about well maintenance included disinfection and the well protection such as masonry, concrete wall, and lid.

Results and Discussion

Shallow well location and maintenance

Shallow well location and maintenance was recorded in order to collect information regarding specific points of risk to the shallow well, such as a septic tank or livestock yards. The information from the survey indicated that source is situated very close to the shallow well. A minimum distance between the well and the source had been suggested to be 50 feet (Bonner, 2004), while the distance between the wells and the sources in this study was between 15 and 85 feet. Furthermore, there were inappropriate using and poor maintenance of the wells. The container and robes, used to draw water, were seen lying on the ground between uses and some wells were not closed properly. Methajan (1997) reported the inappropriate shallow well consumption behaviors in Tambol Soppad. These behaviors included: not having lids or drawing containers and not cleaning the containers. As a result, these behaviors lowered water quality and increased the quantity of contaminated bacteria.

Metal contents

The results of metal, NO_3, hardness and total coliform bacteria analyses were summarized in Table 1. The pH of shallow groundwater ranged between 7.2 and 8.2. It was in the range recommended by the World Health Organization (WHO) and the Pollution Control Department of Thailand (PCD) (pH 7.0-8.5 for drinking water). Three of eight analyzed metals (F, Fe, Zn) were detected in shallow groundwater (as shown in Table 1). Fortunately, the concentration of analyzed metals was within the standard norms proposed by the PCD. F was found in 10 samples; the concentrations were between 0.007 and 0.325 mg/l. Zn was detected in 4 samples, its concentrations were between 0.025 and 0.678 mg/l. In contrast to F and Zn, Fe was found in every sample, its concentrations range from 0.028 to 0.951 mg/l. There were 2 samples in which the Fe level was higher than suitable allowance (>0.5 mg/l). However, the Fe content in all samples was still less than a maximum allowable proposed by the PCD. A similar study done by Singh et al. (2006), a contamination of F and Fe was reported. They suggested that the contamination of some groundwater aquifer with F and Fe indicated natural influences.

Water hardness

Water hardness is determined by the measurement of calcium and magnesium ions in the water. It is commonly expressed in parts per million (ppm) of calcium carbonate ($CaCO_3$). In this study, the results showed that the water hardness of 15 samples was higher than the suitable allowance (>300 mg/l). High concentrations of calcium and magnesium ions in water create several problems for its use at home and industry. These problems include formation of calcium carbonate deposits and human diseases, for example, kidney stone (Curhan et al., 1993). The U.S. Department of Interior and the Water Quality Association classify the water hardness into four categories as follows: soft (total hardness $CaCO_3$ 0-60 mg/l), moderately hard (61-120 mg/l), hard (121-180 mg/l) and very hard (>180 mg/l) (McNally et al., 1998). Although the water hardness in some samples was in acceptable limit proposed by the PCD, it was classified as moderately hard or hard. Moreover, there were 21 samples classified as very hard water. Although hard water is not a serious health risk, it can create a problem because of mineral building-up on fixtures. The hard water also contributes to poor soap and detergent performance. The cost of improvement would be high but the benefits obtained in terms of water quality would be much greater. There are many ways to help control the water hardness, for example, the use of an ion exchange water softener unit; moreover, the softener could also remove the Fe from the water. By using the water softener, untreated water passes through a bed of ion exchange medium, when calcium, magnesium and iron are exchanged with sodium on the medium, thus making the water soft.

Table 1 Summary of the results of metals, NO_3, water hardness and total coliform bacteria analyzes.

Well no	pH (mean /S.D.)	Metal mg/l (mean/S.D.)								NO_3 mg/l (mean/S.D.)	Total Hardness as $CaCO_3$ mg/l (mean/S.D.)	Coliform Bacteria MPN/ 100 ml (mean)
		As	Cd	Cu	F	Fe	Mn	Pb	Zn			
Standard* Suitable Allowance	7.0-8.5	-	-	≤ 1.0	≤ 0.7	≤ 0.5	≤ 0.3	-	≤ 5.0	≤ 45	≤ 300	-
Maximum Allowable	6.5-9.2	0.05	0.01	1.5	1.0	1.0	0.5	0.05	15.0	45	500	<2.2
1	7.5/ 0.3	-	-	-	-	0.445/ 0.007	-	-	-	42.01/ 0.29	$197.0/ 10.8^d$	17
2	7.2/ 0.2	-	-	-	0.009/ 0.004	0.325 /0.015	-	-	-	33.05/ 1.24	$825/ 25.3^d$	>1600
3	7.6/ 0.3	-	-	-	-	0.338/ 0.043	-	-	-	53.05/ 1.24	$123.5/ 12.4^c$	350
4	7.4/ 0.8	-	-	-	0.124/ 0.002	0.434 /0.035	-	-	-	41.87/ 3.49	$725/ 45.3^d$	>1600
5	7.3/ 0.8	-	-	-	-	0.062 /0.005	-	-		58.00/ 1.75	$223.4/ 21.4^d$	240
6	7.2/ 0.3	-	-	-	-	0.232 /0.001	-	-		102.0/ 21.40	$1249.5/ 14.8^d$	18
7	7.9/ 0.2	-	-	-	-	0.042 /0.001	-	-		33.20/ 4.92	$108.5/ 7.2^b$	9.4
8	7.2/ 0.1	-	-	-	-	0.486/ 0.020	-	-	-	78.05/ 1.96	$85/ 3.1^b$	1.3
9	7.1/ 0.1	-	-	-	0.007/ 0.002	0.227/ 0.008	-	-		59.30/ 5.35	$60.89/ 1.8^b$	5.6
10	7.4/ 0.4	-	-	-	0.020/ 0.007	0.867/ 0.116	-	-		69.20/ 1.87	$176.5/ 9.9^c$	4.9
11	7.2/ 0.3	-	-	-	-	0.088/ 0.002	-	-		96.32/ 14.20	$1352.5/ 23.3^d$	23
12	7.4/ 0.4	-	-	-	-	0.073/ 0.008	-	-		40.32/ 3.24	$170.5/ 11.0^c$	4.9
13	7.6/ 0.2	-	-	-	-	0.064/ 0.005	-	-		78.98/ 14.26	$118.0/ 14.1^b$	9.4
14	7.4/ 0.3	-	-	-	-	0.373/ 0.035	-	-		95.77/ 12.21	$65.0/ 4.2^b$	13
15	7.8/ 0.1	-	-	-	0.134/ 0.007	0.951 /0.013	-	-		78.30/ 4.35	$166.0/ 19.1^c$	>1600
16	7.2/ 0.5	-	-	-	0.018/ 0.008	0.412 /0.026	-	-	-	99.30/ 8.35	$698.0/ 16.8^d$	250
17	7.3/ 0.2	-	-	-	-	0.169 /0.004	-	-	-	80.32/ 3.24	$495.7/ 7.2^d$	23
18	8.2/ 0.3	-	-	-	0.015/ 0.005	0.076 /0.002	-	-	-	109.4/ 15.90	$822.5/ 31.3^d$	9.4

Table 1 Summary of the results of metals, NO_3, water hardness and total coliform bacteria analyzes (continued).

Well no	pH (mean /S.D.)	Metal mg/l (mean/S.D.)								NO_3 mg/l (mean/S.D.)	Total Hardness as $CaCO_3$ mg/l (mean/S.D.)	Coliform Bacteria MPN/ 100 ml (mean)
		As	Cd	Cu	F	Fe	Mn	Pb	Zn			
Standard* Suitable Allowance	7.0-8.5	-	-	≤ 1.0	≤ 0.7	≤ 0.5	≤ 0.3	-	≤ 5.0	≤ 45	≤ 300	-
Maximum Allowable	6.5-9.2	0.05	0.01	1.5	1.0	1.0	0.5	0.05	15.0	45	500	<2.2
19	7.8/ 0.1	-	-	-	-	0.464 /0.009	-	-	-	25.94/ 3.31	1656.5/ 11.1^{d}	350
20	7.2/ 0.4	-	-	-	-	0.079 /0.001	-	-	-	184.07/ 19.15	246.5/ 8.9^{d}	1.8
21	7.7/ 0.4	-	-	-	0.325/ 0.015	0.066 /0.001	-	-	-	46.58/ 3.44	68.0/ 4.4^{b}	3.7
22	7.7/ 0.3	-	-	-	-	0.058 /0.004	-	-	0.025/ 0.023	151.43/ 15.68	106.0/ 6.9^{b}	79
23	7.4/ 0.2	-	-	-	-	0.199 /0.021	-	-		38.12/ 4.57	66.5/ 13.5^{b}	240
24	7.3/ 0.1	-	-	-	-	0.085 /0.019	-	-	-	83.84/ 5.56	369.5/ 19.4^{d}	1.8
25	7.5/ 0.1	-	-	-	-	0.065 /0.003	-	-	-	113.5/ 15.71	159.0/ 11.8^{c}	1.8
26	7.3/ 0.4	-	-	-	0.018/ 0.003	0.234 /0.009	-	-	-	176.35/ 13.42	76.5/ 9.2^{b}	4.9
27	7.6/ 0.1	-	-	-	0.089/ 0.004	0.089 /0.020	-	-	-	78.18/ 14.22	269.0/ 6.1^{d}	1.8
28	7.4/ 0.1	-	-	-	-	0.092 /0.003	-	-	0.349/ 0.014	48.45/ 10.56	319.0/ 21.2^{d}	33
29	7.5/ 0.3	-	-	-	-	0.028 /0.037	-	-	-	89.22/ 10.34	291.0/ 15.8^{d}	4.9
30	7.6/ 0.3	-	-	-	-	0.081 /0.008	-	-	-	63.35/ 13.28	334.5/ 9.3^{d}	1.8
31	7.4/ 0.1	-	-	-	-	0.342 /0.001	-	-	-	196.35/ 18.24	286.0/ 12.4^{d}	45
32	7.2/ 0.2	-	-	-	-	0.359 /0.005	-	-	0.678/ 0.042	30.8/ 6.23	223.0/ 79.7^{d}	240
33	7.3/ 0.5	-	-	-	-	0.125 /0.001	-	-	0.171/ 0.016	140.02/ 10.32	429.5/ 18.3^{d}	>1600
34	7.7/ 0.3	-	-	-	-	0.143 /0.001	-	-	-	47.28/5.01	956.5/ 101.1^{d}	>1600
35	7.3/ 0.1	-	-	-	-	0.292 /0.025	-	-	-	69.12/5.97	456.5/ 5.2^{d}	350

Note.
*The standard norms proposed by the Pollution Control Department of Thailand (PCD).
a, soft water; b, moderately hard; c, hard; d, very hard

Nitrate contamination

While the metal contents in the shallow groundwater studied were generally acceptable, the results indicated that NO_3 and biological contamination were a major problem. The concentrations of nitrate from the present study showed threats to human health; they varied from 25.94 to 196.35 mg/l. The nitrate concentrations in 28 samples were higher than standard (>45 mg/l). The nutrient nitrogen commonly occurs naturally in groundwater, but high nitrate concentration in shallow groundwater might be associated with animal or human waste, septic or sewage systems, as well as lawn and garden fertilization (Zahn & Grimm, 1993). The high concentration of nitrate found in this study may be a result of agricultural activity or various wastes near the shallow wells. According to Power & Schepers (1989) and Spalding & Exner (1993), groundwater nitrate contamination was a major environmental problem in irrigated agriculture areas. Karnchanawong et al.(1993) discovered moderate contamination with nitrate of shallow well water near the Mae-Hia waste disposal site. The nitrate contamination has long been considered a major threat to health in extensive agricultural areas where groundwater is regularly used as a drinking water supply. The principal health risks to consider from the consumption of nitrates in large quantities are methemoglobinemia and the formation of nitrosamines that are carcinogenic when they reach the stomach or the liver (Annouara et al., 2004). Nitrate in excess of 45 mg/l is of health significance to pregnant women and infants under 6 months old (Annouara et al., 2004). Therefore, the results of this study indicated that some shallow wells should not be used as drinking water especially in infant formulas or other infant foods.

Coliform contamination

The threat to human health was not only the high contamination of nitrate in shallow groundwater but the high contamination of coliform bacteria also. Coliform bacteria were detected in all samples. There were only 5 from 35 samples that coliform bacteria did not exceed a maximum allowable (<2.2 MPN/100 ml), while WHO recommends that drinking water should be free from the coliform bacteria (World Health Organization, 2004). The information from questionnaires found most of shallow well consumption behaviors inappropriate (as described in the section of shallow well location and maintenance). As a result, these behaviors increased bacterial contamination (Methajan, 1997). The increase of bacterial contamination results from not only consumption behavior but well location also. Most of the shallow wells in this study located very close to contamination sources such as a septic tank or livestock yards. This resulted in a high contamination of coliform bacteria. Karnchanawong et al. (1993) also claimed that shallow water wells around the Mae-Hia waste disposal site was not suitable for drinking due to the high contamination of total and fecal coliforms. By the Environmental Protection Agency (EPA) standards water is safe to drink if the coliform bacterial count is 0/100 ml; water is safe for other purposes such as swimming and bathing if the coliform bacterial count is less than 200/100 ml. However, the level of coliform bacteria cannot reach zero without treatment of water. The presence of coliform bacteria indicated that the shallow groundwater had been contaminated with the fecal materials of human beings or other animals. When this contamination occurred, the water might have been contaminated by pathogens or disease producing bacteria or viruses existing in fecal material. The presence of high fecal contamination was an indicator that a potential health risk exists for people in these villages exposed to this water.

Conclusions

The results of this study showed a widespread nitrogen and bacteriological contamination of the shallow groundwater wells in Muang District. This suggested that its long-term use as a major drinking water source could have an impact on the health of inhabitants. This situation is thought to be a direct consequence of the poor maintenance and unsuitable location of the shallow well. To keep the well safe from contamination, the possible sources of contamination such as a septic tank or livestock yards should not be close by. The distance between the wells and the sources ranges from 15 to 85 feet, while a minimum distance between the well and the source suggested is 50 feet. Howard et al. (2003) suggested that for heavy contamination, the possible source was within 30 feet. Information from this study indicated that the shallow wells were very close to the possible sources of contamination, especially a septic tank. The bacteriological contamination appearing to the water in wells was from inappropriate well using or poor maintenance of the well. The containers and robes, used to draw water in some wells, were seen lying on the ground between uses and some wells were not closed properly. These have influences on the bacteriological quality. The problem could be, however, corrected either by implementing an education program or by modifying the well, for instance, sealing of the opening with the concrete and installing a water hand or foot pump (Figure 2).

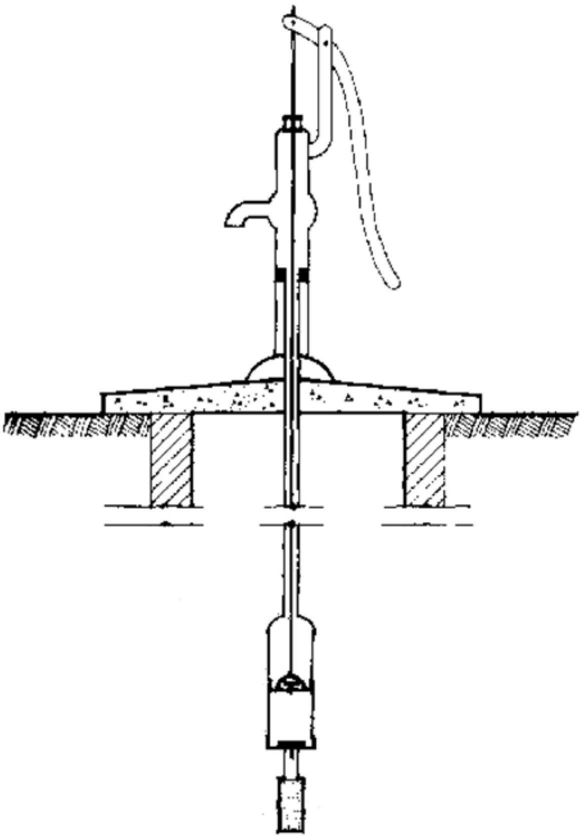

Figure 2 Diagram of hand pump.

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