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Critical Factors on Chemical Properties and Heavy Metals in Water for Livestock Farms in Thailand

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Original Article

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Abstract

This study aimed to investigate chemical quality of animal drinking used in livestock farms in Thailand. Samples and information from 68 pig farms, 35 chicken farms and 9 duckling farms were collected during March to August 2011. Water quality data were analyzed and compared with standard levels using the Mann-Whitney U and Wilcoxon Signed Rank Tests. Results revealed that median chemical values of water for livestock were generally within standard levels, except manganese and iron, which were detected in surfacewater with median values of 0.183 and 0.506 ppm, respectively, and are both higher than standard limits for drinking water. Median pH value in groundwater was 6.85, which was significantly (p < 0.05) lower than pH value (7.23) in surfacewater, and median level of hardness was 169.5 ppm in groundwater, which was significantly higher than that of surface water. Logistic regression was performed to identify a common source of water chemical contaminants and revealed that farms located outside the western region of Thailand and using surfacewater for their livestock were at risk of the high manganese levels in the water. Moreover, analyzed data from Department of Groundwater Resources of Thailand demonstrated high amount of hardness, manganese and iron in groundwater of Thailand, correlated with our findings. Thus, farms using surface or underground water should be aware of high level of manganese, iron and hardness.

Keywords: chemical quality, GIS, heavy metal, livestock, water

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บทคัดย่อ

ปัจจัยวิกฤตที่ส่งผลต่อคุณภาพทางเคมีและโลหะหนักในน้ำที่ใช้ในฟาร์มปศุสัตว์ในประเทศไทย

ธีราภรณ์ เมฆอรุณ [1,2] สุวิชา เกษมสุวรรณ [3] ณัฐวุฒิ รัตนวณิชโรจน์ [4] หทัยรัชต์ หาญอนันตชัย [5] รัชนีกร มิ่งขวัญ [6] สุธา ขาวเธียร [7] พิษณุ ตุลยกุล [2,3]*

การศึกษานี้เป็นการศึกษาคุณภาพทางเคมีของน้ำที่ใช้เลี้ยงสัตว์ในฟาร์มปศุสัตว์ในประเทศไทย โดยทำการเก็บตัวอย่างและข้อมูลจากฟาร์มเลี้ยงสุกรจำนวน 68 ฟาร์ม ฟาร์มเลี้ยงไก่เนื้อจำนวน 35 ฟาร์มและฟาร์มเลี้ยงเป็ดจำนวน 9 ฟาร์ม ระหว่างเดือนมีนาคมถึงเดือนสิงหาคม พ.ศ. 2554 จากข้อมูลการวิเคราะห์คุณภาพน้ำโดยเปรียบเทียบกับค่ามาตรฐานน้ำสำหรับเลี้ยงปศุสัตว์โดยวิธี Mann-Whitney U และ Wilcoxon Signed Rank Tests พบว่าน้ำที่ใช้เลี้ยงปศุสัตว์ในประเทศไทยมีค่ามัธยฐานขององค์ประกอบทางเคมีของน้ำอยู่ในเกณฑ์มาตรฐานน้ำสำหรับเลี้ยงปศุสัตว์ ยกเว้นปริมาณแมงกานีสและเหล็กซึ่งตรวจพบในแหล่งน้ำผิวดินเท่ากับ 0.183 และ 0.506 พีพีเอ็ม และมีค่าสูงกว่าค่ามาตรฐานน้ำดื่มตามลำดับ นอกจากนี้ค่าความเป็นกรดด่างในแหล่งน้ำใต้ดินมีค่ามัธยฐานเท่ากับ 6.85 ซึ่งต่ำกว่าในแหล่งน้ำผิวดินอย่างมีนัยสำคัญ ($p < 0.05$) และค่ามัธยฐานความกระด้างในแหล่งน้ำใต้ดินมีค่าที่สูงเท่ากับ 169.5 พีพีเอ็มซึ่งสูงกว่าในแหล่งน้ำผิวดินอย่างมีนัยสำคัญทางสถิติ สำหรับการวิเคราะห์แหล่งที่มาขององค์ประกอบทางเคมีที่ตรวจพบในแหล่งน้ำที่มีค่าเกินมาตรฐานด้วยวิธี Logistic regression พบว่าฟาร์มเลี้ยงปศุสัตว์ที่ไม่ได้ตั้งอยู่ในเขตภาคตะวันตกของประเทศไทยและเป็นฟาร์มที่มีการใช้แหล่งน้ำผิวดินเพื่อให้สัตว์บริโภคมีความเสี่ยงต่อปริมาณแมงกานีสที่สูงในแหล่งน้ำนั้น นอกจากนี้จากข้อมูลทางธรณีวิทยาและคุณภาพแหล่งน้ำใต้ดินจากกรมทรัพยากรน้ำบาดาลแสดงให้เห็นว่าแหล่งน้ำใต้ดินของประเทศไทยมีค่าความกระด้าง ระดับแมงกานีสและเหล็กในปริมาณที่สูง ดังนั้นฟาร์มที่มีการใช้น้ำผิวดินหรือน้ำใต้ดินควรตระหนักถึงปริมาณของแมงกานีส เหล็กและความกระด้างที่สูง ซึ่งเป็นไปในแนวทางเดียวกันกับข้อมูลจากการศึกษานี้

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Introduction

Currently, the numbers of livestock farms in Thailand are increasing, particularly pigs and poultry which are raised commercially on intensive farms located mainly in the western and central parts of Thailand (DLD, 2011). Generally, water resources used on these farms are from two main sources, surface water and groundwater. Selection of water resource for animal consumption predominantly depends on geographical conditions of each farm.

In previous surveys of water quality, problems of water quality were found in both surfacewater and groundwater. For example, accumulated amounts of nitrate in groundwater were found where livestock farms were located near agricultural land, originating from the use of nitrogen containing fertilizer (Thorburn et al., 2003). In Rayong, a province in Thailand where heavy industrial factories are located, the water resources were contaminated by heavy metals. The amounts of cadmium, zinc, and mercury in its groundwater exceeded standard levels approved by Department of Natural Resources and Environment (Makkasap and Satapanajaru, 2012). Moreover, heavy metals were found in the estuary of Bangpakong River, Thailand. The contamination was determined to be produced by extensive numbers of industrial factories along the river including power plants, battery and electronic factories (Bordalo et al., 2001).

Contaminated water can have an impact on animal health and production, for example levels of total dissolved solid (TDS) over 3,000 mg/l can cause diarrhea, decrease growth rates, and increase chicken mortality rates. Hardness in water has an indirect effect. It decreases the effectiveness of enrofloxacin treatment in broilers (Sumano et al., 2004). Water with a pH over 8.5 lowers chlorine's disinfectant capability (Nakagawara et al., 1998). There was a report that chickens receiving 0.12 milligrams of cadmium combined with 4 milligrams of zinc per day had decreased egg shell thickness (Korénekova et al., 2007). If cadmium was increased to 25 mg/kg body weight, broilers exhibited irritation, flaky skin, and weight loss (Akyolcu et al., 2003). Pigs exposed to cadmium had a lower daily growth rate and decreased estrogen secretion (Han et al., 2006). Heavy metals have indirect effects on animal health and production. Zinc sulphate can combine with tetracycline to form a chelating compound, decreasing the absorption of drugs in animals' digestive tract and therefore the effectiveness.

Heavy metals absorbed by farmed animals can inadvertently find their way into human food chain via animal products such as milk, meat, eggs, liver, and kidney. These heavy metals will accumulate in human body and may have detrimental health effects. Cadmium can damage the nervous system and internal organs, leading to Parkinson's disease (Okuda et al., 1997). Lead at a level of only 49 ppb in human blood not only affects the nervous system but also damages the reproductive system (Telisman et al., 2007).

Therefore, understanding of the water chemical quality in livestock farms in various agricultural areas will be a very beneficial tool, allowing farmers and farm owners to select high quality water resources for animal consumption during production. It will also promote better understanding of groundwater in their areas and encourage them to give precedence to water chemical sampling and analysis. Without a database referring to water quality it is inevitable that water contaminated with heavy metals and chemicals will enter the animal food chain, subsequently affecting animal production and human health. The objective of this research was to study the chemical quality of water used for livestock consumption in Thailand and to evaluate the risk factors associated with water chemical contamination.

Materials and Methods

Farm selection and sampling procedures: Data and water chemical quality information from 112 livestock farms (68 pig, 35 broiler and 9 duck farms), in rural areas of Thailand, were collected between March to August 2011. A province was selected according to convenient sampling method and then farms that were located in different districts were chosen. The number of farm samples required was calculated by Win Episcope 2.0 (Thrusfield et al., 2001) and the prevalence was specified at 61% referring to the prevalence data of groundwater where the chemical quality exceeds the standard levels received from Department of Ground Water Resources. Confidence interval was set at 95% and accepted error was 10%.

General information of farms: Information was gathered from farms by face-to-face interviewing by local veterinarians using a specifically designed questionnaire. Topics included in the questionnaire were composed of general farm information, data of water resources used for livestock consumption, location of farm, and any further information that might contribute to chemical contaminated water resources such as local industries.

Chemical quality information of water used for livestock consumption: Quantification of chemical properties of water used for livestock consumption on each farm composed of pH, TDS, saltiness, conductivity, hardness, calcium, nitrite, nitrate, sulfate, fluoride, chloride, phosphate and heavy metals (iron, copper, zinc, cadmium, lead, nickel, cobalt, chromium, manganese, arsenic) were recorded. The pH values were determined by EC20 pH/ISE meter. TDS, salinity, conductivity and hardness were determined by a CO150 conductivity meter, titration method using EDTA (APHA et al., 2005). The remaining parameters of nitrite, nitrate, sulfate, fluoride, chloride and phosphate were analyzed with a spectrophotometer HACH DR 2000/2010. Heavy metal digestion was determined according to the standard method SW-846 and method 3050B (EPA, 1996), and then analyzed with ICP-OES method using the ULTIMA2, Siamese International Group, Italy.

Statistical analysis: Descriptive and inferential statistics were used to evaluate water chemical quality values. Mann-Whitney U Test was used to determine difference of water chemical quality values between groundwater and surface water. The chemical quality values were compared with standard levels by using the Wilcoxon Signed Rank Test. Association between each factor obtained from the questionnaire and the chemical value was investigated through univariate logistic regression. Only significant factors at p-value ≤ 0.05 were further analyzed by multivariate logistic regression. All analyses were carried out by statistic program NCSS 2007 version 07.1.14 (Hintze, 2009).

Geographical mapping of chemical quality in groundwater: Information of groundwater quality from Department of Groundwater Resources and geographic coordinates of groundwater wells were applied. The information was regularly collected during 1997-2005. Values of each water chemical quality, in all wells, were analyzed for water quality by using Inverse Distance Weighting (IDW) interpolation method. Then, the geographical mapping of these data was analyzed by software ArcGIS 10 for Desktop (ESRI, 2011) in order to demonstrate the chemical quality in each area of groundwater resources.

Results

Location of livestock farms and types of water resources used for animal consumption: Data collected from the questionnaire indicated that livestock farms in Thailand were located within a four-kilometer radius of potential provenance sources of water pollution. These sources are composed of agricultural areas (71), villages (60), other livestock farms (21) and factories (46). Farm water sources were as follows, 68 farms used groundwater, 27 farms used surface water and 3 farms used tap water. Most of the pig farms (40) and poultry farms (26) included in this study used groundwater for animal consumption. Surface water was used primarily in duck farms and tap water was used in all poultry farms.

Chemical values of water used for animal consumption: Median values of pH, hardness, TDS, sulfate, nitrate, chloride, fluoride and heavy metals from laboratory analysis of water samples from livestock farms are showed in Table 1. The hardness value of groundwater was higher than surface water, but the pH value was lower. Both water resources had chemical values within the baseline when compared to the standard of water quality for livestock. There were no notable differences in the chemical values between the six regions included in this study (northern, eastern, western, northern-eastern, central and southern). With respect to heavy metals, only manganese and iron in surface water exceeded the standard levels of human drinking water, they were significantly higher than groundwater at levels of 0.183 and 0.506 ppm, respectively. All other metals detected had a concentration of lower than 0.1 ppm. In all areas hardness was found to be above the standard drinking water limit due to the high manganese and iron levels.

Chemical quality of groundwater resources during 1997–2005: According to the result from Inverse Distance Weighting (IDW) analysis by using the geographic information system program, the tendency of chemical concentration in groundwater resources was mapped as shown in Fig 1-3. It was

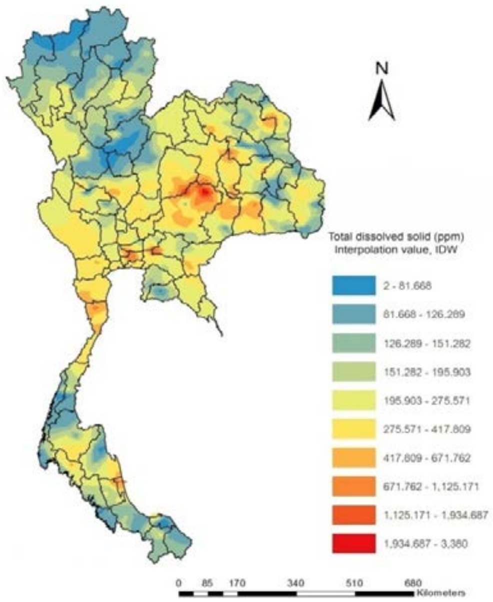

Figure 1 Tendency of hardness interpolation values of groundwater resources in Thailand by Inverse Distance Weighting (IDW) method

demonstrated that high amount of hardness, manganese and iron were presented generally in underground water taken from various parts of Thailand.

Risk factors associated with water chemical quality: A total of 22 factors obtained from the questionnaire were analyzed to determine risk factors associated with poor water chemical quality. Four factors correlated with high manganese concentration of over 0.05 ppm: the water resources of farms in the western

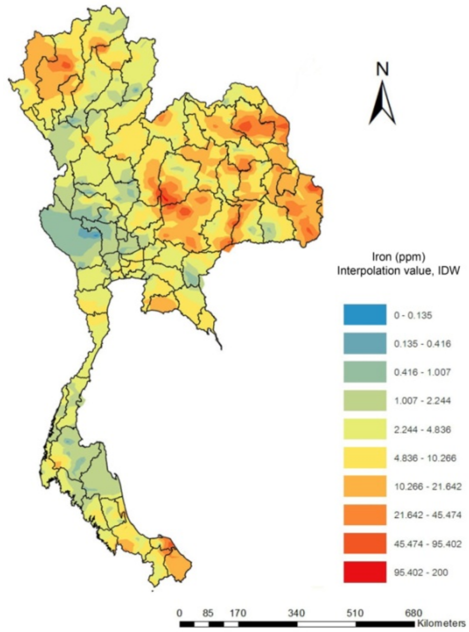

Figure 2 Tendency of iron interpolation values of groundwater resources in Thailand by Inverse Distance Weighting (IDW) method

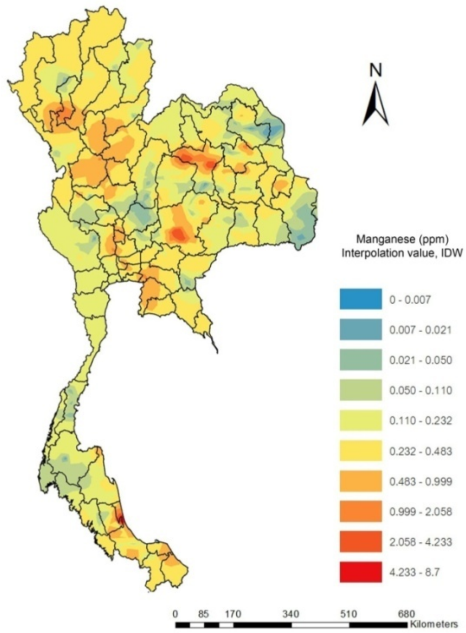

Figure 3 Tendency of manganese interpolation values of groundwater resources in Thailand by Inverse Distance Weighting (IDW) method

region, the farm animal species, types of water resource and depth of groundwater, as shown in Table 2; no correlation was found between these factors. When entering these four factors into a multivariable logistic regression model, the result indicated only two risk factors in the final model, which were the farms not located in the western region and the farms using surface water with a p-value < 0.05 and R^2 of 0.97762, as shown in Table 3. Both factors are risk factors that cause high manganese level in water, considered from odd ratio at 4.195 and 5.618, respectively. Thus, the farms located outside the western region and using surface water for animal consumption had a greater chance of detecting manganese levels above the standard value in their water resources than other farms.

Table 1 Standard limit of water quality for livestock and median of chemical values of groundwater and surface water used for livestock consumption

Chemical	Unit	Standard of water Quality for livestock	Ground water			Surface water		
			Median	Q1	Q3	Median	Q1	Q3
pH[a]	-	6.8-7.5 [/1]	6.85	6.48	7.17	7.23	6.85	7.47
Hardness[a]	ppm	180 [/1]	169.5	108	365	112	47.75	170.75
TDS	ppm	500 [/2]	265	153	536.5	286	198	435
Sulfate	ppm	250 [/2]	14	6	36.47	12	7	45
Nitrate	ppm	10 [/2]	7.48	5.28	11.55	8.14	6.38	17.93
Chloride	ppm	250 [/1]	29	13.1	198	71.25	24.12	100
Fluoride	ppm	4 [/2]	0.3	0.2	0.62	0.45	0.14	0.62
Mn[a]	ppm	0.05 [/2]	0.0227	0.0098	0.1347	0.1830[b]	0.0567	0.4545
Fe[a]	ppm	0.3 [/2]	0.1554	0.0932	0.3349	0.5060[b]	0.1747	0.9477

[a] Chemical value of groundwater was different from surface water at *p*-value 0.05 (Mann-Whitney U test)
[b] Values of chemical significantly exceeded the standard of water quality for livestock (Wilcoxon Signed Rank test).
[/1] : Thomus and Sneed (1996), [/2] : EPA (2004)

Table 2 Factors and univariate logistic regression result (*p*-value) of each factor when high manganese concentration in water (> 0.05 ppm) is the dependent variable

Factor	*p*-value	Odd ratio
Farm location		
- Central region (Yes/No)	0.216	4.137
- Eastern region (Yes/No)	0.252	2.160
- Northeastern region (Yes/No)	0.645	0.717
- Western region (Yes/No)	0.014	0.274
- Southern region (Yes/No)	0.107	3.903
Farm animal species (Pig farm/Poultry farm)	0.041	0.183
Number of pigs in farm	0.292	1.000
Type of water resources (surface water/groundwater)	0.008	0.204
Depth of groundwater (meter)	0.016	0.971
Distance between waste water drain site and drinking water resources for animal (meter)	0.280	1.001
Characteristic of water (clear/ turbid)	0.117	3.804
Characteristic of soil around water resources		
- Loose soil (Yes/No)	0.169	0.396
- Clay (Yes/No)	0.836	0.900
- Sandy soil (Yes/No)	0.443	2.000
- Laterite red earth (Yes/No)	0.173	3.222
Color of soil around water resource		
- Dark brown or black (Yes/No)	0.569	1.339
- White or gray (Yes/No)	0.885	0.920
- Yellow or red (Yes/No)	0.285	1.950
Place located in 4-km radius from farm		
- Village (Yes/No)	0.664	1.278
- Agricultural area (Yes/No)	0.827	0.865
- Farming area (Yes/No)	0.648	1.263
- Factory area (Yes/No)	0.231	1.959

Table 3 Final logistic regression model of factors associated with higher manganese in water resources than standard drinking water

Variable	*p* -value Chi-square	b	S.E.	Confidence interval (95%)	OR	*p* -value
Intercept	-	-1.251	0.489	-2.209,-0.292	0.286	0.010
Farm not located in the western region	0.013	1.433	0.579	0.298, 2.569	4.195	0.013
Surface water resources	0.007	1.726	0.644	0.463,2.989	5.618	0.007

Model R^2 = 0.97762, final log Likelihood = -37.056

Discussion

Information from the questionnaire indicated that most livestock farms in Thailand were located near agricultural areas, communities, and factories which are potential sources of contaminants such as nitrate, insecticides, mercury and lead which can migrate or be discharged into the water resources. This study revealed that in every area the chemical factors in the livestock water resources were within standard limits and seemed appropriate for the animals' good health, as shown in Table 1. However, our findings were similar to previous reports that stated that livestock farms located in the central region of Thailand, alongside active agricultural farms, might be at risk of nitrogen contamination in surface water resources arising from chemical fertilization (Ribbe et al., 2008). Insecticide residues like organochlorine were detected in Mae Klong River located near agricultural areas. Similarly significant levels of ammonia and nitrate in the underground water nearby pig farms in Poland were found (Tymczyna et al., 1999; Poolpak et al., 2008). In the eastern and the western regions of Thailand, where numerous intensive pig farms are located, livestock farms located in these areas may be affected by chemical compounds arising from pig farm waste water discharge. Thus, water quality monitoring, at least twice a year, on farms located in these risk areas is highly recommended.

This study showed that groundwater might contain higher hardness levels than surface water as it flows through many rock and soil layers. Water is retained within the aquifer for a long time resulting in a higher amount of dissolved minerals such as calcium and carbonate than surface water. Well water's dissolved mineral levels are around 100 ppm while groundwater levels are approximately 10 ppm. Although the mean value of hardness in groundwater from this study was found to be within the standard many farms still have problems with high water hardness levels (Hardness > 180), non-specific area. Hard water may not directly affect animal health, but it has an indirect impact on farm management. For instance, precipitate of calcium, magnesium hydrochloride, and calcium sulfate may cause furring of piping systems on farms, therefore reducing water flow rates which may result in animals' insufficient water intake. In a report regarding antibiotics, which are generally dissolved in water to treat poultry disease, an experiment was carried out to determine the effectiveness of enrofloxacin dissolved in water of different hardness levels to treated broilers. It was found that hard water, at a level above 180 ppm, significantly decreased the drug's effectiveness assessed by measuring the drug concentration in serum hourly after drug intake (Sumano et al., 2004).

This study showed that the pH values of surfacewater and groundwater in some areas were over the standard limit. This acidic water could erode piping systems and cause metal contamination of the water. Moreover, using water with a high pH level can reduce the effectiveness of chlorine disinfection and cause antibiotic capability degradation, particularly, amoxicillin, which was reported to deteriorate more quickly when dissolved in high pH water (Ákos and Nagy, 2009). Therefore, farms may face problems attributed to the ineffectiveness of antibiotics when dissolved in hard water which may cause loss of livestock, income, and business growth opportunities.

However, the contamination of toxic heavy metal was not found in the water resources used in livestock farms in Thailand, except that manganese and iron were found in the surface water used in the farms, were over the standard limits, which should not exceed 0.05 and 0.3 ppm, respectively, and was higher than in ground water. This agrees with a study conducted in Scotland that found that manganese concentration had positive relationship with the amount of iron in groundwater (Homoncik et al., 2010). Similarly, a water chemical measurement study conducted on water resources in Thailand in 2003 reported that Chao Phraya River had 0.13 ± 0.01 ppm of manganese and 2.11 ± 0.60 ppm of iron, while groundwater resources near the river had 0.062 ± 0.007 ppm of manganese and 0.035 ± 0.035 ppm of iron (Kruawal et al., 2005). In Nigeria, a higher level of iron (0.1 ppm) was detected in surface water than in groundwater (Omo-Irabor et al., 2008). In general, these metals can be easily found in groundwater resource because surface water contains dissolved oxygen which causes low dissolution of manganese and iron as it is in precipitate form. Manganese and iron both have low toxicity. Water resources with the amounts of manganese and iron higher than 0.05 and 0.3 ppm do not directly affect animal's health, but the color and taste of the water may change, restraining animals from consuming it, particularly piglets. If manganese levels are greater than 0.02 ppm, pipelines will be furred and may eventually be blocked. Manganese is often dissolved in water in bicarbonate form, which will also affect water supply system due to an accumulation of rust in the pipe caused by an oxidation reaction when water is pumped up to the surface, resulting in sediment. Another problem frequently found is that some bacteria consume these minerals, as their food, and form a bio-film structure which can obstruct water supply system. Manganese and iron from natural rock layers can be commonly found in water resources and livestock farms in Kanchanaburi, Chachoengsao, Chonburi, Trang, Lopburi, Lampang, and Saraburi provinces, making these areas at greater risk of iron contamination than other provinces due to the existence of iron ore. Farm owners who encounter pipe obstruction problems or water changing in color and smell should consider sending water samples to be analyzed for metal levels.

The maps in Fig 1-3 show the quality of groundwater using latest database information (from years 1997-2005) and indicate the areas at risk. The author would like to recommend and encourage every farm owner to search for basic information of water resources before making a decision to use particular water resources for their livestock. Hardness is commonly found in ground water resources in Thailand, having high manganese and iron levels. Therefore, livestock farms which use groundwater as resources for their animal consumption should determine all water quality in advance in order to avoid chemical composition that might affect's animal health. From a previous study, it was found that chemical values (i.e. TDS, Ca^{2+}, Mg^{2+}, Na^{+}, Cl^{-}, SO_4^{2-} and F^{-}) in dry season were usually lower than those in rainy season (Matini et al., 2012). From a study on the change of groundwater composition when wasteland is converted for agricultural use in China from 1982 to 2004, an increase in pH, Mg^{2+}, NH^{4+}, SO_4^{2-}, NO^{3-}, NO^{2-} and Cl^{-} was found, however, Ca^{2+} and HCO^{3-} decreased (Jiang et al., 2008; Jamshidzadeh and Mirbagheri, 2011).

Manganese in water is usually in a soluble form when no oxygen is present; therefore, it is possible for a deep groundwater well to have more manganese than a shallow well due to the lack of oxygen. There are few reports on manganese pollution from waste water between farm animal species, however, a report on broiler waste product with high manganese levels of 556 ppb in the flock were presented (Sistani et al., 2003). In a recent study of manganese levels in a river in China, it was found that high concentrations of manganese in the river were the result of stainless steel factories contaminating the sediment and soil, which subsequently released the manganese into the water (Wang et al., 2010). Manganese pollution in rivers associated with mining activities showed high contamination with a manganese median level of 13.7 ppm (Olı´as et al., 2004). As mineral resources in Thailand are different in each region, a source of manganese can only be found in the northern, north-eastern and eastern regions and is found rarely in the western region (DMR, 2011). This is similar to our findings shown in Table 3. Final logistic regression model of factors associated with higher manganese in the water resources than standard drinking water indicated that farms located in the western region had the least risk of exceeding the manganese limit compared to other areas. Livestock farms that use surface water resources for animal consumption are more at risk of exceeding manganese limits than those using groundwater resources. Correspondingly, according to the result of this study of the water quality comparison between types of water resources, it was found that the groundwater resources had significantly less manganese than the surface water and that the manganese was originated from human activities.

The difference in water quality on each livestock farm in different areas depends on the natural resources and is influenced by human activities. Therefore, livestock farms in Thailand should give precedence to regular water quality measurement in order to prevent animal health problems. Livestock farming outside the western region and using surface water for animal consumption should pay attention to manganese contamination of the water resources as it may cause economic loss due to decline in production. In further studies, environmental risk factors such as geographical characteristic, rock layer, and mineral source can be examined and combined for better comprehensive analysis results.

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