# Heavy Metal Pollution Index for Assessment of Seasonal Groundwater Supply Quality in Rural Area, Kalasin, Thailand

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## ABSTRACT

The quality of drinking water is world-wide considered to be an important issue for public health safety and must be the key objective of water supply systems. The aim of this study was to assess the heavy metal pollution index (HPI) for water supply quality in a rural village named Bannongvang village located in Kalasin province. Concentrations of heavy metals including iron (Fe), manganese (Mn) and zinc (Zn) were analyzed for eight sampling stations by flame atomic absorption spectrometer. The results were evaluated in accordance with the drinking water quality standards suggested by the World Health Organization and Thailand Department of Health Standards. The finding of HPI values based on the mean concentrations in rainy and dry season was 96 and 57, respectively. The values of HPI in dry season were low for all sampling stations and lower than the critical index value for drinking water (HPI<100). However, the HPI values in rainy season indicated that 37.5% of the sampling stations were critically polluted (HPI>100). All sampling stations were noted in the suitable range for drinking purposes in dry season, but most stations in rainy season, the concentrations of heavy metals exceeded the permissible limit for drinking purposes. Therefore, the water supply quality was required for the development of preliminary water treatment before its use for household purposes.

*Keywords: heavy metal pollution index (HPI), water supply, permissible limit, preliminary treatment*

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## INTRODUCTION

Groundwater is the major source of water supply for domestic, agricultural and industrial sectors in many countries. In Thailand, groundwater has also been promoted as one of the purest forms of water available for supplying to meet the overall demand of people in rural and semi-urban areas. Groundwater is a common source for solving inadequate and inaccessible surface water supply systems in many rural areas for single homes and small villages. The groundwater quality is directly influenced by land uses and human activities, therefore it is important to consider the suitability of water for different purposes. Its quality relies on the infiltrated water, precipitation, surface water and sub-surface geochemical processes (Jafar et al., 2013). Changes in local topography and water discharge from activities directly affect both the quality and quantity of the groundwater (Vasanthavigar et al., 2010). The pollution of groundwater by hazardous or heavy metals is a serious worldwide problem because these metals are permanent and most of them have toxic effects on living organisms for human consumption when they exceed the permissible limit (Sirajudeen et al., 2014; Chakraborty et al., 2010). Heavy metals are one of the main environmental problems, occurrence in waters from materials such as chemical weathering of minerals and soil leaching (Biswas et al., 2017), or anthropogenic sources such as industrial and domestic effluents (Pradip et al., 2017).

The physical and chemical characteristics of groundwater play an important role in classifying and assessing water quality. Therefore, various water quality parameters have been applied for the assessment of water pollution for human consumption, according to heavy metals contamination (Sarala & Uma, 2013; Ardani et al., 2015). In recent years, many researchers have evaluated heavy metal contamination in groundwater and surface water by using the heavy metal pollution index (HPI) (Pradip et al., 2017; Balakrishnan and Ramu, 2016; Sirajudeen et al., 2014). HPI is calculated from an assessment of the suitability of groundwater for human consumption with respect to metal contamination. HPI is a useful approach tool for assessing the combined influence of individual heavy metal indicators of the overall water quality (Reza & Singh, 2010) and a view of the suitability of groundwater for human consumption (Rizwan et al., 2011). The heavy metal pollution index has been used by Boulos & Rania (2015) as an effective tool for groundwater quality assessment in Damascus Oasis, Syria. Kumar et al. (2012) have also used a HPI model for an appraisal of heavy metals in groundwater in Chennai city.

Water is necessary for human and animal life. The water supply quality is a very important factor indicating the quality of life. Thailand faces challenges in ensuring a supply of clean drinking water. The rural water supply system has become a more critical issue in the socio-economic condition of the country. In addition, lack of proper maintenance and insufficient knowledge of the staff are mostly found in Thai rural water supply. Yupaporn et al. (2014) assessed the efficiency of the village water supply in Ubonratchathani and found that the village water supply quality of 48% not followed the water standard. Tanawat et al. (2009) have also found that the management, water monitoring and the number of staff were insufficient to work in the rural water supply. A lack of knowledge and understanding of the water supply procedure due to lack of a proper training program caused the efficiency and water quality of the village water supply system (Korkeit, 2013). Bannongvang village has own water supply distributes to people who live in the area. Water supply is used for household purposes such as cooking, cleaning, and drinking. However, there is a lack of monitoring and maintenance information in the village water supply. Therefore, it is important to assess the water supply quality with respect to the physical and chemical parameters as well as heavy metal contamination in order to ensure a supply of safe water. The seasonal assessment of HPI with respect to heavy metals contamination in drinking and household water supply system of Bannongvang village located in rural areas were studied and presented in this paper.

## METHODOLOGY

### Study Area

The region covers both agricultural land and residential area. Agriculture is the major activities and major crops are paddy, cassava, and watermelon. The study area locates in the Bannongvang village in Namon district, Kalasin, northeastern Thailand (as seen in Figure 1) and covers an area of 160 km$^2$. This area has a semiarid climate type with temperature ranging from 19°C to 45°C. The water supply system covers around 800 users. In the past, surface water sources had been used for the water supply system in this area. However, the surface water was polluted by agriculture and household drainage. As a consequence, poor water quality affected people and hence, this source was stopped using for water supply. Therefore, groundwater has been used as the major source for the water supply of this village. The groundwater is pumped to the preliminary water treatment using natural draft aeration to oxidize iron and manganese. After aeration, the chemically precipitated iron and manganese are removed by filtration. The treated water is stored in the high tank before distributing it to the users.

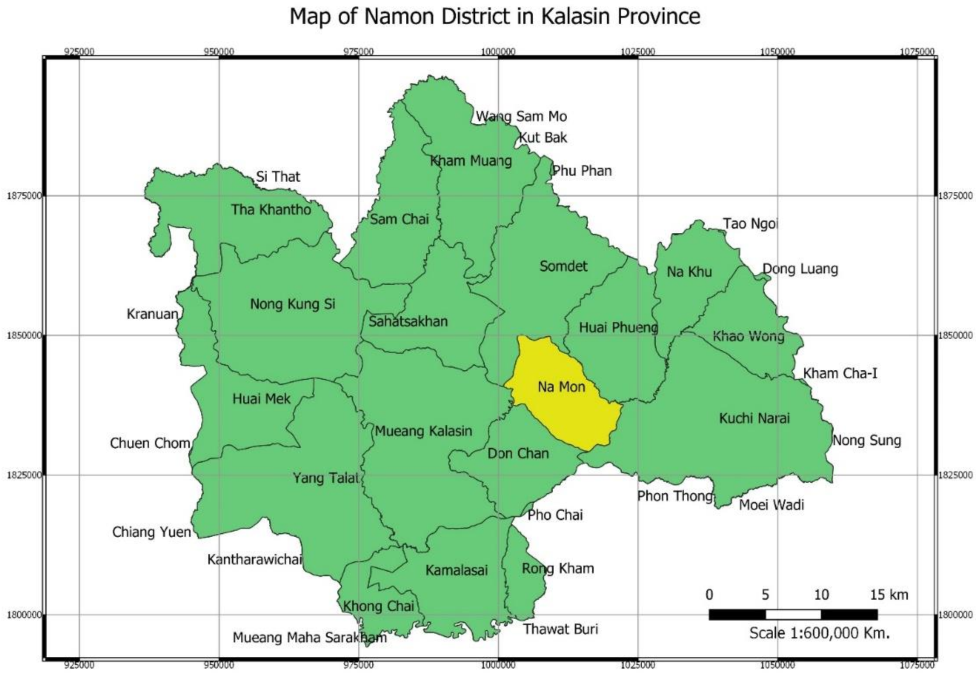

**Figure 1** Map of Kalasin Province

## Sampling and Analysis

Eight sampling stations were collected from the municipal water supply in the Bannongvang village (as seen in Figure 2). Three samples at each sampling station were collected directly from tap water for assessment of water supply quality during the post-monsoon season (September 2018) and dry season (December 2018). The first station was at the pumping station where the samples were collected at the entry point of the supply water to the user's house. Other sampling stations were at the users' house. The water samples were collected from the nearest water users of the distribution line in the village, middle and the farthest which represented the quality of the piped water. Water supply samples were collected in clean one liter of polyethylene bottles. At the time of sampling, bottles were thoroughly rinsed 2-3 times with water at its source to be sampled. The water samples were collected after flushing water for about 2-3 minutes to remove the stagnant water as per standard procedures (American Public Health Association, 2014). The collected water samples were transported to the laboratory at the same day and preserved in a refrigerator at 4°C before analysis.

Some physical parameters were tested, namely pH, Total Hardness (TH), Total Dissolved Solids (TDS). Hydrogen ion concentration (pH) was measured on the site by using a digital pH meter while other parameters were determined in the laboratory within 48-72 hours of the sampling following the standard methods (American Public Health Association, 2014). The standard methods of Water and Wastewater standards (American Public Health Association, 2014) were used for analysis of the various physico-chemical parameters. TDS was carried out by gravimetric analysis. TH was measured by volumetric titration methods with EDTA using Eriochrome black T (EBT) as the indicator. Heavy metals such as iron (Fe), manganese (Mn) and zinc (Zn) were also analyzed by using Flame Atomic Absorption Spectrophotometer (FAAS) (Model: PerkinElmer PinAAcle 900F Atomic Absorption Spectrometer). The concentrations of standard solution for each metal ions for construction of calibration curve by FAAS were prepared from 0.04-3 mg/l (Fe), 0.01-0.6 mg/l (Mn), and 0.006-0.75 mg/l (Zn). The chemical analysis of water samples was carried out in the laboratory of the Faculty of Science and Health Technology at Kalasin University.

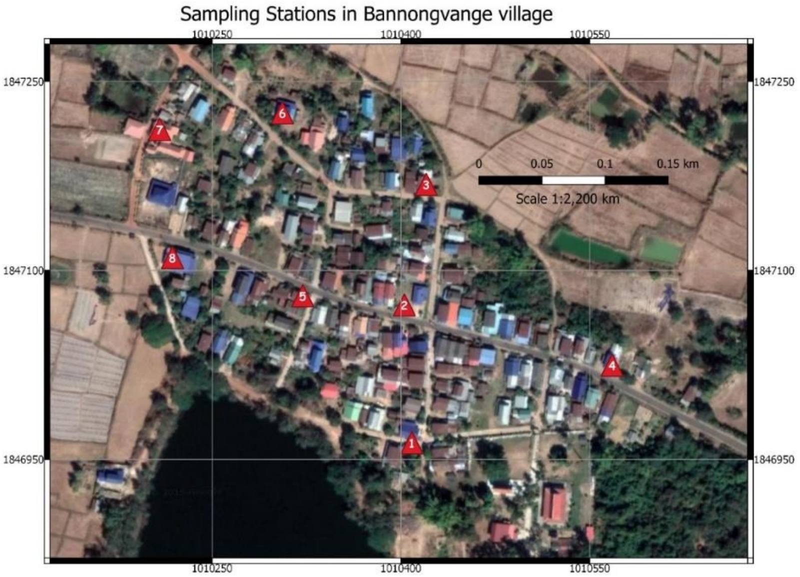

**Figure 2** Eight sampling stations at Bannongvang Village in Namon District, Kalasin, Thailand

## Heavy metal pollution index (HPI)

The heavy metal pollution index is a calculation of the rating that shows the composite influence of individual heavy metal on the overall water quality (Sheykhi & Moore, 2012). The HPI method was developed by assigning a rating or weight ($W_i$) for each chosen parameter. The rating is an arbitrary value between zero and one, reflecting the relative importance of individual quality consideration. In this study, the limit of concentration (i.e., the highest permissible value of water supply, $S_i$) used the international standards (WHO). In computing the HPI, Prasad and Bose (2001) considered unit weight ($W_i$) as a value inversely proportional to the recommended standard ($S_i$) of the corresponding parameter as proposed by Reddy (1995). The HPI is calculated with the following equation:

$$HPI = \frac{\sum_{i=1}^{i=n}(Q_i x\, W_i)}{\sum_{i=1}^{i=n} W_i}$$

where $W_i$ is the unit weight of $i^{th}$ parameters, $Q_i$ is the sub-index of the $i^{th}$ parameter, n is the number of parameters considered. The weighted arithmetic index method has been used for the calculation of HPI.

The sub-index ($Q_i$) is calculated by

$$Q_i = \frac{V_i}{S_i} x100$$

Where $V_i$, and $S_i$ are the monitored heavy metal concentration and standard permissible values of the i$^{th}$ parameter, respectively. The HPI value indicates the level of heavy metal pollution as seen in Table 1. The critical pollution index value for drinking water must be less than 100. If the samples have heavy metal pollution index values greater than 100, water is not potable (Balakrishnan & Ramu, 2016).

**Table 1** The Evaluation of heavy metal pollution, HPI value (Sobhanardakani et al., 2012)

| Degree of pollution | HPI Value |
|---|---|
| Low heavy metal pollution | <100 |
| Heavy metal pollution on the threshold risk | =100 |
| High heavy metal pollution | >100 |

## RESULTS AND DISCUSSION

### Physical parameters analysis

Physical parameters including pH, TDS, and TH were measured in the water supply samples. The physical parameters and heavy metal concentrations of water supply samples in rainy and dry season are summarized in Table 2. The guideline values as specified by the WHO (2011) and the Thailand Department of Health Standards, TDH (2009) for drinking water quality were used to analyze the results. Table 3 presents a summary of descriptive statistics of the physical parameters and the metal concentrations in the water supply samples (mg/L). The results of the samples showed a range between 7.6 and 8.1 of pH with an average of 8.0, which indicates the alkaline nature of the water supply of the study area. The pH and TDS values of all the samples are within the Thai permissible limit prescribed for drinking water (Department of Health Standards) and guideline values of WHO (2011). The total dissolved solid test measures the total amount of dissolved minerals in the water reported that TDS in rainy season ranged from 133 mg/L to 290 mg/L, with an average of 215. The TDS values in rainy season were lower than the values in dry season, which ranged from 227 mg/L to 340 mg/L, with an average of 271. High TDS levels may cause excessive staining of water pipes and household appliances and can shorten the service life of these appliances (Jafar et al., 2013).

Results show a range between 239 mg/L and 354 mg/L of total hardness in rainy season with an average of 304 mg/L and a range between 397 mg/L and 487 mg/L of total hardness in dry season with an average of 435 mg/L (as seen in Table 3). Half of all samples in rainy season and all samples in dry season exceeded the permissible limit of 300 mg/L of the WHO (2011) but they were not exceeded the permissible limit of 500 mg/L of the Thai standard for drinking water (Department of Health Standards). However, water with hardness above 200 mg/L may cause scale deposition in the water distribution system and increase soap consumption (Hayelom, 2015). The hardness in water is caused by sedimentary rocks and seepage and runoff from soils (Akram & Rehman, 2018). Hardness is an important factor for household purposes because pipes can become clogged with scale.

**Table 2** Heavy metal concentrations (mg/L) and HPI for the individual sampling station (n=3)

| Sampling location | pH | | TDS (mg/L) | | Hardness (mg/L) | | Fe (mg/L) | | Mn (mg/L) | | Zn (mg/L) | | HPI | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rain | Dry | Rain | Dry | Rain | Dry | Rain | Dry | Rain | Dry | Rain | Dry | Rain | Dry |
| station 1 | 8.1 | 8.1 | 183 | 277 | 345 | 487 | 0.29 | 0.25 | 0.33 | 0.21 | 0.30 | 0.21 | 99 | 73 |
| station 2 | 8.0 | 8.0 | 227 | 340 | 294 | 448 | 0.33 | 0.24 | 0.34 | 0.20 | 0.46 | 0.13 | 107 | 69 |
| station 3 | 8.0 | 8.1 | 220 | 270 | 239 | 454 | 0.16 | 0.16 | 0.39 | 0.16 | 0.13 | 0.12 | 88 | 52 |
| station 4 | 7.9 | 7.9 | 227 | 323 | 258 | 450 | 0.21 | 0.16 | 0.43 | 0.17 | 0.13 | 0.16 | 102 | 52 |
| station 5 | 8.0 | 7.9 | 217 | 243 | 337 | 405 | 0.27 | 0.09 | 0.27 | 0.16 | 0.23 | 0.10 | 85 | 40 |
| station 6 | 8.1 | 8.1 | 290 | 243 | 354 | 400 | 0.26 | 0.14 | 0.53 | 0.27 | 0.22 | 0.06 | 124 | 65 |
| station 7 | 7.6 | 8.1 | 133 | 227 | 271 | 435 | 0.19 | 0.16 | 0.33 | 0.18 | 0.27 | 0.06 | 83 | 53 |
| station 8 | 8.1 | 8.0 | 220 | 243 | 333 | 397 | 0.25 | 0.19 | 0.28 | 0.20 | 0.28 | 0.05 | 85 | 62 |
| WHO (2011) | 6.5-8.5 | | 600.00 | | 300.00 | | 0.30 | | 0.30 | | 3.00 | | | |
| TDH (2009) | 7.0-8.5 | | 600.00 | | 500.00 | | 0.50 | | 0.30 | | 5.00 | | | |

**Table 3** Descriptive statistics of the metal concentrations in the water samples (mg/L) (n=24)

| Sampling location | pH | | TDS (mg/L) | | Hardness (mg/L) | | Fe (mg/L) | | Mn (mg/L) | | Zn (mg/L) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rain | Dry | Rain | Dry | Rain | Dry | Rain | Dry | Rain | Dry | Rain | Dry |
| Mean | 8 | 8.0 | 215 | 271 | 304 | 435 | 0.24 | 0.17 | 0.36 | 0.19 | 0.25 | 0.11 |
| Max | 8.1 | 8.1 | 290 | 340 | 354 | 487 | 0.33 | 0.25 | 0.53 | 0.27 | 0.46 | 0.21 |
| Min | 7.6 | 7.9 | 133 | 227 | 239 | 397 | 0.16 | 0.09 | 0.27 | 0.16 | 0.13 | 0.05 |
| Range | 0.6 | 0.2 | 157 | 113 | 115 | 91 | 0.2 | 0.2 | 0.3 | 0.12 | 0.3 | 0.2 |
| Standard Deviation | 0.2 | 0.1 | 44 | 41 | 44 | 32 | 0.05 | 0.05 | 0.08 | 0.04 | 0.11 | 0.06 |

### Heavy metal concentration analysis

In this study, metals such as Fe, Mn, and Zn were considered. The results in Table2 and 3 show that the concentration of Fe in rainy season varied between 0.16 and 0.33 mg/L with an average value of 0.24 mg/L and 87.5 % of the samples have a concentration below 0.30 mg/L. High iron concentration may stain plumbing fixtures and clothes, and produce undesirable tastes as well as an objectionable reddish-brown color to water. All water supply sample concentrations in dry season do not exceed the maximum permissible limit of 0.3 mg/L as specified by the WHO (2011).

The results of the concentration manganese show all the water samples in dry season listed below the maximum permissible limit. However, a range between 0.27 and 0.53 mg/L of Mn concentration in rainy season with an average of 0.36 mg/L (Table 2) and 75 % of the samples exceeded the permissible limit of 0.3 mg/L of Thailand Department of Health Standards (2009) for drinking water and the guideline value WHO (2011). Manganese occurs naturally in many surface water, groundwater, and food sources. Although manganese is an essential element for humans and animals, excess Mn concentration may cause neurotoxicity, as shown experimentally and in neonates given parenteral nutrition (Agency for Toxic Substances and Disease Registry, 2012, Erikson et al., 2007).

The concentration of Zn in the study area of both seasons varied between 0.05 and 0.46 mg/L and all the samples have a concentration below 3.0 mg/L defined by

WHO (2011). All samples listed below the maximum permissible limit as specified by the Department of Health Standards (2009) and guideline values of WHO (2011).

The concentration of trace elements in rainy season, such as iron and zinc were within the permissible limit for drinking except for only one station (12.5%). On the other hand, high manganese concentration in rainy season at a number of sampling stations (75%) clearly indicated the unsuitable water supply for drinking and domestic purposes. All sampling stations in the village in dry season were noted in the suitable range for drinking purposes, but almost stations in rainy season were unsuitable for drinking and domestic purposes. According to the overall assessment of the water supply quality in rainy season was found suitable for drinking purposes, in 25% of the stations sampled.

## Analysis of heavy metal pollution index

The HPI values in the study area in rainy and dry seasons are determined by incorporating the mean concentration values of recorded heavy metals. The details of the HPI calculation for both seasons are presented in Table 4. The mean HPI in the study area of rainy and dry seasons were 96 and 57, respectively. However, the mean HPI in both seasons classified the water samples in the category of low heavy metal pollution (Table 1). HPI was also calculated separately for each individual sampling station (Table 2). The results indicated that the values in rainy season were higher than the values in dry season (as seen in Figure 3). The results in rainy season show that 50% of the sampling stations have an HPI higher than the mean value of 96. Whereas, 37.5 % of the samples in rainy season (Figure 1) reach the limit of high heavy metal pollution (HPI>100). This indicated the effect of the water treatment system on water supply quality in that region. The overall pollution level in rainy season should be considered unacceptable for drinking water, thus indicating that water samples are critically polluted with respect to heavy metals. However, as seen in Figure 1 all HPI values in dry season were low heavy metal pollution for all sampling stations and lower than the critical index value for drinking water (HPI<100). The higher concentration of Fe, Mn, and Zn in rainy season is largely controlled by agrochemical fertilizers and pesticides cause the accumulation of Fe, Mn, and Zn in groundwater.

These minerals were commonly found in soil and rock and could dissolve into groundwater as it percolated through soil and rock. High manganese concentration might cause neurotoxicity and a health risk to the rural people due to drinking these contaminated.

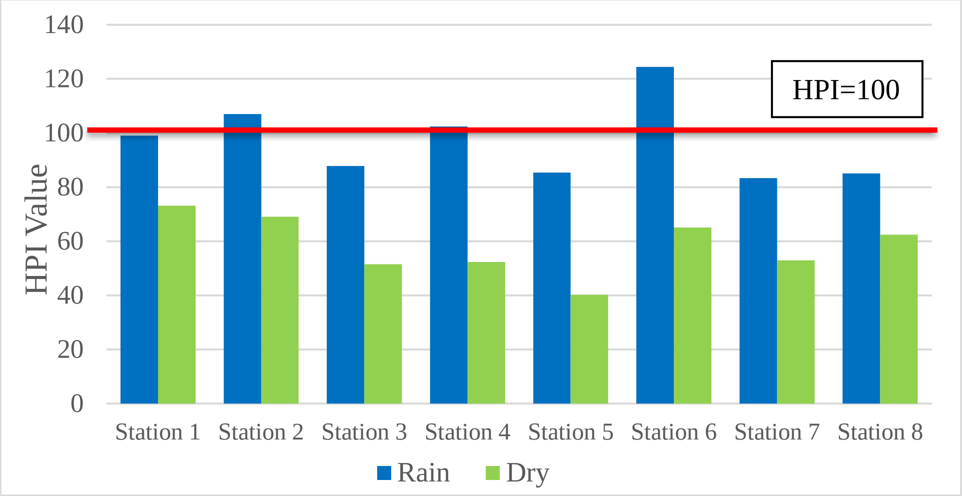

**Figure 3** HPI values of individual sampling stations compared to Heavy metal pollution on the threshold risk (HPI=100)

It was concluded that drinking water in Bannongvang village is considered as a good quality only in dry season (HPI<100) with respect to considered heavy metals. The HPI of each individual sampling station showed the high values (HPI>100%) in rainy season in this area, thus indicating that 37.5% of the samples are critically polluted with respect to heavy metals. The water contained both iron and manganese, staining that could vary from dark brown to black. Therefore, this was sometimes the cause of consumer complaints about red or dirty water. However, this rural village had used natural draft aeration to remove abundant metals contained in groundwater. The frequency of maintenance of the preliminary treatment is important to maintain the efficiency of the aeration and filtration system. The government, therefore, should take the necessary steps and control for mitigating the risk of supply water contamination.

**Table 4.** HPI Calculation for water sample in the water supply system

| Heavy metal | Mean con. (mg/L) | | Standard value (mg/L), $S_i$ | Unit Weightage, $W_i$ | sub-index, $Q_i$ | | $Q_i$ x $W_i$ | | Mean HPI | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Rain | Dry | | | Rain | Dry | Rain | Dry | Rain | Dry |
| Fe | 0.24 | 0.17 | 0.30 | 3.33 | 80 | 57 | 267 | 189 | 96 | 57 |
| Mn | 0.36 | 0.19 | 0.30 | 3.33 | 120 | 63 | 400 | 211 | | |
| Zn | 0.25 | 0.11 | 3.00 | 0.33 | 8 | 4 | 3 | 1 | | |
| | | | | $\Sigma W_i = 7.00$ | $\Sigma Q_i$ x $W_i$ = | | 669 | 401 | | |

## CONCLUSIONS

The water supply in Bannongvang village located in a rural area in Kalasin province was sometimes not satisfactory because its color was unpleasant. The eight sampling stations were collected from the municipal water supply in the village. Water supply using groundwater as a source was generally alkaline, hard and brackish. However, pH and TDS were within the permissible limit for drinking and domestic purposes. All sampling stations in the village in dry season were noted in the suitable range for drinking purposes, but almost stations in rainy season were unsuitable for drinking and domestic purposes. The values of concentration of trace elements in rainy season indicated high abundant metal, such as iron and manganese in this area. It indicated that the groundwater in the studied area was likely affected by leaching of heavy metals from agriculture and urban activity. Therefore, this area needed adequate preliminary treatment to overcome high iron and manganese concentration problems for drinking and domestic purposes. These elements can be removed during softening with lime, but most commonly iron and manganese is removed by filtration after oxidation (with air, potassium permanganate, or chlorine). However, other heavy metals polluted by agricultural activities, such as arsenic, cadmium, and leads were not analyzed in this study. Other important parameters indicated that microbiological quality analysis and other heavy metals should be analyzed for drinking purposes to represent the quality of the water supply of this village in the future works.

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