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# Estimation of Optimum Alum Doses of Mountain Water for Water Supply Treatment in Hill Tribe Villages in Chiang Rai Province, Thailand

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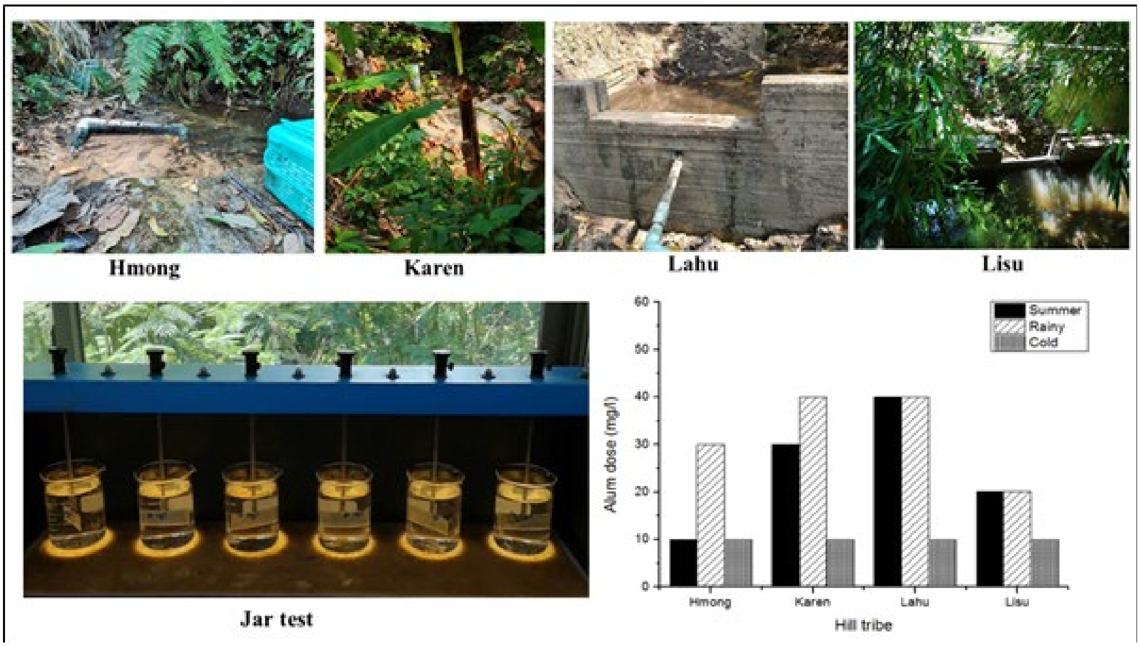
**Abstract**
*Hill tribe villages are located in mountainous and remote areas. Primary water supply and drinking water sources are mountain water from a small weir on the mountain. Most mountain waters found turbidity higher than 1 NTU, and water quality was unclean to use and drink. This research applied different concentrations of alum doses to observe turbidity reduction. Optimum alum does apply to reduce turbidity for mountain water samples from Hmong, Karen, Lahu, and Lisu for three seasons.*

*The optimum alum dose is between 20 - 40 mg/l in rainy seasons and 10 – 40 mg/l in summer. The cold season was low optimum alum dose at 10 mg/l for all hill tribe villages. Therefore, alum coagulants can be used to treat the mountain water supply and drinking that can implement the main problem of mountain water in hill tribe village.*

**Keywords:** Hill Trbe, Mountin Water, Jar Test, Turbidity, Potassium Alum, Optimum Alum Dose

**Graphic Abstract**



## 1. Introduction

Hill tribe villages are located in the mountainous area in Northern Thailand. The hill tribes in Thailand are divided into six main groups, Akha, Hmong, Karen, Lahu, Lisu, and Yao. Each hill tribe groups have they language, culture, and beliefs, which are different from the Thai people. Most hill tribes live in the mountainous border areas and remote areas difficult to accessed government facilities such as water supply, electricity, and health care service.

The mountain water is a primary source to use in hill tribe villages in northern, Thailand. To build the concrete or soil weirs were used for storing mountain water. The water was supplied through polyvinyl chloride (PVC) or steel pipes that distribute to households in hill tribe villages. Therefore, mountain water has been using in hill tribe villages that are without treatment. Poor-quality water supply and drinking water was found exceeding of World Health Organization (WHO) standard such as coliform bacteria and fecal coliform bacteria, turbidity, iron, color, and pH and found high turbidity about 36% of drinking water [1]. The turbidity of the colloids in water is the small particle in water that cannot be settled or removed naturally due to their light and stability. The stability of particles in natural water depends on a balance between the repulsive electrostatic force of the particles and the attractive forces known as the van der Waals forces.

Since particles in water have a net negative surface charge, the principal mechanism controlling particle stability is electrostatic repulsion [2]. The turbidity is a physical property of water that determines drinking water and water supply standards [3-5]. Therefore, a water treatment plant can reduce the turbidity by using a coagulant or alum. As these chemicals hydrolyze, they form insoluble precipitates that destabilize particles by adsorbing to the surface of the particles and neutralizing the charge (thus reducing the repulsive forces). Selection of the type and dose of coagulant depends on the characteristics of the coagulant, the concentration and type of particles, concentration and characteristics of natural organic matter (NOM), water temperature, and water quality.

Coagulants are chemicals that are used to assist with the removal of turbidity present in untreated raw water such as aluminum sulfate (Al2 (SO4)3 18H2O), polyaluminium chloride (Al2(OH)3Cl3 ), and ferric chloride (FeCl3). The coagulants do this by forming settleable particles in the form of flocs, which are then removed in downstream clarification or filtration treatment processes. Alum is the first coagulant of selection because of its lower cost and its worldwide availability [6]. Jar test of standard practice for coagulation-flocculation of raw water is a practice for the evaluation of a treatment to reduce dissolved, suspended, colloidal, and unsettle mater from coagulants, followed by gravity settling [7]. The Jar test is a common laboratory procedure used to determine the optimum dose of different coagulants or alum, on a small scale to predict the functioning of large-scale treatment operating conditions for water or wastewater treatment. Jar testing aims to determine the amount of coagulant dosage and to determine appropriate conditions for water treatment plants operation. Many researchers have applied the Jar test experient to estimate coagulant to treat water [8-10].

Therefore, the optimum alum dose is the amount of alum to apply in the water treatment plant to assist particles to settle on the basin. The effectiveness of the coagulation process in a water treatment plant is highly dependent on many factors, including the dosage of coagulant and coagulant aids and also pH of operation. This study aims to find the optimum alum dose of mountain water of hill tribe village. Mountain water is a primary source has been found high turbidity exceeded the water supply and drinking water standard and alum can reduce the turbidity what is the main problem of mountain water supply.

## 2. Methadology

### 2.1 Study Sites and Sampling Stations

The hill tribe villages are located in Chiang Rai Province in northern Thailand which all use mountain water and drink mountain water. There are four water sampling stations in Hmong, Karen, Lahu, and Lisu villages, which are located in the mountainous area remote area. The Hmong tribe villages (N20o02'43.74" E099o53'38.27" and 810 masl) are located in the Chiang Khong district, while the Lahu (20o03.142'56.44" E 099o49.458'57.89" and 570 masl) and Karen tribe villages (N19o58'42.68" E099o41'52.88" and 451 masl) are located in the Muang District of Chiang Rai Province. The Lisu villages (N 20o21'55.48" E 099o 28'11.50" and 1,232 masl) are located close to the Thai-Myanmar border in the Mae Fah Luang District.

### 2.2 Mountin Water Sampling and Analysis

A total of 12 mountain water samples were collected by a grab sampling technique from the weir of mountain water in four hill tribe villages consist of 4 samples from summer, 4 samples for the rainy season, and 4 samples for the cold season in 2019. Polyethylene (PE) bottles were utilized to collect the water samples from the weir of mountain water points. A total of seven liters of water samples were in PE bottles which were chilled at 4°C in an icebox until use for Jar test experiment within 72 hours. To device, one liter of water was employed to measure turbidity, total dissolved solids (TDS), and pH. For six-liter of mountain water was prepared to experiment with the Jar test method. The turbidity was measured by a turbidity meter (Turb 43 IE, WTW, Wissenschaftlish, Weiheim, Germany). The pH was measured by a pH meter (pH 34i SET 2, WTW, Wissenschaftlish, Weinheim, Germany). The TDS were determined by filtering water through filter paper (pore size of 0.45 µm) and were measured by a TDS meter (TDSTestr11, Waterproof, Oakton, USA).

### 2.3 Jar Test

Measured qual volume at one liter of mountain water in each beaker NO. 1-6, and moved the beakers to the Jar Test machine. Then weighed the coagulant (Alum: Potassium alum ($KAl(SO_4)_2 \cdot 12H_2O$ ) 10 mg, 30 mg, 40 mg, 50 mg, and 60 mg by using a digital balance. Turn on of Jar test machine by started the "flash mix" speed of approximately 100 rpm for 1 minute. Added the fine solid alum 10-60 mg, at predetermined dosage levels and sequence beaker 1-6. Reduced the speed to keep floc particles uniformly suspended throughout the "slow mix" period. The slow mix for 30 rpm for 30 minutes. After the slow mix period, turn off the Jar test machine and observe the settling of floc particles. Finally, measured the turbidity, pH, and TDS from each jar test a point one-half of the depth of samples. The expected optimum alum dose must decrease the turbidity cut-off set at 1.0 NTU follow to the water supply standard of the Metropolitan Waterwork Authority, MWA, in Thailand.

### 2.4 Data Analysis

A statistical analysis was performed by using SPSS version 24.0 software (SPSS version 24 (SPSS, Chicago, IL). The Kolmogorov-Smirnov test was performed to check the normality of data. Spearman correlation was used to assess the correlations of the mountain water qualities. The level of significance was set to α = 0.01 and 0.05, respectively.

## 3.Result

### 3.1 Estimation of Optimum Alum Doses

### 3.2 Hmong

The mountain water was sampling raw water for six liters from a weir on-mountain in summer, rainy, and cold seasons in 2019. Then we measured the turbidity, TDS, and pH of mountain water. In summer, the quality of mountain water, that found 1.47 NTU for turbidity, 90 mg/l for TDS, and 7.88 for pH. In rainy seasons, the quality of mountain water was found that 4.10 NTU for turbidity, 60 mg/l for TDS, and 8.57 for pH. Finally, in the cold season found 1.30 NTU, 70 mg/l for TDS, and 8.07 for pH. Comparison of the turbidity of mountain water among three seasons found that the turbidity of rainy season > summer season > cold season as shown in Figure 1.

Jar test experiment, we added various alum concentrations from 10 mg/l to 60 mg/l in mountain water. Alum concentrations at 10 mg/l, 20 mg/l, 30 mg/l, 40 mg/l, 50 mg/l, and 60 mg/l reduced the turbidity to 0.88 NTU, 1.11 NTU, 0.94 NTU, 0.91 NTU, 0.90 NTU, and 0.62 NTU, respectively, from 1.47 NTU of mountain water in summer season as shown in Figure 1. In addition, Alum concentrations from 10 mg/l to 60 mg/l reduced the turbidity to 1.33 NTU, 1.50 NTU, 0.97 NTU, 0.74 NTU, 0.98 NTU, and 0.92 NTU, respectively, from 4.10 NTU of mountain water in the rainy season. Finally, Alum concentrations from 10 mg/l to 60 mg/l, all samples reduced the turbidity to 0.01 NTU from 1.30 NTU of mountain water in the cold season.

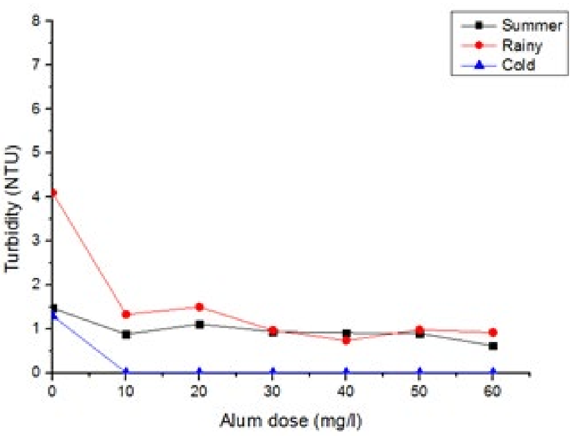



**Figure 1:** Jar test of mountain water from Hmong village

**Figure 5** was the result of optimum alum dose for mountain water in Hmong village. The appropriately dose used in the rainy season was 30 mg/l. Both summer and cold seasons were using for 10 mg/l. In the rainy season of alum concentration use in water treatment was higher than in summer and cold seasons.

### 3.3 Karen

The mountain water was sampling raw water for six liters from a weir on-mountain in summer, rainy, and cold seasons in 2019. Then we measured the turbidity, TDS, and pH of mountain water. In summer, the quality of mountain water, that found 4.30 NTU for turbidity, 90 mg/l for TDS, and 8.67 for pH. In rainy seasons, the quality of mountain water was found that 5.41 NTU for turbidity, 100 mg/l for TDS, and 7.19 for pH. Finally, in the cold season found 0.47 NTU, 80 mg/l for TDS, and 8.01 for pH. Comparison of the turbidity of mountain water among three seasons found that the turbidity of rainy season > summer season > cold season as shown in Figure 2.

Jar test experiment, we added various alum concentrations from 10 mg/l to 60 mg/l in mountain water. Alum concentrations at 10 mg/l, 20 mg/l, 30 mg/l, 40 mg/l, 50 mg/l, and 60 mg/l reduced the turbidity to 1.20 NTU, 1.57 NTU, 0.96 NTU, 0.64 NTU, 0.68 NTU, and 0.80 NTU, respectively, from 4.30 NTU of mountain water in summer season as shown in Figure 2. In addition, Alum concentrations from 10 mg/l to 60 mg/l reduced the turbidity to 4.15 NTU, 4.30 NTU, 1.20 NTU, 0.90 NTU, 0.86 NTU, and 0.88 NTU, respectively, from 5.41 NTU of mountain water in the rainy season. Finally, Alum concentrations from 10 mg/l to 60 mg/l, all samples reduced the turbidity to 0.21 NTU for alum 10 mg/l , 0.01 NTU for alum 20-60 mg/l which all reduced from 1.30 NTU of mountain water in the cold season.

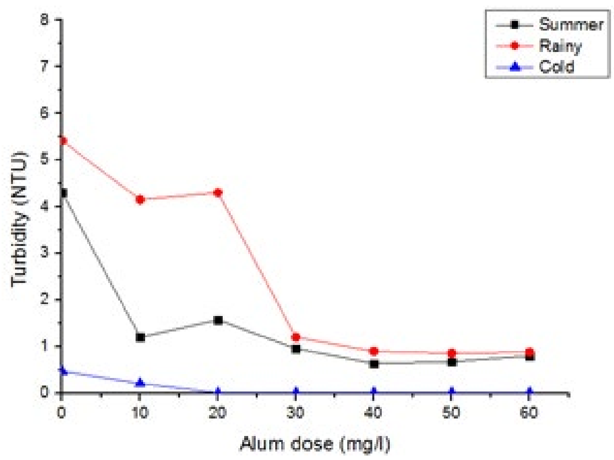



**Figure 2:** Jar test of mountain water from Karen village

Figure 5 was the result of optinum alum dose for mountain water in Karen village. The appropriately alum dose used in the rainy season was 40 mg/l. In summer, the The appropriately alum dose was 30 mg/l, and in cold season was 10 mg/l of alum dose. Comparison of appropriately alum doses among three seasons found that the alum doses of rainy season > summer season > cold season.

### 3.4 Lahu

The mountain water was sampling raw water for six liters from a weir on-mountain in summer, rainy, and cold seasons in 2019. Then we measured the turbidity, TDS, and pH of mountain water. In summer, the quality of mountain water, that found 5.44 NTU for turbidity, 70 mg/l for TDS, and 6.96 for pH. In rainy seasons, the quality of mountain water was found that 7.22 NTU for turbidity, 60 mg/l for TDS, and 7.55 for pH. Finally, in the cold season found 2.35 NTU, 70 mg/l for TDS, and 7.96 for pH. Comparison of the turbidity of mountain water among three seasons found that the turbidity of rainy season > summer season > cold season as shown in Figure 3.

Jar test experiment was added various alum concentrations from 10 mg/l to 60 mg/l in mountain water. Alum concentrations at 10 mg/l, 20 mg/l, 30 mg/l, 40 mg/l, 50 mg/l, and 60 mg/l reduced the turbidity to 1.11 NTU, 1.45 NTU, 2.11 NTU, 0.67 NTU, 0.96 NTU, and 0.73 NTU, respectively, from 5.44 NTU of mountain water in summer season as shown in Figure 3. In addition, Alum concentrations from 10 mg/l to 60 mg/l reduced the turbidity to 2.75 NTU, 2.63 NTU, 2.34 NTU, 0.83 NTU, 0.71 NTU, and 1.02 NTU, respectively, from 7.22 NTU of mountain water in the rainy season. Finally, added alum concentrations from 10 mg/l to 60 mg/l, the turbidity reduced to 0.63 NTU for alum 10 mg/l , 0.39 NTU for alum 20 mg/l, 0.01 NTU for alum 30-60 mg/l, which all reduced from 0.47 NTU of mountain water in the cold season.

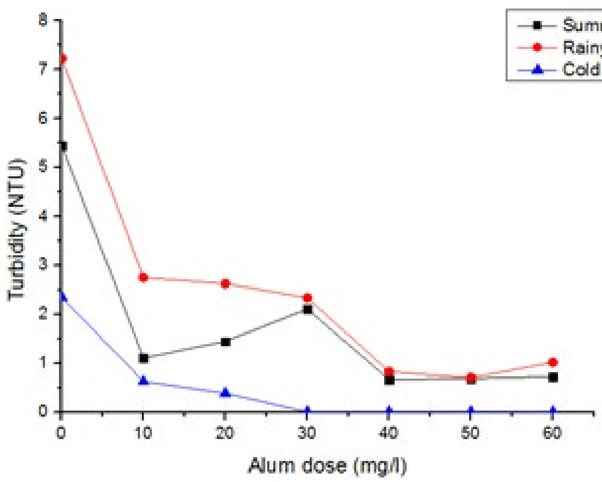



**Figure 3:** Jar test of mountain water from Lahu village

Figure 5 was the result of optinum alum dose for mountain water in Lahu village. The appropriately alum dose used in the rainy and summer seasons were 40 mg/l. In cold season, the the appropriately alum dose was 10 mg/l. Comparison of appropriately alum doses among three seasons found that the alum doses of rainy season = summer season > cold season.

### 3.5 Lisu

The mountain water was sampling raw water for six liters from a weir on-mountain in summer, rainy, and cold seasons in 2019. Then we measured the turbidity, TDS, and pH of mountain water. In summer, the quality of mountain water, that found 5.61 NTU for turbidity, 30 mg/l for TDS, and 8.39 for pH. In rainy seasons, the quality of mountain water was found that 4.01 NTU for turbidity, 30 mg/l for TDS, and 8.37 for pH. Finally, in the cold season found 2.80 NTU, 30mg/l for TDS, and 7.65 for pH. Comparison of the turbidity of mountain water among three seasons found that the turbidity of summer season > rainy season > cold season as shown in Figure 4.

Jar test experiment, we added various alum concentrations from 10 mg/l to 60 mg/l in mountain water. Alum concentrations at 10 mg/l, 20 mg/l, 30 mg/l, 40 mg/l, 50 mg/l, and 60 mg/l reduced the turbidity to 1.15 NTU, 0.79 NTU, 0.70 NTU, 1.42 NTU, 2.28 NTU, and 2.05 NTU, respectively, from 5.61 NTU of mountain water in summer season as shown in Figure 4. In addition, Alum concentrations from 10 mg/l to 60 mg/l reduced the turbidity to 1.26 NTU, 0.84 NTU, 0.68 NTU, 1.95 NTU, 2.09 NTU, and 1.91 NTU, respectively, from 4.01 NTU of mountain water in the rainy season. Finally, Alum concentrations from 10 mg/l to 60 mg/l, all samples reduced the turbidity to 0.01 for alum 10-60 mg/l which all reduced from 2.80 NTU of mountain water in the cold season.

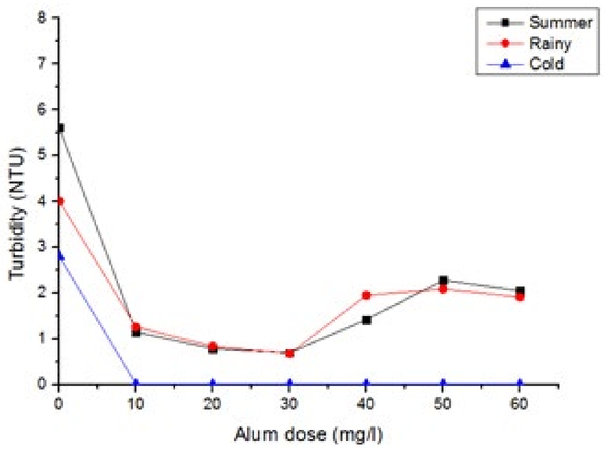



**Figure 4:** Jar test of mountain water from Lisu village

Figure 5 was the result of optinum alum dose for mountain water in Lisu village. The appropriately alum dose used in the rainy season and summer were 20 mg/l. In cold season, the the appropriately alum dose was 10 mg/l. Comparison of appropriately alum doses among three seasons found that the alum doses of rainy season = summer season > cold season.

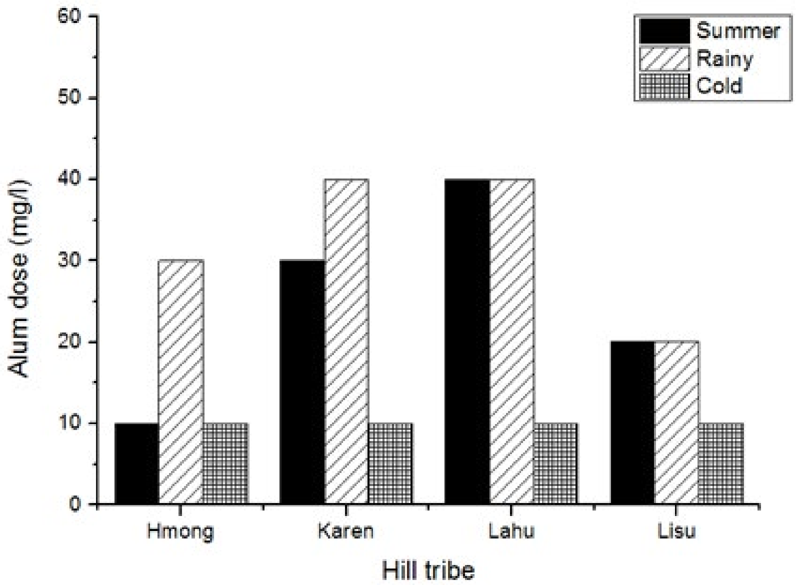



**Figure 5:** Estimation of optimum alum does of raw water in three seasons from hill tribe village.

Our studies applied alum in form of potassium alum ($KAl(SO_4)_2 \cdot 12H_2O$) which is the difference from previous studies. Table 1 shows optimum coagulant doses 10-14 mg/l for turbidity 1.30-7.22 NTU. The mountain water was raw water samples which low turbidity than other surface waters for Jar test experiments. The optimum coagulant doses of raw water used between 12-300 mg/l which depended on raw water types, coagulant types, quality of raw water such as pH, temperature, natural organic matters (NOM).

| Coagulant types | Raw water types | Quality of raw water | Optimum coagulant doses (mg/l) | References |
|---|---|---|---|---|
| Potassium alum ($KAl(SO_4)_2 \cdot 12H_2O$) | Mountain water from hill tribe village | 1.30 - 7.22 NTU | 10-40 mg/l | This study |
| Aluminium sulphate $Al_2(SO_4)_3$ | Water reservoir | 15.10 NTU | 100 mg/l | Lanciné et al., 2008 |
| Aluminum sulfate ($Al_2(SO_4)_3.18H_2O$) and ferric chloride ($FeCl_3.6H_2O$) | Initial turbidities of water samples in laboratory | 100 NTU | 40-50 mg/l | Baghvand et al., 2010 |
| Alum (liquid aluminium sulphate) and polymer | Raw water from Sri-Gading water treatment plant | 5.46 NTU | 12 mg/l | Zainal-Abideen et al., 2012 |
| Aluminum sulfate ($A_12(SO_4)_3$ $18H_2O$) | River | 15- 950 NTU | 22-90 mg/l | León-Luque et al., 2016 |
| Indian sago starch and Chitin | Surface water | 100 NTU | 100 – 300 mg/l | Saritha et al., 2017 |

**Table 1: Literature reviews of coagulant types and raw water**

## 4. Correlations of Alum Doses and Water Qualities

The alum concentrations doses added in 10 – 60 mg/l of mountain water had a slightly positive correlation with TDS [r=0.29 (p-value<0.050)] as shown in Table 2. TDS is a measure of the dissolved combined content of all inorganic and organic substances present in a liquid in molecular, ionized, or micro-granular, suspended form. TDS concentrations are often found high concentration when alum was high concentration in raw water. In contrast, the alum concentration doses had a slightly negative correlation with pH [r=-0.40 (p=value<0.010)]. Thus, adding alum is like adding a strong acid. A strong acid will lower the pH.

| | Alum concentrations | Turbidity | TDS | pH |
|---|---|---|---|---|
| Alum concentrations | 1 | | | |
| Turbidity | -0.20 | 1 | | |
| TDS | 0.29* | -0.03 | 1 | |
| pH | -0.40** | 0.21 | -0.20 | 1 |

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

**Table 2: Correlations of alum doses and water qualities**

## 5. Conclusions

The optimum alum does apply to reduce turbidity for mountain water samples from Hmong, Karen, Lahu, and Lisu for three seasons. The optimum alum dose is between 20 - 40 mg/l in rainy seasons and 10 – 40 mg/l in summer. The cold season was low optimum alum dose at 10 mg/l for all hill tribe villages. Therefore, alum coagulants can be used to treat the mountain water supply and drinking that can implement the main problem of mountain water in hill tribe village.


## Acknowledgements

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## Availability of Data and Materials

The data are available upon the reasonable request to the corresponding author.

## Authors Contributions

Suntorn Sudsandee involved in conceptualization, laboratory analysis, writing - original draft, editing, and project administration. Natthathida Patthanacheroen involved in data collection and laboratory analysis.


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