# Assessment of heavy metals contamination in water in Dong Mai craft village

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### Abstract

*Industrialization, climate change and craft village production activities produce a variety of water pollutants in Vietnam. Classical multivariate statistical analysis was used to evaluate the characteristics of As, Cu, Zn, Pb contamination in water in Dong Mai village, Hung Yen province, by using the evaluation indicators such as the metal index (MI), the enrichment factor (EF), the potential ecological risk factor (ERF) and the potential ecological risk index (ERI). This research showed that the classical statiscal analysis was significant to identify contamination sources and origin. It was notabled that high loading of (As, Cu, Zn) and Pb in water in principal components (PC1 and PC2) with seasonal variations was indicative of both geogenic and anthropogenic pollution as primary sources in terms of MI and EF. The ERF and ERI of heavy metals in Dong Mai's surface water as well as the ground water were at the low level (ERF<40 & ERI < 150). The result of the assessment highlights the need for a comprehensive and detailed study program on heavy metal content in the water resources in a wider area to identify the magnitude and details of the problem associated with heavy metal contamination for the development of a remediation plan and more effective pollution preventing measures.*

## 1. INTRODUCTION

Trace elements in water have been difficult to degrade and highly toxic, especially the excessive accumulation of toxic trace elements which not only threaten safety of invertebrates and fish ecosystems, but also cause serious health effects on human beings [2, 19]. Some trace elements are extremely toxic even at low concentrations, such as arsenic (As) and lead (Pb) [4]. Exposure to Pb could seriously damage the kidney, liver, central nervous system and blood system [14], Pb has been one of the 67 important risk factors leading to global diseases [18].

Vietnam recorded the eighth highest economic growth in Asia [15], and has high resource demands. In Vietnam, so called "craft village", which is defined as rural villages with existing craft and non-farming activities drawing the participation of at least 30% of all households and making at least 50% of the village's total income. It was estimated that ninety waste recycling craft villages are distributed across the country, mainly in the Northern part [29]. However, in most craft villages, production activities develop spontaneously, with household size and outdated production technology, thus creating environmental pollution problems, directly affecting the environment. The craft village of recycling lead from batteries at Dong Mai village is not an exception.

Dong Mai is a village in the Northern part of Vietnam, and has been recycling Pb-acid battery for many years. A local news report suggested that of 715 households in the village, at least 61 were involved in Pb recycling, total more than 500 workers [26]. The General Department of Environment's report in 2008 warned that Dong Mai villagers can lose up to 10 years of their lifespan due to environmental pollution. The metal concentrations in water and related health risk in Dong Mai battery recycling village have not been well reported previously. Considering the situation in Dong Mai, characteristics assessment of exposure status in the village residents is necessary.

The specific objectives include to study the distribution of As, Pb, Cu, Zn in the water environment and characteristics assessment of heavy metals pollution in Dong Mai craft village aim to get an overall view of the pollution situation as well as help the policy makers for implementing policies to improve the better environment and raising the people's awareness of the environment in the production as well as living process locally. Within the grassroots research project 2024, Dong Mai is one of the study areas, where heavy metals in the water were under study, an attempt of application of metal quality indices to identify the source of heavy metals and their concentration distribution characteristics is carried out. The

results of the assessment would assist to make a decision on farther comprehensive and detailed study programs on heavy metal contents in different water resources in the craft villages in particular as well as the other heavy metal pollution areas of Vietnam in general.

## 2. MATERIALS AND METHODS

### 2.1. Site description

The Pb recycling area is located in the Dong Mai village, Chi Dao commune, Van Lam district, Hung Yen province, northern Viet Nam. Since the 1970s, the traditional village of Dong Mai has been developing a professional Pb recycling program, which involves processing old batteries, Pb smelting and slag sifting. Initially, Pb smelting was performed by individual households within the home and garden areas. In 2000, the village started to use a self-contained Pb dust suction system consisting of hundreds of large bags. The suction capacity of this system was 7 tons of Pb dust per one night per one smelter. This groundbreaking technology was very efficient at minimizing the amount of Pb released to the air. Since 2015, Pb smelting has occurred in 2 new smelter systems operated by two companies located approximately 1km away from the residential area in Dong Mai village because the old smelters were closed [7].

### 2.2. Method for sampling and analysis

Sampling in Dong Mai was carried out in high precipitation season (HPS) and low precipitation season (LPS) in 2015. The possible wastewater outflows, tributaries, irrigation canals, upstream locations and other human-ecological interactions were taken into account in choosing the targeted sampling locations. Water sample collection two times a day (8-9am, 16-17pm) was recommended to observe diurnal (24h) concentration patterns of heavy metal. Average amount of water sample was 500ml and filled to the top of the sample bottle to remove air that may be left in the bottle,

avoiding chemical reactions such as oxidation to ensure accuracy and reliability for sample. The general information including well depth and capacity of each well was supported by well's owner. The samples were measured of pH using pH meter (Horiba U52) as well as electrical conductivity EC, redox potential Eh on-site (measured values were recorded in the field-diary); and then preserved by $HNO_3$ (0.2%) to ensure the retention of metal ions in the water. In the laboratory, samples were shaken well and filtered with specialized water filter paper. The filtered samples were treated with 1% $HNO_3$ acid in a 100ml volumetric vial.

Heavy metal elements were analyzed by inductively coupled plasma-mass spectrometer on Varian Ultramass 700 ICP-MS. Inductively Coupled Plasma (ICP) Mass Spectrometry (MS) (ICP-MS) is a multi-element technique that uses an ICP plasma source to dissociate the sample substance into its constituent atoms or ions. The analysis detection limit by quadrupole analyzer is from 100ppt (part per trillion) for Fe to 0.1ppt for Cd and Pb. The short-term precision (measurements in the period of 5-10 minutes) is 0.5-2% and long-term precision (measurements in the period of several hours) is 2-4% [28].

### 2.3. Data analysis by using metal quality indices (MQI) in water

#### 2.3.1. The metal index (MI)

The metal index (MI) was applied to analyze the metal content of the water samples in comparison to the maximum allowable concentrations from the Vietnamese National Water Regulation [21, 22, 23].

The metal index (MI) was applied to analyze the quality of drinking water [24], canal water [12] and river water [3]. Based on *Tamasi and Cini, 2004* [27], *MI* is calculated as follows: $MI = \sum [C_i / (MAC)_i]$

where $C_i$ is the concentration of each heavy metal in each sample, and *MAC* is the maximum allowable concentration based on the standards of Vietnamese. *MI* is considered the contemporary aggregate tendency of the quality status [12], which provides an overall understanding of the water quality for policymakers as well as the community. The higher the concentration of a metal compared to its respective *MAC* value, the worse the quality of water. *MI*> 1 is a threshold of warning [3], even though the $C_i$ may be less than $(MAC)_i$ for certain metals [27]. *Table 1* shows the water quality classification categories of *MI*.

**Table 1. Classification of water quality based on the Metal Index (MI) [24]**

| MI | Class | Nature of water quality | MI | Class | Nature of water quality |
|---|---|---|---|---|---|
| < 0.3 | I | Very pure | 2.0-4.0 | IV | Moderately affected |
| 0.3-1.0 | II | Pure | 4.0-6.0 | V | Strongly affected |
| 1.0-2.0 | III | Slightly affected | >6.0 | VI | Seriously affected |

*2.3.2. The enrichment of trace elements (EF)*

In order to understand the enrichment status of metal elements in the study area, enrichment factor (*EF*) was used for analysis. The enrichment factor was the ratio of the metal element content in the water body of the study area to the average river content in the world [9]. According to the enrichment factor, the enrichment conditions could be divided into 6 categories: when *EF*>100, it was abnormal enrichment; 10<*EF*<100, indicating super enrichment; 5<*EF*<10, indicating significant enrichment; 1.5<*EF*<5, indicating slight enrichment; 0.5<*EF*<1.5, indicating that it is not enriched. If *EF*<0.5, this indicates a loss [17].

*2.3.3. The ecological risk factor (ERF)*

The potential ecological risk factor (*ERF*) of a given single heavy metal was calculated according to the methods of *Hakanson, 1980* [13] as follows:

$$E^i_{r} = T_r \, x \, C^i_{f} = T_r \, x \, (C_0 / C_r)$$

where $E^i_r$ is the potential ecological risk factor of substance "*i*"; $T_r$ is the toxic response factor of substance "*i*" (which is 10 for As, 5 for Cu and Pb, and 1 for Zn [13]); $C^i_f$ is the contamination factor of substance "*i*"; $C_0$ is the measured concentrations in the water of substance "*i*", and $C_r$ is the background reference level for substance "*i*" (Vietnam's national technical regulation on surface water and groundwater quality (QCVN 08:2023/BTNMT & QCVN 09:2023/BTNMT) [21, 22] was adopted as $C_r$ in this study As = 0.01 (mg/l), Cu = 0.1 (mg/l), Zn = 0.5 (mg/l) and Pb = 0.02 (mg/l) for surface water; As = 0.05 (mg/l), Cu = 1 (mg/l), Zn = 3 (mg/l) and Pb = 0.01 (mg/l) for ground water).

The *ERF* was calculated for each replicate sample, and subsequently, the minimum, maximum, and mean values were determined to summarize the results. According to *Hakanson, 1980* [13], the ecological risks were classified into five terminologies based on the *ERF* values: (1) *ERF*<40, low potential ecological risk; (2) 40≤ *ERF*<80, moderate potential ecological risk; (3) 80≤ *ERF*<160, considerable potential ecological risk; (4) 160≤ *ERF*<320, high potential ecological risk; and *ERF*≥320, very high ecological risk.

*2.3.4. The potential ecological risk index (ERI)*

The potential ecological risk index (*ERI*) proposed by *Hakanson, 1980* [13] has been widely used to assess the potential ecological risk of heavy metals in aquatic ecosystems [31]. In this study, the *ERI* was used to evaluate the ecological risks of heavy metals in the surface water of both villages. The *ERI* was calculated by the following equation: $ERI = \sum [(ERF)_i]$; where *i* is the number of studied elements.

Based on the *ERI* values, the potential ecological risk was classified into 4 terminologies: *ERI*<150, low ecological risk; 150≤ *ERI*<300, moderate ecological risk; 300≤ *ERI*<600, considerable ecological risk; and *ERI*≥600, very high ecological risk.

## 2.4. Statistical analysis

Principal component analysis (PCA), together with correlation analysis (CA) and hierarchical cluster analysis, has proven to be a useful multivariate statistical technique for disclosing the origins of heavy metal contamination [25]. In this study, Spearman's correlation analysis was conducted to analyze the correlations between the variables, the sign of the correlation coefcient value shows whether the relationship is positive or negative, while the absolute value of correlation coefcient reveals the linear relationship's strength. PCA is often used in data reduction to identify common factors (principal components and PCs) that explain most of the variance observed in a large number of manifest variables. The reduced, new set of orthogonal (non-corrected) PCs by PCA is arranged in decreasing order of merit. PCA was made with varimax rotation of standardized component loadings for maximizing the variation among the variables under each factor [1]. The eigenvalue for the factor represents the strength of variance for the interpretive variables, and only eigenvalues ≥ 1.0 were considered in this study. The hierarchical cluster analysis (HCA) can be used for grouping data into classes according to characteristics, sources, and features that are similar or dissimilar. The HCA can be obtained by employing the most widely used data clustering method and application of Ward's method of linkage. Dendrogram is a pictorial representation of the HCA result based on either the analyzed parameters or sampling locations [5]. According to the dendrogram, in this study, we used the grouping data that lying in the CD (>0) & (≤10) to distinguish and arrange all the parameters which have same source, feature and characteristics in one group. The three analyses were all performed using SPSS software, version 20.0.

## 3. RESULTS AND DISCUSSIONS

### 3.1. Environment of surface water in the craft villages by using metal quality indices (MQI) in water

*3.1.1. The metal index (MI)*

Based on the *MI*, the following sequence was observed: average *MI* [As (0.978) > Pb (0.908) > Cu (0.086) > Zn (0.037) in LPS and Pb (0.626) > As (0.606) > Cu (0.060) > Zn (0.033) in HPS] in the surface water in Dong Mai village. According to the percentage of samples with *MI* >1, the selected sites around Dong Mai village were slightly to moderately threatened by As and Pb pollution for aquatic life usage (MI>1). *Fig.1* demonstrated the *MI* for the morning and evening for both seasons.

In general, the contents of Cu, Zn, As and Pb in the water body of the Dong Mai village in the dry season were higher than those in the wet season, mainly because the water amount in the wet season was larger and the trace elements in the water body diluted. The
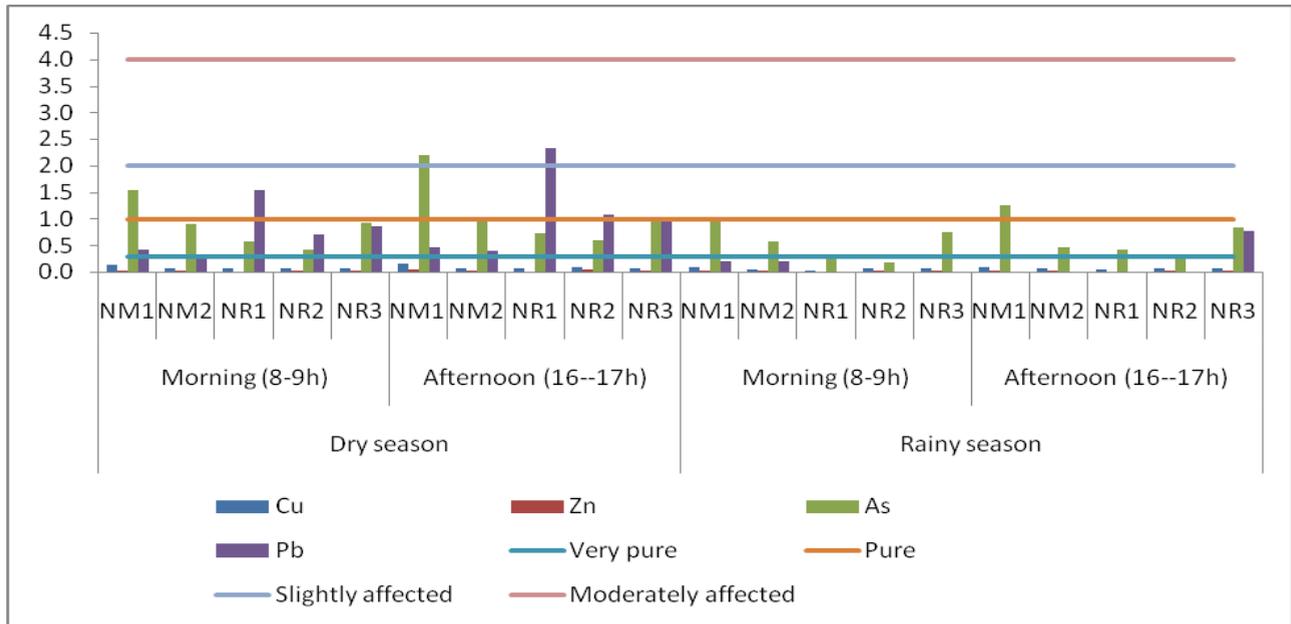
▲ *Fig.1. Seasonal variations of the metal index (MI) value of the surface water*

metal concentrations in the dry season were greater than those in the rainy season, which may be related to the dilution effect of rainfall in the rainy season. Electrical conductivity (EC) is a measure of water capability to transmit electric current. Electrical conductivity was within range 264 to 662 (µS/cm) in LPS and 182 to 532 (µS/cm) in HPS.

The results of principal component analysis and correlation analysis were shown in *Table 2*. In order to verify the applicability of the principal component analysis, Kaiser-Meyer-Olkin (KMO) and Bartlett tests were conducted on the data of heavy metal concentrations. In general, the KMO value is > 0.5 when the Bartlett's detection significance is p < 0.05, indicating that the principal component analysis was effective [6]. The KMO and Bartlett (p) test values of the Dong Mai's surface water were 0.529 and 0.00, respectively, showing that the principal component analysis was effective for our data. The principal components analysis (PCA) was the uncorrelated variables, obtained by multiplying the original correlated variables with the eigenvalues. Surface water samples exhibited 77.33% in total sample variance, was reflected by two principal components, with characteristic values greater than one, respectively, indicating that the principal component factor model can explain the variabilities of most variables [30]. In general, absolute load values > 0.75, 0.75–0.5, and 0.5–0.3 are considered as strong, medium, and weak loads, respectively [10].

For the surface water in Dong Mai village, PC1 explained 52.56% of variance and showed medium to strong positive loads related to EC, Eh, *MI2* and strong negative loads related to *MI4*. EC represented the levels of surface water's ion concentrations, reflecting the combination of rock weathering and human activities in the water body. The EC value was positively correlated with *MI2* (r= 0.790) that standed for metal index of Zn element. Zn is usually believed to come from urban sewage [11], agricultural combustion, or fungicides [8, 20], and it may also come from rock weathering [16, 25]. The inverse relationships between the loads of (Eh, EC, *MI2*) and *MI4* as well as the negative SC between [(Eh, *MI4*) (r= -0.525), (EC, *MI4*) (r= -0.713), (*MI2, MI4*), (r= -0.509), respectively] indicated that Zn and Pb had different sources. The cluster of EC & *MI2* had the shortest cluster distance (CD) (<5) (*Fig.2a*) which represented strong linkage with minimum CD that indicated those parameters had influencing power during seasonal variations. Therefore PC1 indicated that the metal index of Pb element (*MI4*) came from the lead-recycled activities in Dong Mai village but the metal index of Zn element (*MI2*) may come from rock weathering here.

PC2 explained 24.54% of variance and showed weak to strong positive loads related to *MI2*, EC, *MI3*, *MI1* and strong negative loads related to pH (*Table 2*). For surface water of Dong Mai village, pH & Eh and *MI1* & *MI3* formed a cluster with the shortest CD (<5) (*Fig.2a*) which represented strong linkage with minimum CD that indicated those parameters had influencing power during seasonal variations. The metal index of Cu element (*MI1*) and the metal index of As element (*MI3*) were clustered in one main group with the shortest CD (<5); at the same time, they had positive significant correlation (SC) (r= 0.722), indicating that they had similar patterns and sources in the groundwater in Dong Mai village. Heavy metals Cu, Zn and As that were assembled together in less distance had a higher attraction with similar identical behavior during temporal variations and also exerted a possible effect on each other.

**Table 2. Rotated principal component loadings of metal index (MI), pH, Eh and EC values in the Dong Mai's surface water.**

| Variables | PC1 | PC2 | Variables | PC1 | PC2 |
|---|---|---|---|---|---|
| Eh | 0.783 | | MI3 | | 0.852 |
| pH | | -0.753 | MI4 | -0.962 | |
| EC | 0.639 | 0.594 | Eigenvalue | 3.68 | 1.73 |
| MI1 | | 0.907 | % of variance | 52.56 | 24.77 |
| MI2 | 0.803 | 0.415 | Cumulative % | 52.56 | 77.33 |

*Note: The load values > 0.50 or < -0.5 were shown in bold italics. MI1, MI2, MI3, MI4 stands for metal index of Cu, Zn, As, Pb element, respectively.*

By observing the raw data (before calculation of mean values), notable oscillations in the concentrations of some heavy metals between morning and evening were identified. *Fig. 3* summarized these diurnal as well as seasonal changes in the selected sample sites where considerable changes were observed.
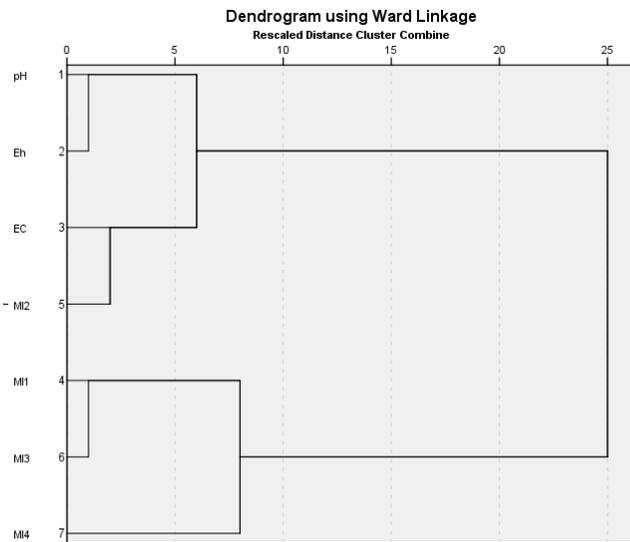


▲ *Fig.2a. Hierarchical cluster tree of grouping ph, Eh, EC and metal index (MI) in surface water by cluster analysis*
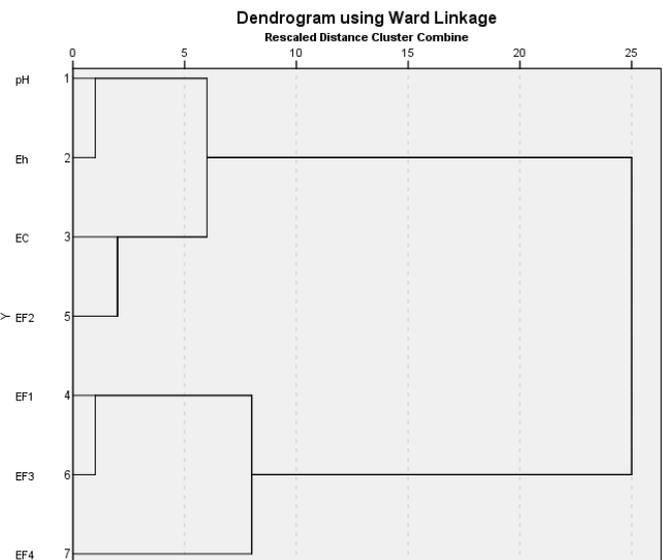


▲ *Fig.2b. Hierarchical cluster tree of grouping pH, Eh, EC and enrichment factor of trace elements (EF) in the surface water by cluster analysis*

The cluster of [*MI1, MI3*] along with *MI4* also formed a cluster had strong linkage (>5, <10), indicated their moderate relatedness but contributed largely to the surface water and significantly impacted to each other. Moreover, they had a negative SC between pH & the metal index of Cu, As element (*MI1, MI3*) (r= -0.557 and r= -0.478, respectively) and a positive SC between [EC & (*MI1, MI2, MI3*)] (0.639, 0.790, 0.525, respectively) as well as the positive SC between [(*MI1, MI2*) & (*MI1, MI3*)] (0.691, 0.722, respectively), indicating that the metal index of Cu, Zn, As had same source from rock weathering. Therefore PC2 indicated that the metal index of Cu, Zn, As element (*MI1, MI2, MI3*) came from rock weathering here.

*3.1.2. The enrichment factor of trace elements (EF)*

Based on the enrichment factor *EF*, the following sequence was observed: average *EF* [Pb (229.873) > Zn (31.033) > As (15.774) > Cu (5.791) in LPS and Pb (158.378) > Zn (27.416) > As (9.779) > Cu (4.033) in HPS] in the surface water in Dong Mai village. *Fig.4* demonstrated the *EF* for the morning and evening for both seasons.
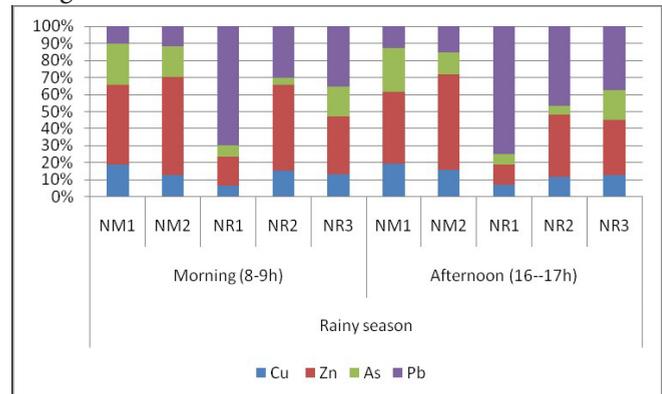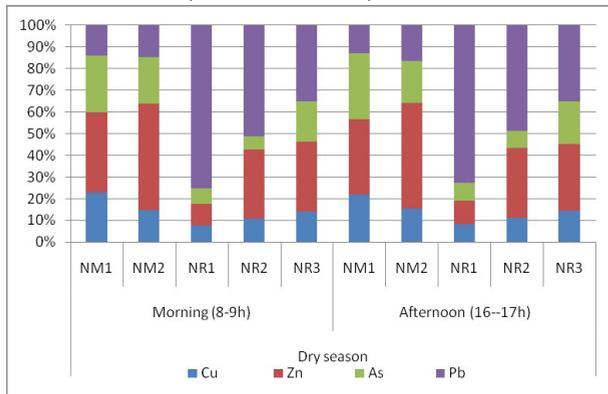




▲ *Fig.3. Diurnal trends in heavy metal concentration for selected sample sites*

The KMO and Bartlett (p) test values of the Dong Mai's surface water were 0.545 and 0.00, respectively, showing that the principal component analysis between pH, Eh, EC and the enrichment factor of trace elements (*EF*) was effective for our data. Surface water samples exhibited 77.37% in total sample variance, was reflected by two principal components, with characteristic values greater than one, respectively.

In the case of surface water of Dong Mai, PC1 explained 52.58% of variance and showed medium to strong positive loads related to EC, Eh, *EF2* and strong negative loads related to *EF4* (*Table 3*). Furthermore, [EC, *EF2*] formed a cluster with the shortest CD (<5) (*Fig.2b*) which represented strong linkage with minimum CD that indicated those parameters had influencing power during seasonal variations. The cluster of [(pH & Eh) along with EC] also formed a cluster had strong linkage (>5, <10) but lesser than cluster [pH & Eh]

(<5), contributed largely to the environment, which had positive signinficant correlation between EC & *EF2* represented the enrichment factor of Zn element had the linear relationship with EC (0.796), so that the *EF2* originated from rock weathering source.

PC2 explained 24.79% of variance and showed weak, medium to strong positive loads related to *EF2*, EC, *EF3*, *EF1* as well as strong negative loads related to pH, which had positive SC between (EC, *EF1*), (EC, *EF2*) and (EC, *EF3*) (r= 0.638, 0.706, 0.528, respectively) and (pH & Eh], [EC, *EF2*], [*EF1*, *EF3*] formed a cluster with the shortest CD (<5) which represented strong linkage with minimum CD that indicated those parameters had influencing power during seasonal variations. Heavy metals included Cu, Zn, As that were assembled together in less distance had a higher attraction with similar identical behavior during temporal variations and also exerted a possible effect on each other. The cluster of [(pH & Eh) along with EC] also formed a cluster had strong linkage (>5, <10) but lesser than cluster [pH & Eh] (<5), but contributed largely to the environment. It was thus concluded that the enrichment factor of Cu, Zn & As had a same source. The cluster of [(EF1, EF3) along with EF4] also formed a cluster (>5, <10) had strong linkage but lesser than cluster [pH, Eh, EC], which had positive SC between (*EF1*, *EF2*), (*EF1*, *EF3*) (r= 0.705, 0.714, respectively) as well as negative SC between (*EF2*, *EF4*) r= -0.512), indicating
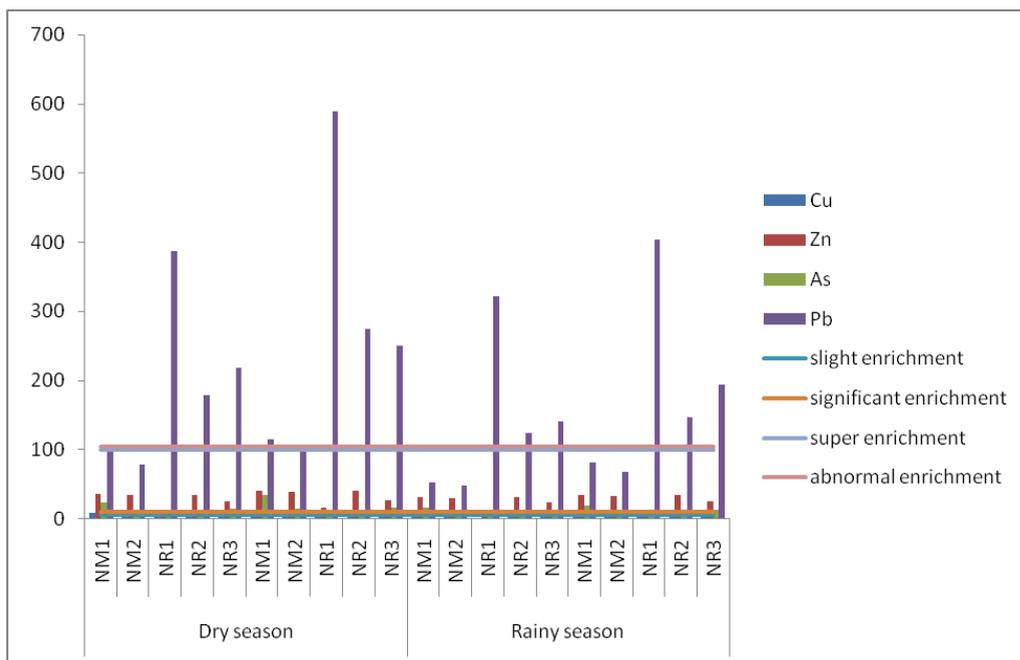


▲ *Fig.4. The enrichment factor of trace elements (EF) value of the surface water in Dong Mai.*

**Table 3. Rotated principal component loadings of the enrichment factor of trace elements (EF), pH, Eh and EC values in the Dong Mai's surface water**

| Variables | PC1 | PC2 | Variables | PC1 | PC2 |
|-----------|-----|-----|-----------|-----|-----|
| Eh | 0.783 | | EF1 | | 0.907 |
| pH | | -0.753 | EF3 | | 0.852 |
| EC | 0.639 | 0.594 | Eigenvalue | 3.680 | 1.735 |
| EF2 | 0.806 | 0.412 | % of variance | 52.58 | 24.79 |
| EF4 | -0.961 | | Cumulative % | 52.58 | 77.37 |

*Note: The load values > 0.50 or < -0.5 were shown in bold italics. EF1, EF2, EF3, EF4 stands for enrichment factor of Cu, Zn, As, Pb element, respectively.*

that PC2 represented the combination of rock weathering related to Cu, Zn, As and the enrichment factor of Pb element had the source from human activities.

*3.1.3 The ecological risk factor (ERF)*

*Fig.5* represented the potential ecological risk factor of Cu, Zn, As and Pb in the surface water of Dong Mai village. The *ERFs* of Dong Mai's suface water were at the low level (ERF<40).
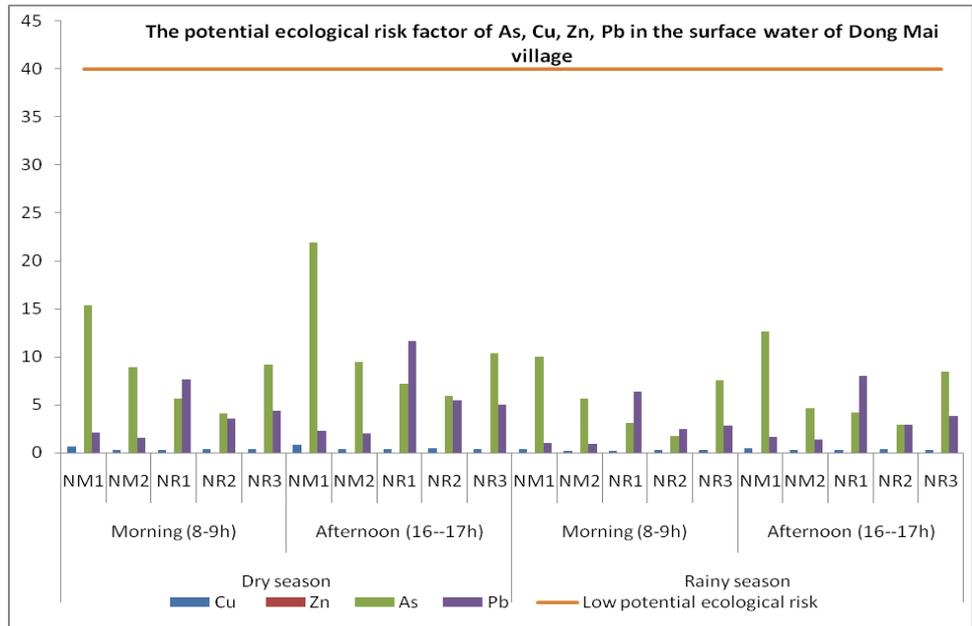
*3.1.4. The potential ecological risk index (ERI)*

In this study, the *ERI* was used to evaluate the ecological risks of heavy metals in the surface water. The potential ecological risk indexes of heavy metals in the surface water were all in the low level (*Fig.6*).

**3.2. Environment of groundwater of the craft villages by using metal quality indices (MQI) in water**

*3.2.1. The metal index (MI)*

Based on the *MI*, the following sequence was observed: average *MI* [Cu (0.0034) < Zn (0.0107) < As (0.1453) < Pb (0.1964) in LPS and Cu (0.0028) < Zn (0.0094) < As (0.1183) < Pb (0.1359) in HPS] in the groundwater in Dong Mai village. The selected sites around Dong Mai village were very pure by As and Pb. and *Fig.7* demonstrated the *MI* for both seasons.

For the groundwater in Dong Mai village, the weak negative SC between (pH, EC) (r= -0.546, p<0.05), (pH, Eh) (r= -0.477, p<0.05) and (*MI1*, *MI3*) (r= -0.462, p<0.05),



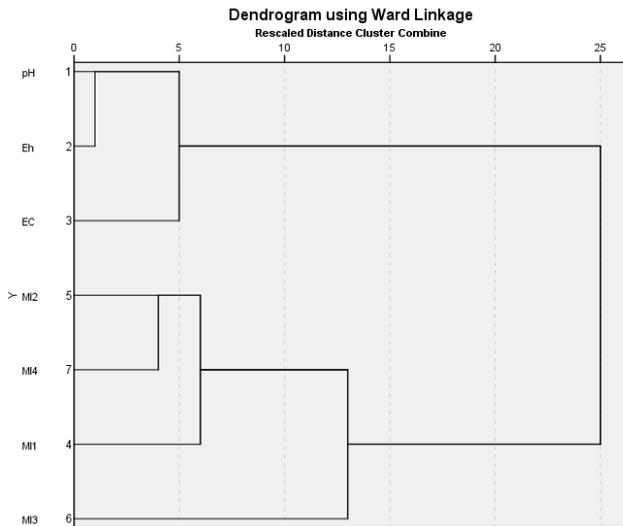▲ *Fig.5. The potential ecological risk factor of As, Cu, Zn, Pb in the surface water.*
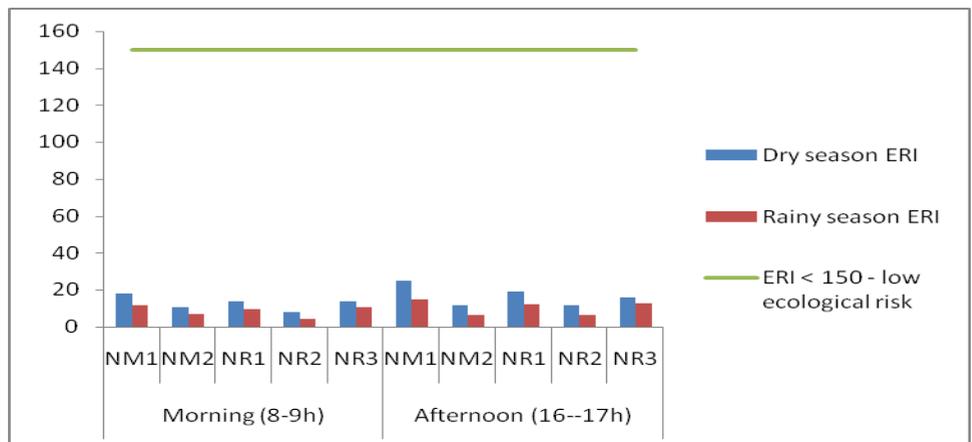


▲ *Fig.6. The potential ecological risk index (ERI) of heavy metals in the surface water*

so that an increase in the level of pH may lead in the decrease of EC & Eh as well as an increase in the level of the metal index of Cu element (*MI1*) may lead in the decrease of the metal index of As element (*MI3*). The metal index of Zn element (*MI2*) and the metal index of Pb element (*MI4*) were clustered in one main group
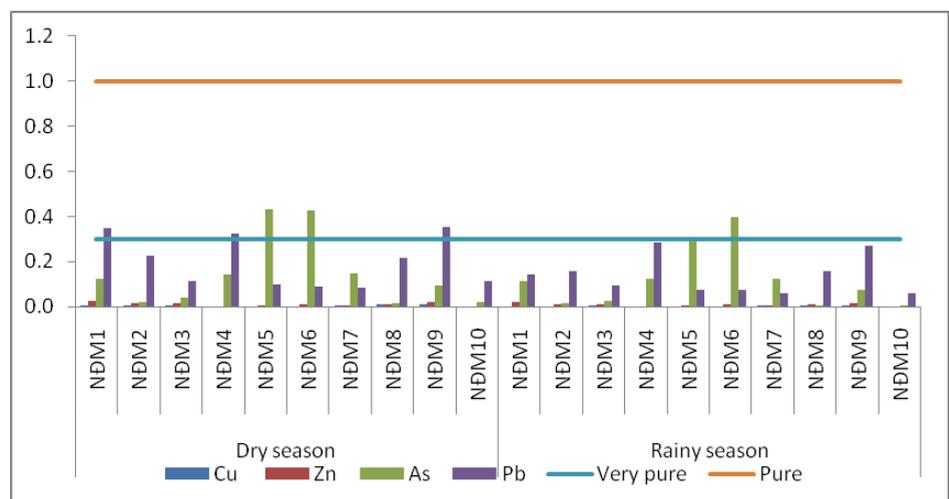


▲ *Fig.7. Seasonal variations of the metal index (MI) value of the groundwater*

with the shortest CD (<5) (*Fig.8a*); at the same time, they had positive SC (r= 0.469, p<0.05), indicating that they had similar patterns and sources in the groundwater in Dong Mai village. The cluster of [*MI2, MI4*] along with *MI1* also formed a cluster had strong linkage (>5, <10), but contributed largely to the groundwater, furthermore, the metal index of Cu element (*MI1*) and the metal index of Zn element (*MI2*) also had a same source by rock weathering and human activities (r= 0.605, p<0.01).

## 3.3. Environment of wastewater of the craft villages by using metal quality indices (MQI) in water
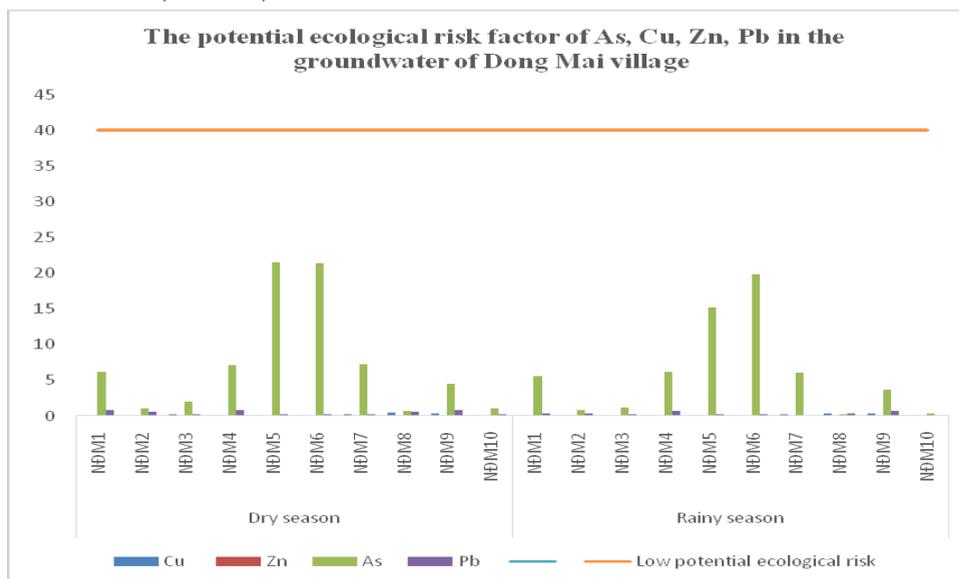
### 3.3.1. The metal index (MI)

Based on the *MI*, the following sequence was observed: average *MI* [As (0.014) < Cu (0.076) < Zn (0.244) < Pb (3.075) in HPS and As (0.073) < Cu (0.136) < Zn (0.369) < Pb (4.096) in LPS] in the wastewater in Dong Mai village. The selected sites around Dong Mai village were very pure and seriously affected by Cu, Zn, As and Pb, respectively, in HPS. In LPS, the selected sites around here were very pure to seriously affected by Cu, Zn, As and Pb, respectively and *Fig.10* demonstrated the *MI* for both seasons.



▲ *Fig.8a. Hierarchical cluster tree of grouping pH, Eh, EC and metal index (MI) of groundwater by cluster analysis*
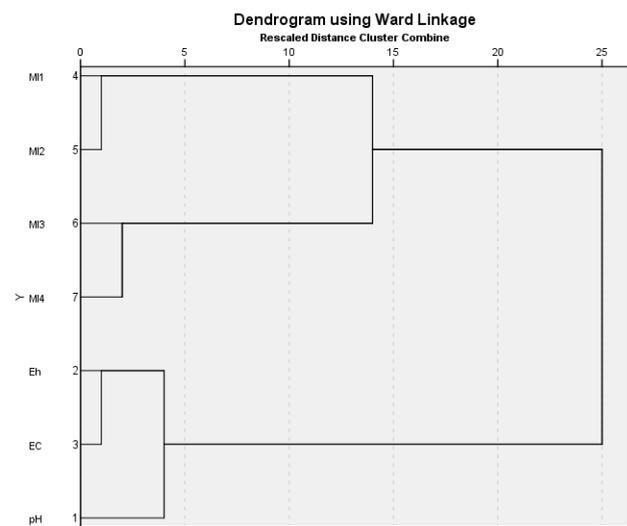


▲ *Fig.8b. Hierarchical cluster tree of grouping pH, Eh, EC and metal index (MI) of wastewater by cluster analysis*

### 3.2.2. The ecological risk factor (ERF)

*Fig.9* represented the potential ecological risk factor of Cu, Zn, As and Pb in the groundwater of Dong Mai village. The *ERFs* of Cu, Zn, As and Pb of the groundwater were at the low level (*ERF*<40).

For the wastewater in Dong Mai village, the metal index of Cu element (*MI1*) and the metal index of Zn element (*MI2*) were clustered in one main group with the shortest CD (<5) (*Fig.8b*); they had strong positive SC (r= 0.976, p<0.01), indicating that they had similar patterns and sources in the wastewater in Dong Mai village. The strong positive SC between (pH, *MI1*) (r= 0.802, p<0.05), (pH, *MI2*) (r= 0.731, p<0.05), an increase in the level of pH may lead in the increase in the level of metal index of Cu and Zn element. The cluster of [*MI3, MI4*] also formed a cluster had strong linkage (<5) and the strong negative SC between pH and metal index of Pb element (r= -0.898), therefore, the metal index of As element (*MI3*) and the metal index of Pb element (*MI4*) also had



▲ *Fig.9. The potential ecological risk factor of As, Cu, Zn, Pb in the groundwater*
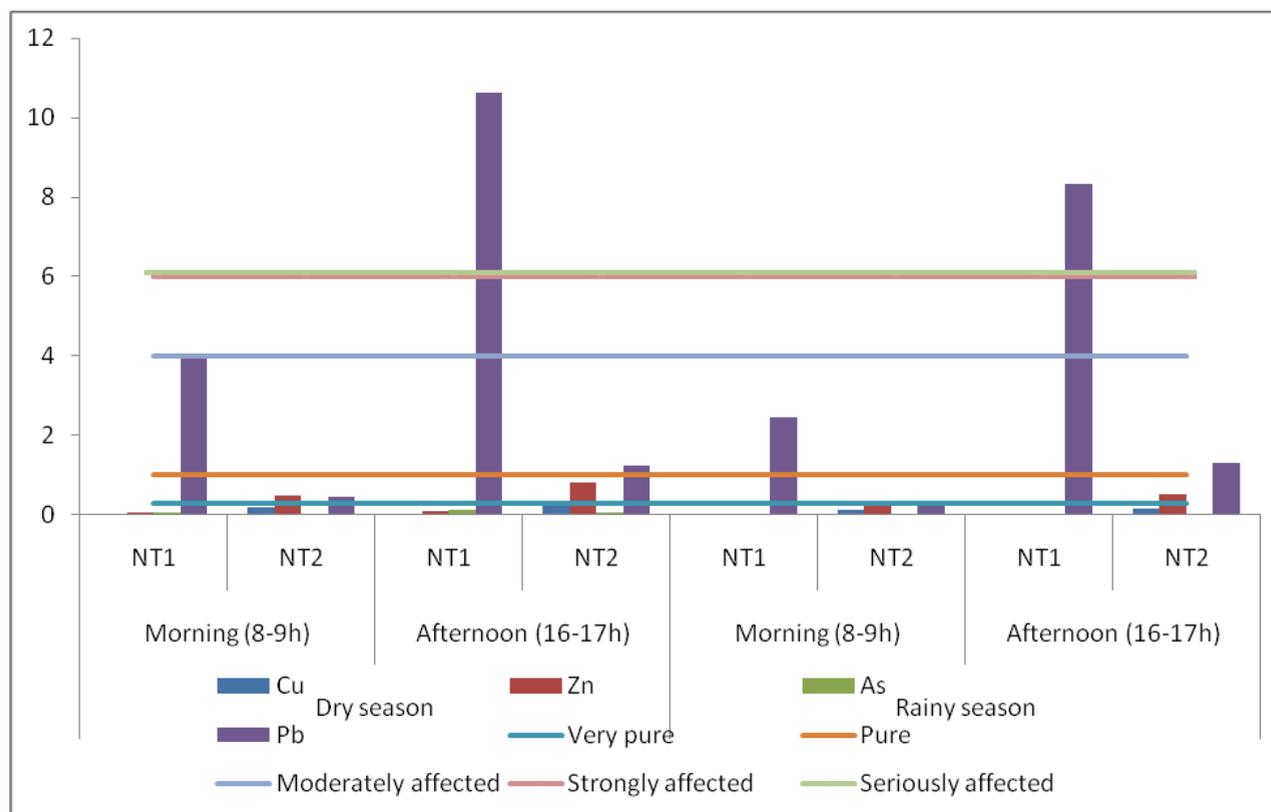
▲ *Fig.10. Metal index (MI) value of the wastewater of Dong Mai village*

a same source but contributed largely to the wastewater, an increase in the level of pH may lead in the decrease of the level of the metal index of Pb element (*MI4*) and vice versa.

## 5. CONCLUSION

In this study, the characteristics of As, Cu, Zn, Pb contamination in water Dong Mai (Hung Yen) handicraft village was avaluated. The main conclusions were obtained as follows.

Principal component analysis (PCA) was conducted separately for each type of water environment. PCA had eigenvalue >1 focused on 2 components. PCA suggested that the contribution of metals in water was derived from the anthropogenic in addition to lithogenic sources. High loading of Pb in surface water came from the lead-recycled activities in Dong Mai village but Zn, Cu, As may come from rock weathering in terms of the metal index (*MI*) and the enrichment factor (*EF*). The potential ecological risk factor and the potential ecological risk index of Dong Mai's surface water were at the low level (ERF<40 & ERI < 150).

For the groundwater in Dong Mai village, Cu & As, Zn & Pb, Cu & Zn had the same pattern and source by rock weathering and human activities by an increase in the level of pH may lead in the decrease of EC and Eh as well as an increase in the level of one of heavy metals may lead in the decrease of each other metal and vice versa in terms of metal index (*MI*). The potential ecological risk factor of Cu, Zn, As, Pb of Dong Mai's groundwater were at the low level (ERF <40).

Cu & Zn, As & Pb also had same source, but contributed hugely to the wastewater and an increase in the level of pH may lead in the decrease of Pb and vice versa in terms of metal index (*MI*).

A more comprehensive program of water sampling and analysis of Cu, Zn, As, Pb and other heavy metals is needed to be carried out for Dong Mai village in particular and in a wider area in Hung Yen province in general since the results of this study have shown an ecological risk of heavy metals concentration in the surface as well as ground water.

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