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# Trends of labile trace metals in tropical urban water under highly contrasted weather conditions

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## Abstract

The spatio-temporal trend of trace metals (Cd, Co, Cr, Cu, Ni, Pb, and Zn) in a tropical urban estuary under the influence of monsoon was determined using Diffusive Gradient in Thin Films (DGT) *in situ* samplers. Three (3) different climatic periods were observed: Period 1- dry with dredging activity; Period 2- intermediate meaning from dry to wet event; and Period 3- wet having continuous rainfall. Conforming to monsoon regimes, these periods correspond to the following: transition from winter to summer; winter; and summer monsoons, respectively. The distinction of each period is defined by their specific hydrological and physico-chemical conditions.

Substantial concentrations of the trace metals were detected. The distribution and trend of the trace metals under the challenge of a tropical climate were able to follow using DGT as a sensitive *in situ* sampler. In order to identify the differences among periods statistical analyses were performed. This allowed discriminating Period 2 (oxic water) as significantly different compared to other periods. The spatio-temporal analysis was then applied in order to distinguish the trend of the trace metals. Results showed that the trend of trace metals can be described according to their response to: (i) seasonal variations (Cd and Cr); (ii) spatio-temporal conditions (Co, Cu, Ni, and Pb); and (iii) neither (i) nor (ii) meaning exhibiting no response or having constant change (Zn). The correlation of the trace metals and the physico-chemical parameters reveals that Cd, Co, Cu, and Cr are proportional to the dissolved oxygen (DO); Cd and Ni are correlated pH; and Zn lightly influenced by salinity.

**Keywords:** labile trace metal, urban water, tropical climate, monsoon, statistics, DGT

# 1 Introduction

2  
3  
4 3 Tropical waters are dynamic environments. There are loads of factors that influence these  
5 4 aqueous systems such as different activities like estuarine mixing, tidal currents, sediment  
6 4 remobilization, and fine grain sediments transport (Kuehl *et al.* 1996 and Breckel *et al.* 2005).  
7 5 Moreover, seasonal timescales (*e.g.* monsoonal climate) induced by precipitation and other  
8 6 weather conditions affect the hydrological cycle (Chakraborty *et al.* 2010). Under monsoon  
9 7 regime, seasonal differences are pronounced and mostly distinguished by the absence and  
10 8 presence of precipitation (Takahashi 2013). This type of climate is challenging as uptight  
11 9 circumstances are at hand. Alterations in the hydro-climatic scheme can be experienced  
12 10 (Hestir *et al.* 2013). For instance, incident of disruptions of the ocean-atmosphere interactions  
13 11 can occur (Shirasago-Germán *et al.* 2015). These are principal sources of disturbance in water  
14 12 basins.  
15 13

16 14 Nowadays, the increasing apprehensions on the tropical waters not only rest in the  
17 15 hydro-climatic conditions but on the water quality as well. Particular interests are on the trace  
18 16 metals in terms of contamination and environmental risks. These are important environmental  
19 17 issues. Studies aim to know the possible effects of metals in urban runoff (Herngren *et al.*  
20 18 2005) and pollution discharges (Ki *et al.* 2011) in the aquatic system and the biota.  
21 19

22 20 Trace metals are ubiquitous, easily transported to water (Chen *et al.* 2014). The  
23 21 behavior of the trace metals in estuaries varies greatly due to environmental factors like  
24 22 hydrodynamic residence time, mixing patterns of transport processes and reservoir  
25 23 management (Hatje *et al.* 2003; Masson *et al.* 2006; Masson *et al.* 2011). Another factor is the  
26 24 water chemistry that changes from freshwater to saltwater that influences their occurrence  
27 25 (Jian and Wen 2009). The trend differs according to seasonal changes and suspended  
28 26 sediments concentrations (Park *et al.* 2011). Precipitation, for example, can play as an  
29 27 atmospheric wash out that delivers trace metals to aquatic ecosystem through deposition  
30 28 mechanism (Özsoy and Örnektekin 2009). To deduce, in tropical waters, trace metals can be  
31 29 perceived as active components in the environment and, at the same time, reactive elements in  
32 30 the aqueous systems. These directed towards serious intentions and efforts to assess the water  
33 31 quality of tropical waters including estuaries specially those who are situated in highly  
34 32 urbanized zones.  
35 33

36 34 Labile trace metals are vital in examining the state of these tropical waters. This  
37 35 fraction can eventually help in assessing toxicity and associated risks (Pinhero and Domingo  
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1 2005). However, measuring these specific forms requires collecting voluminous water which  
2 is tedious and time consuming (Graveline *et al.* 2010). Alternatively, *in situ* sampling  
3 technique can be employed. It can provide data over longer periods of time and reduces some  
4 of the drawbacks of grab sampling (INAP 2002).

5 For this reason, Diffusive Gradient in Thin-Films (DGT) is used to monitor trace  
6 metals in aquatic system. This device has the ability to perform measurements (Davison and  
7 Zhang 1999) at a lower cost. It is an *in situ* method that can sequester labile fractions (Naylor  
8 *et al.* 2004; Li *et al.* 2005; Søndergaard *et al.* 2008; Vystavna *et al.* 2012a and 2012b) even at  
9 very low concentrations (Zhang *et al.* 1995). This technique for measuring trace metal and  
10 monitoring water bodies is long-established and delivers valuable results with lesser sampling  
11 activities needed (Alfaro-De la Torre *et al.* 2000; Clarisse *et al.* 2009; Gao *et al.* 2010; Wu *et*  
12 *al.* 2011; Villanueva *et al.* 2013).

13 The purpose of this research is mainly to determine the labile trace metals response to  
14 differing climatic and physico-chemical conditions in a dynamic estuarine system in a tropical  
15 setting. The Pasig River in Manila, Philippines was chosen due to the distinct water dynamics  
16 (as this is an estuary in nature) and climate background. The seasonal changes are pronounced  
17 and contrasting because of the influence of the monsoon and precipitation anomalies over  
18 tropical regions (Villafuerte *et al.* 2014). These variations are caused by surface reverse  
19 directions and local winds (Han *et al.* 2009).

20 This study would like establish the trend of labile trace metals in a tropical water  
21 facing monsoon seasons. The focus is on determining the importance of the episodic events  
22 on the trace metal loads and availability of the labile fractions in highly industrialized and  
23 urbanized tropical water. The specific objectives are: (1) to describe the trend of the labile  
24 trace metal (Cd, Co, Cr, Cu, Ni, Pb and Zn); (2) to distinguish the effect of seasonal changes  
25 under monsoon regime in a tropical aquatic system in terms of hydrochemistry and physico-  
26 chemical conditions; and (3) to determine which among labile trace metals are more  
27 vulnerable to spatio-temporal changes.

28 Three (3) local seasons were considered: dry, transition from dry to wet (intermediate),  
29 and wet. The difference in the seasonal pattern can lead to a premise that the trace metals  
30 trend will also be significantly distinct from each period. To assess if this premise holds,  
31 statistics were performed. Hydrochemistry and physical conditions were utilized as  
32 parameters. Spatio-temporal analysis was applied to better explain the labile trace metal  
33 trends.

# 1 **Materials and Methods**

## 3 **Site description**

5 The Pasig River is an estuary of about 27 km long and approximately 80 m wide. The  
6 catchment is composed of 4 main tributaries (San Juan River, Marikina River, Napindan  
7 River, and Pateros-Taguig River) and 43 minor tributaries. It is located in the heart of Manila,  
8 Philippines (Fig. 1) and connects Laguna Lake (east), the biggest freshwater lake in the  
9 Philippines and the Manila Bay (west). The salinity intrusion from the bay can reach towards  
10 the whole stretch of the Pasig River to the mouth of the lake.

11 Manila Bay mostly serves as a shipyard. Laguna Lake has many functions that include  
12 aquaculture and fishery (open fishing), irrigation, power generation and navigational lane.  
13 This site is situated in a highly industrialized and urbanized area with a rough estimated  
14 population of 11,500,000 plus fluxes of informal settlers which are about 30% of the total  
15 Metro Manila region (Aiga and Umenai 2002). This water body normally receives non point  
16 sources of effluent wastes of different forms. Poor solid waste management is in addition a  
17 challenge in the area.

## 19 **Sampling Design**

21 The sampling design followed seasonal patterns in the study area. Sampling campaigns were  
22 conducted that corresponded to: Period 1- dry with an ongoing dredging activity (April to  
23 May 2010); Period 2- intermediate: from dry to wet season (January 2011); and Period 3- wet  
24 season (May to June 2011). The rainfall behavior during the sampling campaigns is presented  
25 in Table 1. Following these differing precipitation rates, the hydrology of the Pasig catchment  
26 varied strongly in between periods.

27 Four sites (Fig. 1) were chosen representing the upstream (point 1: mouth of the  
28 Manila Bay), midstream (points 2 and 3 which are near the San Juan and Marikina River,  
29 respectively); and downstream (point 4: mouth of the Laguna Lake), with an approximate  
30 distance of 7 km in each site. Point 4 signals freshwater interference in the river. In each site,  
31 DGT in duplicates were fully immersed for 18 days. DGT field blank was provided per  
32 sampling campaign. Strict protocols of DGT deployment (Villanueva 2013) were followed for  
33 all sampling campaigns. Immediately, after the retrieval, the DGT probes were rinsed with de-

1 ionized water and placed in pre-cleaned properly marked resealable plastic containers. A  
2 cooling compartment was prepared to transport the probes directly to the laboratory. DGTs  
3 were put in the refrigerator before the extraction of the trace metals.

4 During each sampling campaign, physical parameters such as dissolved oxygen (DO),  
5 water temperature, salinity, conductivity and pH were measured *in situ* using YSI 6600 V2  
6 data probe at a depth of approximately 1m below the water surface. The range of values is  
7 presented in [Table 2](#). According to the study of [Materum 2010 and Villanueva 2013](#), total  
8 organic carbon (TOC) of the Pasig River ranged from 3.4 to 4.5 mg/L during May 2010 and  
9 3.5 to 7.4 mg/L for January 2011.

### 11 **Determination of trace metals concentration**

12  
13 Standard solution Chelex-100 DGT probes were purchased from DGT Research Ltd,  
14 Lancaster, UK. DGT field blanks were extracted and analyzed using the same procedure for  
15 the DGTs immersed in the water. Laboratory procedural blanks were prepared. The detection  
16 limits were determined following the already established procedure ([Pettke et al.2012](#)). In the  
17 laboratory, the membrane filter and the diffusive gel were carefully removed from the piston  
18 using Teflon tweezers. The gel was separated and placed into a clean *polypropylene* micro  
19 centrifuge tube. 1 ml of 1M of HNO<sub>3</sub> (Fisher Scientific Analar grade) was added. After 24  
20 hours, dilution was performed. The trace metals were determined using inductively coupled  
21 plasma-mass spectrometry (Thermo Scientific\*ELEMENT2\*ICP-MS). From the elution  
22 solution, the accumulated mass of the trace metals then the concentrations were calculated.  
23 The detailed laboratory procedures ([Dunn et al. 2007; Aung et al. 2008](#)) and calculations  
24 ([DGT Research 2002](#)) can be found elsewhere ([INAP 2002](#)).

### 26 **Trend Analysis approach**

27  
28 Two (2) approaches were applied: statistical and spatio-temporal analyses. The statistical  
29 analyses permit discriminating the periodical differences. This can also describe the  
30 relationship in between parameters: hydro and physico-chemical variables and trace metal  
31 concentrations. The spatio-temporal analysis is valuable in determining the trends of the trace  
32 metals by evaluating their response in each seasonal or temporal variation and inspecting the  
33 increase or decrease of the concentration in a spatial sense.



## 1 **Statistical tests**

2  
3 In order to determine the significance among periods using the concentrations of the pool of  
4 labile metals, series of statistical tests were utilized. Student *t*-test was considered as it is  
5 appropriate for small data sets (population samples). This test is normally applied for the  
6 comparison of two means (Fritz and Berger 2015). Hence, allowing comparing a period to  
7 another using the concentration of the trace metals as data sets. Two-tailed *t*-test was  
8 employed pairing each period's data sets (trace metals concentrations). The significance level  
9 was determined using the value  $\alpha=0.05$ . To validate and illustrate the difference, hierarchical  
10 cluster analysis was performed.

11 Correlation analysis was applied to determine the potential relationship of the physico-  
12 chemical parameters (DO, water temperature, pH, salinity, and conductivity) and how each  
13 can influence one another. Subsequently, the correlation of the physico-chemical parameters  
14 to the labile trace metals was carried out.

## 16 **Spatio-temporal analysis**

17  
18 The spatio-temporal analysis can discriminate the trend of each labile trace metals by  
19 examining the tendency of concentrations. The variation can be sorted according to the  
20 inclination of each trace metal. This approach aids in determining which trace metals are  
21 susceptible to: (i) seasonal or climatic conditions changes; (ii) spatial or local variations; (iii)  
22 both spatial and seasonal disparities; and (iv) neither spatial nor local situation (absence of  
23 changes). The first can be related to temporal events, while, the second can be associated to  
24 anthropogenic activities and/or instantaneous contamination. The last can be described as  
25 having a conservative or constant trend.

# 1 Results

## 3 Environmental background and Physico-chemical parameters

5 The physico-chemical characteristics of the water were recorded during each sampling period  
6 (Table 2). Period 1 combines two (2) episodic events: dry season and dredging activity. The  
7 area experienced shortage on rainfall. Periods 2 and 3, on the other hand, both experienced  
8 pronounced rainfall (~79 mm). Period 2 showed the lowest record for water temperature,  
9 salinity, and conductivity. This period has the highest DO level. The periods were best  
10 described by the DO as the oxygen levels greatly varied through periods. DO range from 0.45  
11 to 1.05 mg/L on Period 1; 5.9 to 8.2 mg/L on Period 2; and 1.55 to 2.26 mg/L on Period 3.  
12 Only Period 2 passed the Department Administrative Order (DAO 34) of the Philippine  
13 government. The DO requirement is >5 mg/L. The salinity was pronounced on Period 3 (0.39  
14 to 8.44 psu) which also indicated water mixing. In Period 2, salinity was almost constant  
15 along the Pasig River stretch. Compared to DO, salinity and conductivity, pH did not exhibit  
16 strong variations.

## 18 Labile Trace Metals in the Pasig River

20 The general trend observed was that most of labile trace metals concentrations increased  
21 during Period 2 then decreased during Period 3 (Fig. 2 and Table 3). However, throughout the  
22 period, Zn seemed stable. During Period 1, the only DGT-trace metals (at maximum) found at  
23 the river end is Ni located near the mouth of the bay (Point 1). Minimum Ni was detected at  
24 the confluence of San Juan River (Point 2) while Co has the least at the mouth of the bay  
25 (Point 1). Maximum concentrations were mostly near the confluence of San Juan River (Point  
26 2: Cr, Cd and Pb) and convergence of Marikina River (Point 3: Co, Cu and Zn).

27 The minimum concentrations of Cr, Cu, Zn, Cd and Pb were found near the mouth of  
28 the lake area (Point 4). In this period, at the river ends (Points 1 and 4), lower values of Cr,  
29 Co, Cu, Cd and Pb were found. In contrast, Ni has the lower values in the midstream (Points 2  
30 and 3). Zn concentration spatially varies. In Period 2, minimum value of Pb is found near the  
31 mouth of the bay (Point 1); Cr, Cu and Zn were at the confluence of San Juan River (Point 2);  
32 Co and Ni near Marikina River area (Point 3); and Cd near the mouth of the lake (Point 4).  
33 Maximum values of Cr, Cu, Zn and Cd were found near the mouth of the bay (Point 1), while,

1 Co, Ni and Pb at the mouth of the lake (Point 4). At this period, the maximum values are all  
2 found at the river ends (Point 1 and 4).

3 For Period 3, Cu has the least concentration at the mouth of the bay (Point 1).  
4 Maximum values were traced in the sampling points except near the lake: Cr and Cd were  
5 found near the bay area; at the confluence of San Juan River (Point 2: Co, Zn and Pb); and  
6 near at the Marikina River (Point 3: Ni and Cu). Most of the minimum values were at the  
7 mouth of the lake (Point 4: Cr, Co, Ni, Zn, Cd and Pb).

### 9 **Labile trace metal concentrations and statistical difference among periods**

10  
11 The Student *t*-test was performed by pairing the data (Period 1 vs. Period 2; Period 1 vs.  
12 Period 3; and Period 2 vs. Period 3). The result of the statistical test is shown in **Table 5**.  
13 Significant difference were found in between Period 1 and 2 ( $\alpha=0.05$ ;  $p= 0.022$ ) and Period 2  
14 and 3 ( $\alpha=0.05$ ;  $p= 0.016$ ) but not for Period 1 and Period 3 ( $\alpha=0.05$ ;  $p= 0.437$ ).

15 To illustrate, the hierarchical cluster analysis was performed generating a dendrogram  
16 (**Fig. 4a**). The dissimilarity between the periods agreed to the statistical analysis performed  
17 where Period 2 was isolated (left). Observations on the spatial patterns of Periods 1 and 3  
18 showed that for both periods, most of the maximum concentrations of each trace element are  
19 found at the midstream (Points 2 or 3), while, most of the minimum concentrations of each  
20 trace element are at the endstream (Points 1 or 4). Another dendrogram (**Fig. 4b**) was  
21 generated considering only Periods 1 and 3. The result demonstrated that Period 1 is grouped  
22 together, whereas, Period 3 is clustered into 3 groups.

### 24 **Correlation among parameters**

25  
26 The correlation among physico-chemical parameters is shown in **Table 6**. DO has an inverse  
27 relationship to other physico-chemical parameters. This inverse relationship is more  
28 pronounced with respect to the water temperature ( $\alpha=0.05$ ;  $p= -0.91$ ). In terms of salinity,  
29 Periods 1 and 3 showed evident water mixing. Although, the salinity values are lower in  
30 Period 1, water mixing was also observed. There is also a weak confirmation of the inverse  
31 relationship of DO to salinity ( $\alpha=0.05$ ;  $p= -0.42$ ). Water temperature and salinity are  
32 positively correlated to conductivity, whereas, DO showed negative correlation.

1           Among trace metals (Table 7), Zn demonstrated weak correlation to other trace metals.  
2 Direct relationship was present in between the following trace metals: Co-Cd ( $r= 0.80$ ), Co-Cr  
3 ( $r= 0.77$ ), Cu-Cd ( $r= 0.71$ ), Cu-Co ( $r= 0.69$ ), Cu-Cr ( $r= 0.92$ ), and Ni-Cd ( $r= 0.75$ ). In  
4 between the physico-chemical parameters and the trace metals, DO followed the Cd, Co, Cu,  
5 and Cr; and pH is correlated to Cd and Ni. Potential relationship in between salinity and Zn  
6 was traced.

## 9 **Discussion**

### 11 **Environmental background**

13 The Philippines is within the regime of monsoon seasons of Southeast Asia (Loo *et al.* 2014).  
14 This type of climate system is dynamic as it is characterized by wet spell having periodic  
15 heavy rains and dry spell with seasonal changes driven by the wind directions (Stephens *et al.*  
16 2008). The active factors coming from the interaction of the oceans and atmosphere could  
17 lead to droughts and wet episodes (Buckley *et al.* 2014). It has significant impacts on the  
18 environment including water systems (Cook and Jones 2012; Varis *et al.* 2012). Monsoon  
19 climate dictates the variability of the temperature of the water catchments (Meybeck 2009)  
20 and hydrodynamics (Fuchs *et al.* 2012). It can also affect the quality of the water resource  
21 (Wilkerson *et al.* 2002; Hestir *et al.* 2013). For these reasons, under this climate regime, it is  
22 noteworthy to know how the hydrochemistry of the Pasig River responds.

#### 24 *Monsoonal Climate Regime*

26 Seasonality of monsoon can be categorized according to months. Cruz *et al.* 2012 explains  
27 that the main monsoon regimes are the Northeast monsoon and the Southwest monsoon.  
28 Northeast monsoon or the winter monsoon can be expected on November to March.  
29 Southwest monsoon or summer monsoon starts May and ends on September. On October, the  
30 transition from Southwest monsoon to Northeast monsoon occurs. Adhering to the monsoon  
31 regime, Period 1 fell under the transition from Northeast to Southwest monsoon (in between

1 winter and summer monsoon); Period 2 experienced Northeast/winter monsoon; and Period 3  
2 encountered Southwest/summer monsoon.

#### 3 4 *Hydro-physico-chemical variation*

5  
6 The variation of DO followed by the water mixing express the differences among periods.  
7 Through periods there is a shift from almost anoxic to oxalic then hypoxic waters. In terms of  
8 incidence of water mixing, the trend is as follows: Period 3>Period 1>Period 2. The  
9 conductivity follows the trend of the salinity, Period 2 having least values. The water  
10 temperature is almost the same for Periods 1; and 3 and lowest during Period 2. For pH,  
11 Period 1 was more basic than Period 2 and Period 3 played slightly acid to neutral water.

#### 12 13 **Spatio-temporal analysis on trace metals**

14  
15 Period 1 as stated was under a dry weather. Twenty (20) days prior to the sampling campaign,  
16 there was only 0.8 mm of rainfall. A total of 6 mm of rainfall was accumulated within this  
17 sampling period which implied river low flow. At this period, there was an on-going dredging  
18 activity. Dredging is an ecological disturbance that can affect the sediment structure (Mackie  
19 *et al. 2007*; Je *et al. 2007*). Both particulate forms (Nayar *et al. 2004*) and bioavailability  
20 (Lewis *et al. 2001*) of trace metals in the water column could increase (Cabrita 2014) due to  
21 resuspension (Fathollahzadeh *et al. 2015*). Studies showed that the release of the dissolved  
22 trace metals can be attributed to the binding mechanism to the solid phase or on the  
23 mechanisms involving sorptive phases (van den Berg *et al. 2001*). Also the changes in the  
24 water chemistry like pH and ionic strength can affect the release of the dissolved trace metals  
25 (*i.e.* lower pH increase the solubility of the trace metals).

26 In wet seasons, atmospheric deposition, surface run-off (Witt *et al. 2010*), and  
27 atmospheric precipitation (Migliavacca *et al. 2005*; Vuai *et al. 2011*) contribute to trace  
28 metals delivered to the receiving body (Dunn *et al. 2007*) such as rivers (Aung *et al. 2008*).  
29 Periods 2 and 3 both received almost the same amount of precipitation throughout the  
30 sampling campaign. However, twenty days before the sampling activity in Period 3, the  
31 accumulated rainfall amount was only 125.2 mm already, whereas, Period 2 received only  
32 14.4 mm. These periods displayed different hydro-chemical characteristics. The hydro-  
33 chemical condition illustrates the distinction of this period being least in salinity, water

1 temperature, and conductivity at the same time highest in DO values. Period 3 has the highest  
2 recorded water temperature, salinity, and conductivity. Knowing the hydro-chemical  
3 background, the interesting issue is on what can be the response of each of these differing  
4 conditions to the labile trace metal concentrations.

#### 6 *Trace metal variation*

8 The ranges of the trace metal concentrations are summarized in **Table 3**, while, the variations  
9 are presented in **Fig. 2**. Period 2 is discriminated as significantly different to Periods 1 and 3.  
10 In **Table 4**, the anthropogenic activities surrounding the river with the trace metals concern are  
11 identified. To illustrate the distribution of the different labile trace metals per period and site,  
12 pie charts were drawn in **Fig.3**. These pie charts represent relative percentage of the  
13 concentrations of trace metals. Zn has the largest portion during Periods 1 and 3. In Period 2,  
14 Cr has the leading share. The second biggest part among periods is as follows: Period 1:  
15 mostly Cd followed by Cr; Period 2: Zn followed by Cu; and Period 3: Cu then Co.

#### 17 *Spatio-temporal variation of trace metals*

19 As a point of observation, the variation of each trace metals follows three (3) trends. The trace  
20 metals can be group according to their response in a spatio-temporal approach. First, the trace  
21 metals that exhibited seasonal (temporal) variation or changes of the concentrations differ  
22 between periods. Second, trace metals that are sensitive spatially and temporally, indicating  
23 variations in each site and in each period (season). Third, a trace metal that is constant  
24 through time. Seasonal variation is observed in labile trace metals Cd, and Cr. The spatial and  
25 temporal sensitive trace metals are depicted by Co and Cu and mainly by Ni and Pb. Among  
26 the trace metals, Zn has a different trend by appearing constant through time.

#### 28 *Cr and. Zn: The trend and origin*

30 Significant concentrations of trace metals were detected in the Pasig River in varying amount.  
31 There is an interesting aspect in terms of anthropogenic and geogenic origins. In **Fig. 3**, the  
32 largest portions are Cr and Zn. Among the trace metals, Cr showed the most considerable  
33 trend in between periods. The results showed how the dissolved Cr in the Pasig River is  
34 sensitive to seasonal and hydrochemistry changes. There is a notable point in Cr being the

1 highest during Period 2. **Table 4** provided probable sources of emissions situated at the  
2 riverbank. Cr could also be associated to atmospheric fallout or rainfall and surface runoffs  
3 (**Neal et al. 1996**). During Period 3 series of rainfall served as a wash out of Cr that is why  
4 lesser concentration was detected.

5 As the spatio-temporal analysis revealed, unlike Cr, Zn is neither affected by dilution  
6 nor the variation of physico-chemical parameters. Zn is normally abundant in urban water  
7 runoff. It is interesting to look at its geogenic origin. The interaction of Zn with Cd and the  
8 distribution in estuaries can be studied (**Audry et al. 2004; Dudka et al. 1994**).

9 The fractionation of Zn/Cd can explain the trace element pattern as a response to the  
10 geochemical phases. Its concentration ratio changes according to different geochemical  
11 phases occurring in geochemical path such as in streams, rivers, estuaries, coastal seas and  
12 open oceans (**Gerringa et al. 2001**). The result of this study showed that Zn has a significant  
13 relationship to Cd ( $r=0.61$ ). Zn/Cd ratio can give clear estimates on the relative geochemical  
14 behavior (**Mazeina et al. 1999**) and can trace their sources. The Zn/Cd ratio obtained ranges  
15 9.32-11.65 for Period 1; 5.88-8.48 for Period 2; and 502.72-1174.83 for Period 3. The ratio  
16 that ranges from 5–10 can be attributed for oceanic waters (**Gerringa et al. 2001**). In the world  
17 record, the ratio 7.5 is said to be carried by riverine suspended sediments to the oceans in  
18 dissolved phase (**Viers et al. 2009**). Higher ratio (>500), like in Period 3 can be traced in ore  
19 elements from basaltic, igneous rocks and sediments (**Gerringa et al. 2001; Nolting et al.**  
20 **1999; Gottesman and Kampe 2007**). Thus, there is an indication that most of Zn came from  
21 runoff.

### 22 **Importance of the physico-chemical parameters on the labile trace metals**

23 Physico-chemical environmental parameters are very essential in explaining the  
24 chemical spatial distribution of the trace metals. DO plays an important role which is highly  
25 influenced by seasonal changes (**Sokolowski et al. 2001**). As a main point, DO give inverse  
26 relationship to other physico-chemical parameters. This inverse relationship is more distinct  
27 with respect to the water temperature followed by conductivity. There is a weak proportional  
28 relationship in between DO and salinity. Although, the results confirmed the direct  
29 relationship in between conductivity and salinity, two (2) tendencies were noticed. Period 1  
30 showed higher slopes than Period 3. Although salinity is lesser in Period 1, conductivity is  
31 higher. pH displayed weak inverse correlation to salinity and conductivity.

1 Positive correlations ( $r > 0.60$ ) in between most of the trace metals were observed.  
2 Weak correlations ( $r < 0.50$ ) are found in between Cd-Co, Ni-Co-, Ni-Cr, Ni-Cu. Zn portrayed  
3 no correlation with other trace metals. The relationships of the concentrations of physico-  
4 chemical parameters and labile trace metals among periods are presented in Fig. 5 and Table  
5 7.

6 **DO.** Pasig River showed that trace metals (Cd, Co, Cr, Cu, and Pb) are directly  
7 proportional to DO except for Ni and Zn. Oxidic water favors dissolved metals (Buffle and van  
8 Leeuwen 1993). The oxidic levels of each period are distinguished accordingly: Period 1 is near  
9 anoxia; Period 2 shows oxidic water; and Period 3 is hypoxic water (Table 2). Using the  
10 abovementioned parameters and their relationships to the dissolved oxygen, Period 2 should  
11 have the highest trace metal concentration followed by Period 3. Period 1 will give the least  
12 concentrations. This is true for the actual case of Period 2 only but not for Periods 1 and 3.  
13 During Period 3, continuous rainfall led to lesser concentrations of the trace metals. Fig. 5  
14 shows that from hypoxic towards oxidic level the concentrations of most of the trace metals  
15 (Cd, Co, Cr, Cu, Ni, and Pb) increased. In oxidic water, trace metals are mostly driven by  
16 sorption reaction; while, trace metals are controlled by sulfide precipitation in anoxic water  
17 (Buffle and van Leeuwen 1992). Sulfides are strong reducing agents. Low concentration of  
18 trace metals in the anoxic water is due to metal sulfide precipitation (Zwolsman and Van Eck  
19 1993).

20 **pH.** Water pH influences the evolution of the concentration of Cd and Ni. The pH of  
21 the Pasig River is as follows: Period 1- alkaline water; Period 2~ neutral water; and Period 3-  
22 near acidic and neutral water. Following the trace metal and pH relationship, Period 1 should  
23 have the highest concentration, while, Period 3 the least. This is true for the case for Period 3.  
24 However, Period 1 ranked the second in terms of labile trace metal concentration even if the  
25 water is alkaline. Period 2 is in the first order because of sorption. In Fig. 5, it presents that  
26 the concentrations of the trace metals are lower at pH ~7 then there is increase of  
27 concentrations after the neutral level until pH~7.5. The trace metals distribution is affected by  
28 the pH through acid-base reaction (vanLoon and Duffy 2000). Trace metals sorption has  
29 proportional relationship with increasing pH (Munk *et al.* 2002). The adsorption of metal  
30 cations are more likely to happen when pH increases at the water column, as the latter  
31 increases the particle surface negative charge (Gurumurthy *et al.* 2013). This can also mean  
32 that desorption can be experienced predominantly in the acidic water. Water at high pH  
33 promotes insolubility of the trace metals.



1           **Salinity and Conductivity.** Most of the dissolved trace metals in Periods 1 and 3 have  
2 the least concentration near the lake. These periods showed decreasing salinity and  
3 conductivity from the bay to the lake. Flocculation of trace metals can be experienced in the  
4 area where the lowest salinity was found (Gerringa *et al.* 2001; Biati *et al.* 2010). This  
5 observation explains why least trace metal concentrations were found during this period at the  
6 mouth of Laguna Lake (except for Cu and Pb,  $r= 0.47$ ). Zn has consistent trend having the  
7 least concentration near the bay. Zn is mainly influenced by salinity (Boughriet *et al.* 1992).  
8 In this study a probable relationship between Zn and salinity is observed ( $r=0.53$ ). Like  
9 salinity, most of the trace elements have inverse proportion to conductivity. Negative  
10 correlations are mostly found for Co, Cr, and Cu.

### 11           **Water Quality Threshold**

12           The Pasig River is a highly urbanized water resource. Several industries and companies  
13 surround this river. Table 4 shows potential industrial sources of metals. Philippines would  
14 like to comply with the United Nation’s AGENDA 21 on the protection of the quality, supply  
15 and potential source of water. In the past, Pasig River is an important water source for  
16 domestic consumptions of the local inhabitants. Progressively, water quality degradation sank  
17 in, manifested by high turbidity and foul smell. Rehabilitation programs are in place to bring  
18 back Pasig River to its previous state. Therefore, the concern on the state of the water quality  
19 is important.

20           If the occurrence of the trace metals in drinking water set by the World Health  
21 Organization (WHO 2008) will be followed, the following trace metals exceeded the value;  
22 Cr of Period 2 which is above 2  $\mu\text{g/L}$ ; Cu which is above the minimum value of 0.005  $\mu\text{g/L}$ ;  
23 and Ni which is above 0.02  $\mu\text{g/L}$ . Cd and Pb is less than the normal occurrence in drinking  
24 water ( $<1 \mu\text{g/L}$  and  $<5\mu\text{g/L}$ , respectively). The Zn occurrence in the freshwater exceeded the  
25 WHO consideration as it is more than the range of 0.01-0.5  $\mu\text{g/L}$ . Co is less than the norm.  
26 The Canadian Environmental Protection Act, 1999 of the Federal Environmental Quality  
27 Guidelines stated that worldwide, Co concentrations is less than 1  $\mu\text{g/L}$  in surface freshwater  
28 and 0.3-1.7  $\mu\text{g/L}$  in rainwater. This insinuates that the trace metal concentrations measured in  
29 the Pasig River are not negligible.

## 1 Comparison of results to other DGT studies

2  
3 The measured concentrations in this study are compared to other studies that employed DGT  
4 in estuaries and coastal waters influenced by anthropogenic activities. For instance, there is  
5 an interesting study in the Basque-French estuaries (Montero *et al.* 2012) situated in an  
6 industrial and mining area. The measured concentrations in the Pasig River during Periods 1  
7 and 2 are within the range of the values obtained in this study: Cd (2-1570 ng/L) and Ni (30-  
8 3650 ng/L). For Cu (66-515 ng/L), the Pasig River has wider range and higher value. The  
9 coastal sites of Sardinia in Italy (Schintu *et al.* 2010) located in a mining and lead-zinc  
10 smelting area showed higher Cu concentration range (1.45-2.23 µg/L). The minimum value of  
11 Cd concentration in this site is the maximum value obtained in the Pasig River (0.9 µg/L).  
12 Patos Lagoon in Brazil (Costa and Wallner-Kersanach 2013), serves as marina, port and  
13 shipyard, has lower Cu concentration (0.11-0.45 µg/L) than the Pasig River. Zn maximum  
14 concentration of the Pasig River is the minimum value in this site (0.8 µg/L). Baijao site of  
15 the Jiulong River in China is characterized as a highly multi-metal contaminated estuary  
16 (Weng and Wang 2014). Pasig River has higher Cd, Cr, and Pb concentration and wider range  
17 compared to this river. Jiulong River has ranges of 0.04-0.12 µg/L, 1.59-7.72 µg/L, 0.05-0.39  
18 µg/L, respectively. The Co concentration of the Pasig River is within the range of the Jiulong  
19 River (0.15-0.95 µg/L). The study in the Tama River of Japan considered contrasted weather  
20 condition (Aung *et al.* 2007). In this study, Cu was not detected. Compared to the Pasig River,  
21 Tama River Ni, Pb, and Zn concentrations (72 hours deployment: 0.8 µg/L, 0.39 µg/L, 3.6  
22 µg/L, respectively) have higher value than the Pasig River.

23 As a whole, measured concentrations in the Pasig River correspond to the results of  
24 the studies that have shown evident contamination. Although these past studies are relevant,  
25 comparing is not easy. True enough that these sites are similar aquatic systems and DGTs  
26 were utilized however the conditions were not the same. Case in point is the duration of DGT  
27 deployment. DGT samplers in this study were immersed for more than two weeks, whereas,  
28 most of the studies are done in shorter periods: Basque-French estuaries: 10 days; Patos  
29 Lagoon, Brazil: 72 hours; Sardinia, Italy: 3 days; Tama River, Japan: 46, 48, and 72 hours;  
30 and Jiulong River estuary, China: 48 to 72 hours. Besides, not all considered highly seasonal  
31 contrasted conditions. Another important issue is that dredging activity was not a component  
32 of the reported studies.

## 1 **Implication on water resources management**

2  
3 Labile trace metals are composed of inorganic and weak complexes species (Gourlay-Francé  
4 *et al.* 2011). These species can dissociate and/or has tendency for chemical changes. Serious  
5 ecological concerns are arising as these can be dangerous for the microorganisms like  
6 phytoplanktons (Baeyens *et al.* 2011) at a high concentration (Sigg 2014). Hence, it is  
7 recommended to measure the labile trace metals to better assess the water quality of the  
8 surface water.

9 The highest trace metal concentration varies according to season (Table 8). Spatial  
10 analysis indicates sources of the labile trace metals. For instance, Cd and Cr were highest near  
11 the bay area (Site 2 during Period 1 and Site 1 for Periods 2 and 3) and Ni was highest close  
12 to the lake (Site 4 for Periods 1 and 2 and Site 2 for Period 3). In terms of the lowest  
13 concentrations, Cd has lowest value always near the mouth of the lake. In this area also during  
14 Period 3, least concentrations (Cd, Co, Cr, Ni, Pb and Zn) were observed.

15 The Pasig River is in continuous water quality surveillance. The results provide  
16 information that trace metal contributes mostly to the natural water system (*e.g.* Cr and Zn)  
17 and needs more monitoring. From this study, water quality measurements can be done  
18 according to the susceptibility of the labile trace metals to the spatio-temporal trend. This can  
19 give an idea in determining the frequency of sampling campaigns. Labile trace metals that  
20 demonstrated spatio-temporal variation (*i.e.* Co, Cu, Ni, and Pb) need more sampling  
21 frequency. These are more exposed to changes in terms of concentration. Those who are  
22 sensitive to seasonal/temporal changes (*i.e.* Cd and Cr) can entail for lesser sampling  
23 campaigns. This is as the former are more vulnerable to labile trace metal contributors or  
24 sources. While, the one that exhibited constant change (Zn) does not require high sampling  
25 frequency. This means that the order of sampling frequency is as follows: spatio-temporally  
26 inclined>seasonally/temporally sensitive>unvarying or constant. These recommendations  
27 hold unless unanticipated instantaneous contamination is present (*e.g.* oil leaks).

## 1 Conclusion

2  
3 The study determined the labile trace metals trend in tropical water (estuarine) under episodic  
4 event and differing climatic conditions (Period 1: dry and simultaneous dredging; Period 2:  
5 intermediate or in between dry and wet; Period 3: wet). If the monsoon regime will be  
6 followed: Period 1 was under the transition of winter to summer monsoon; Period 2 was in an  
7 event of winter monsoon; and Period 3 encountered summer monsoon.

8 The periods imply also different physico and hydro-chemical characteristics. This  
9 discriminates the trend of trace metals. Considerable amount of trace metals were detected  
10 that can be a point of environmental concern especially during Period 2. The general trend  
11 found in trace metal concentrations is as follows: Period 2 present the higher one followed by  
12 the Period 1 and Period 3 having the lowest concentrations. The trend presented correlations  
13 in between the trace metals and physico-chemical parameters. The statistical tests showed that  
14 only Period 2 is significantly different from Periods 1 and 3.

15 The sensitivity of DGT as an *in-situ* water sampler is established. This is as DGTs  
16 were able to follow the trend of the trace metals under contrasted climate conditions and  
17 episodic event. Evaluation based from the water quality threshold and other DGT studies  
18 proves that substantial trace metals contamination is present in the Pasig River. Furthermore,  
19 from the results: 1. highest trace metals that contribute to the Pasig River were determined (Cr  
20 and Zn); 2. three (3) trends of trace metals were identified: (i) spatio-temporally inclined; (ii)  
21 seasonally or temporally sensitive; (iii) constant or unvarying; and 3. the can latter facilitate in  
22 deciding the frequency of sampling or monitoring. The precedence is of this order: spatio-  
23 temporally inclined (*i.e.* Co, Cu, Ni and Pb)>seasonally/temporally sensitive (*i.e.* Cd and Cr)>  
24 unvarying or constant (*i.e.* Zn).

25 This study provides sound baseline information on the state of the water quality and its  
26 response to seasonal changes and environmental disturbance. It proves that the Pasig River is  
27 susceptible to these changes and disturbance as depicted by the variation of the values  
28 obtained from physico-chemical parameters and labile trace metal concentrations.  
29 Furthermore, major results presented that on one hand, intermediate season (from dry to wet)  
30 can bring higher concentration of trace metals than the environmental disturbance (dredging).  
31 On the other hand, continues rainfall can cause washing effect through dilution (as the  
32 concentration of the labile trace metals notably diminished except for Zn).

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1 **List of Tables**

2 **Table 1** Rainfall rate during the sampling campaigns.

| Rainfall (mm)                          | Period 1 | Period 2 | Period 3 |
|--|----------|----------|----------|
| Days before sampling*                  |          |          |          |
| 10                                     | 0.8      | 5.4      | 19.6     |
| 20                                     | 0.8      | 14.4     | 125.2    |
| Accumulated within the sampling period |          |          |          |
|  | 6        | 79       | 79.8     |

3 \*Days before DGT installation

4 Provided by Manila Observatory (unpublished data 2012)

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23 **Table 2** Physico-chemical parameters' range of values

| Period | Water temperature (°C) | DO (mg/L) | pH        | Salinity  | Conductivity (ms/cm) |
|--------|------------------------|-----------|-----------|-----------|----------------------|
| 1      | 31                     | 0.45-1.05 | 7.89-8.35 | 0.55-3.60 | 6.00-22.00           |
| 2      | 26-27                  | 5.90-8.20 | 7.31-7.73 | 0.39-0.40 | 0.81-0.84            |
| 3      | 31-32                  | 1.55-2.26 | 6.80-7.03 | 0.39-8.44 | 1.00-16.00           |

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38 **Table 3** Concentration range of detected labile trace metals inthe Pasig River (ng/L)

| Trace metals | Concentration ranges |           |          | RSD      |          |          | Detection Limit |
|--------------|----------------------|-----------|----------|----------|----------|----------|-----------------|
|              | Period 1             | Period 2  | Period 3 | Period 1 | Period 2 | Period 3 |                 |
| Cd           | 87-94                | 141-146   | 0.9-1.8  | 1.75     | 1.04     | 0.19     | 0.21            |
| Co           | 28-82                | 119-277   | 62-100   | 11.24    | 34.27    | 9.09     | 6.44            |
| Cr           | 205-236              | 6841-7632 | 13-23    | 6.82     | 184.50   | 2.15     | 10.86           |
| Cu           | 88-314               | 506-867   | 149-251  | 48.93    | 82.92    | 23.17    | 7.63            |
| Ni           | 154-434              | 206-255   | 22-27    | 61.33    | 12.57    | 1.09     | 2.94            |
| Pb           | 95-122               | 50-643    | 7-16     | 6.95     | 131.25   | 2.18     | 1.21            |
| Zn           | 827-1027             | 793-1236  | 431-1468 | 42.34    | 103.60   | 232.11   | 100.00          |

1 **Table 4** Anthropogenic activities surrounding the Pasig River and the major trace metals  
 2 concern

| Site          | Important activities              | Major metals concern       |
|---------------|-----------------------------------|----------------------------|
| <b>Site 1</b> | shipyard                          | Ni                         |
|               | ceramic factory                   | Co, Cr ,Pb                 |
|               | electric company                  | Cu                         |
|               | textile and clothing              | Cr, Zn                     |
|               | thermal power plant               | Cd, Ni, Pb, Zn             |
|               | food company                      | Pb, Cu                     |
|               | gasoline stations                 | Cd, Co, Cr, Cu, Ni, Pb, Zn |
|               | oil refinery                      | Cd, Cr, Pb                 |
|               | navigational lane                 | Cd, Co, Cr, Cu, Ni, Pb, Zn |
|               | oil refinery                      | Cd, Cr, Pb                 |
| <b>Site 2</b> | wood                              | Cu                         |
|               | electricity (electrical industry) | Cu                         |
|               | cigarettes                        | Cd                         |
|               | metal castings                    | Co, Cr, Ni, Zn             |
|               | agroindustry                      | Cd, Cu, Pb                 |
|               | steels                            | Cr, Ni                     |
| <b>Site 3</b> | navigational lane                 | Cd, Co, Cr, Cu, Ni, Pb, Zn |
|               | aquaculture                       | Cd, Co, Cr, Cu, Ni, Pb, Zn |
| <b>Site 4</b> | fishing, irrigation               | Cd, Zn                     |
|               | power generation                  | Cd, Pb                     |
|               | navigational lane                 | Cd, Co, Cr, Cu, Ni, Pb, Zn |

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**Table 5** Student t-test result. \*For 5% level of significance, there is difference on the mean response of Dry vs. Intermediate, and Intermediate vs. Wet as showed in the p-values. (sig. < 0.05)

| Groups |  | t     | df    | sig.<br>(2<br>tailed) | MeanDifferenc<br>e | Std.<br>ErrorDifferenc<br>e |
|--------|--|-------|-------|-----------------------|--------------------|-----------------------------|
| Period | <b>Dry(1)<br/>vs.Intermediate(2)</b><br>°° | -2.43 | 27.77 | 0.022*                | -1109.41           | 455.75                      |
|        | <b>Dry(1) vs.Wet(3)</b><br>°               | 0.78  | 54.00 | 0.437                 | 69.74              | 89.09                       |
|        | <b>Intermediate(2)<br/>vs.Wet(3)</b><br>°° | 2.57  | 28.32 | 0.016*                | 1179.15            | 458.05                      |

°Equal variances assumed °°Equal variances not assumed

**Table 6** Correlation (*r*) among physico-chemical parameters

|                         | Salinity | Dissolved<br>oxygen | Water<br>Temp | pH   | Conductivity |
|-------------------------|----------|---------------------|---------------|------|--------------|
| <b>Salinity</b>         | 1.00     |                     |               |      |              |
| <b>Dissolved oxygen</b> | -0.42    | 1.00                |               |      |              |
| <b>Water Temp</b>       | 0.36     | -0.92               | 1.00          |      |              |
| <b>pH</b>               | -0.40    | -0.25               | 0.09          | 1.00 |              |
| <b>Conductivity</b>     | 0.69     | -0.70               | 0.52          | 0.26 | 1.00         |

1 **Table 7** Correlation (*r*): among labile trace metals and labile trace metals to the physico-  
 2 chemical parameters

|                     | <b>Cd</b> | <b>Co</b> | <b>Cr</b> | <b>Cu</b> | <b>Ni</b> | <b>Pb</b> | <b>Zn</b> |
|---------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| <b>Cd</b>           | 1.00      |           |           |           |           |           |           |
| <b>Co</b>           | 0.48      | 1.00      |           |           |           |           |           |
| <b>Cr</b>           | 0.80      | 0.77      | 1.00      |           |           |           |           |
| <b>Cu</b>           | 0.71      | 0.69      | 0.92      | 1.00      |           |           |           |
| <b>Ni</b>           | 0.75      | 0.12      | 0.38      | 0.28      | 1.00      |           |           |
| <b>Pb</b>           | 0.68      | 0.71      | 0.69      | 0.47      | 0.40      | 1.00      |           |
| <b>Zn</b>           | -0.04     | 0.06      | 0.06      | 0.16      | -0.12     | -0.14     | 1.00      |
| <b>pH</b>           | 0.52      | -0.25     | -0.06     | -0.04     | 0.75      | 0.08      | -0.13     |
| <b>Salinity</b>     | -0.59     | -0.28     | -0.48     | -0.48     | -0.52     | -0.41     | 0.53      |
| <b>DO</b>           | 0.65      | 0.88      | 0.95      | 0.84      | 0.24      | 0.76      | -0.02     |
| <b>Water Temp</b>   | -0.78     | -0.77     | -0.98     | -0.91     | -0.28     | -0.67     | -0.18     |
| <b>Conductivity</b> | -0.29     | -0.60     | -0.63     | -0.63     | -0.12     | -0.38     | 0.25      |

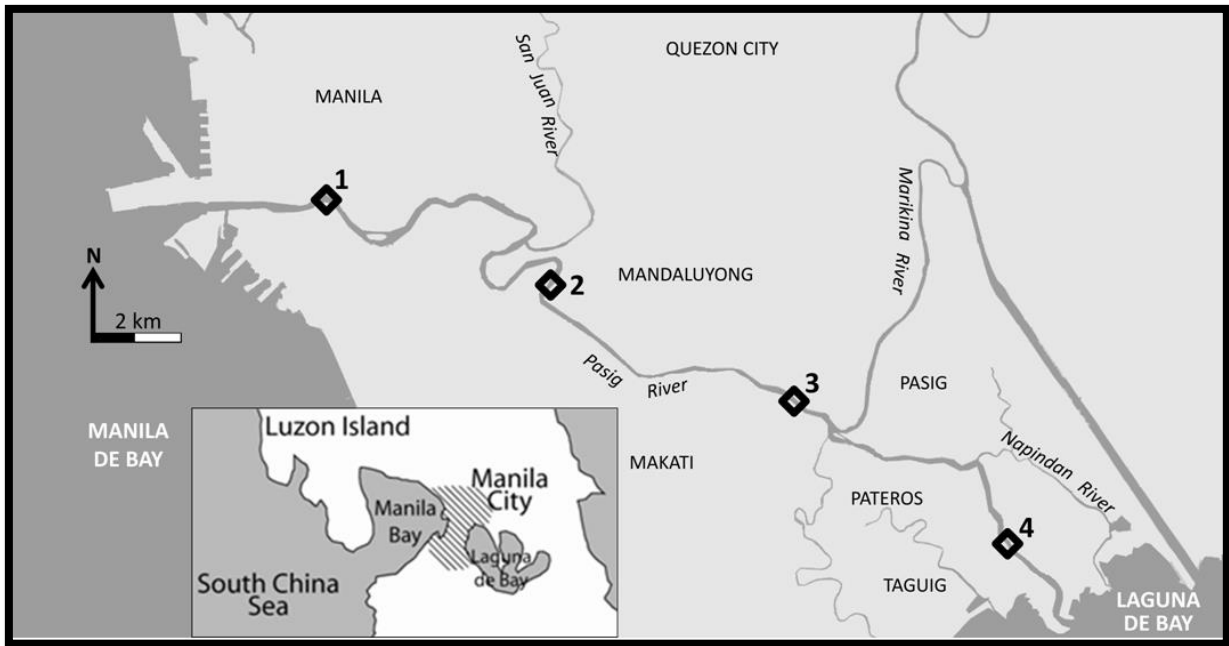
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 4 **Table 8** Detected sites which have highest and lowest labile trace metal concentrations

| <b>Trace metals</b> | <b>Site of highest concentration</b> |          |          | <b>Site of lowest concentration</b> |          |          |
|---------------------|--------------------------------------|----------|----------|-------------------------------------|----------|----------|
|                     | Period 1                             | Period 2 | Period 3 | Period 1                            | Period 2 | Period 3 |
| Cd                  | 2                                    | 1        | 1        | 4                                   | 4        | 4        |
| Co                  | 3                                    | 4        | 2        | 1                                   | 3        | 4        |
| Cr                  | 2                                    | 1        | 1        | 4                                   | 2        | 4        |
| Cu                  | 3                                    | 1        | 3        | 4                                   | 2        | 1        |
| Ni                  | 4                                    | 4        | 3        | 2                                   | 3        | 4        |
| Pb                  | 2                                    | 4        | 2        | 4                                   | 1        | 4        |
| Zn                  | 3                                    | 3        | 2        | 4                                   | 2        | 4        |

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 6 *Site 1: near Manila Bay; Sites 2 and 3: midstream; Site 4: near Laguna Lake*



1 **Figures**



**Fig. 1** The Pasig River map and sampling sites (Point 1: moth of the Manila Bay; Point 2: near the convergence of the San Juan River, Point 3: near the confluence of the Marikina River; and Point 4: near the Laguna Lake)

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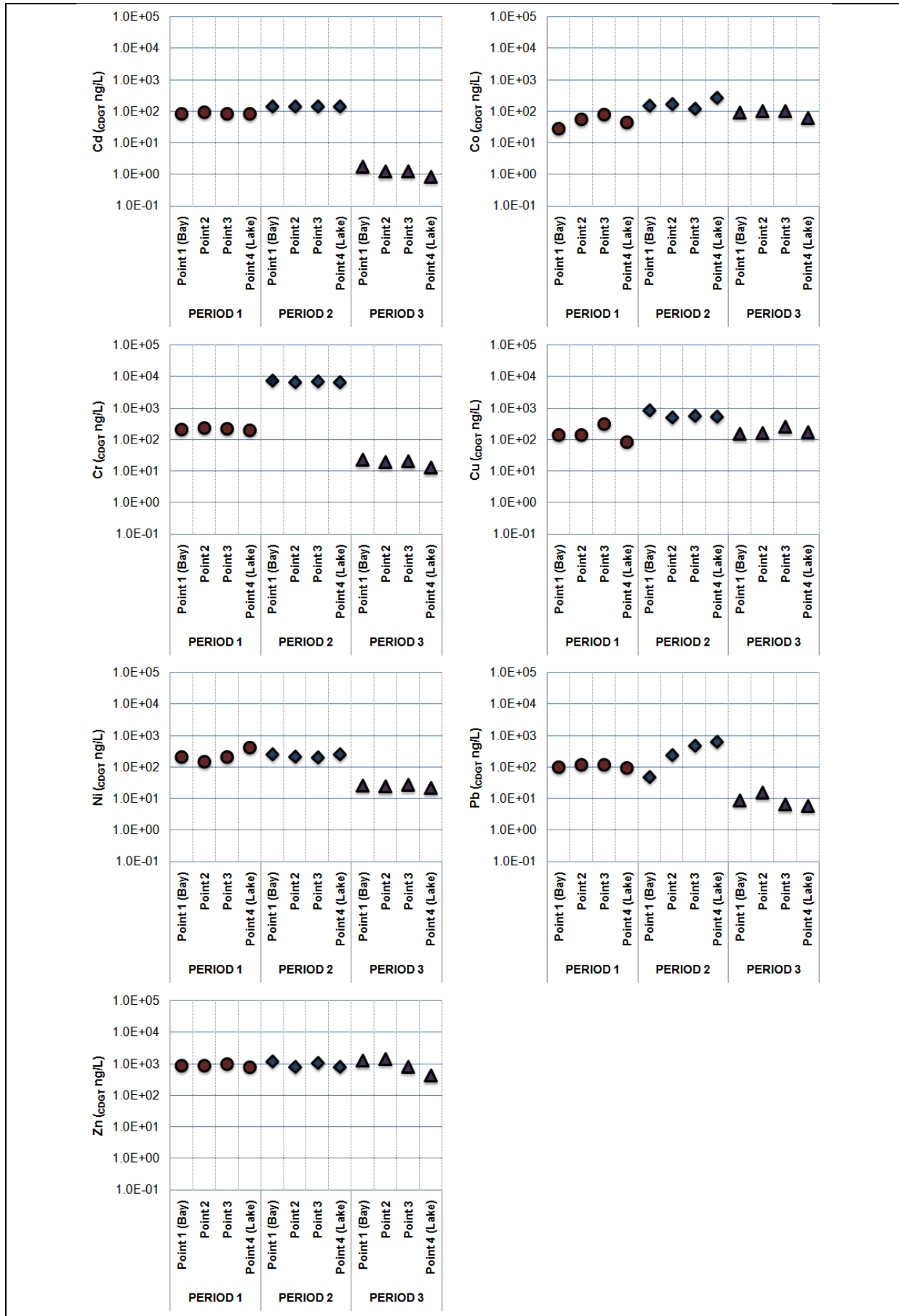


Fig. 2 DGT-labile trace metals' concentrations (ng/L)

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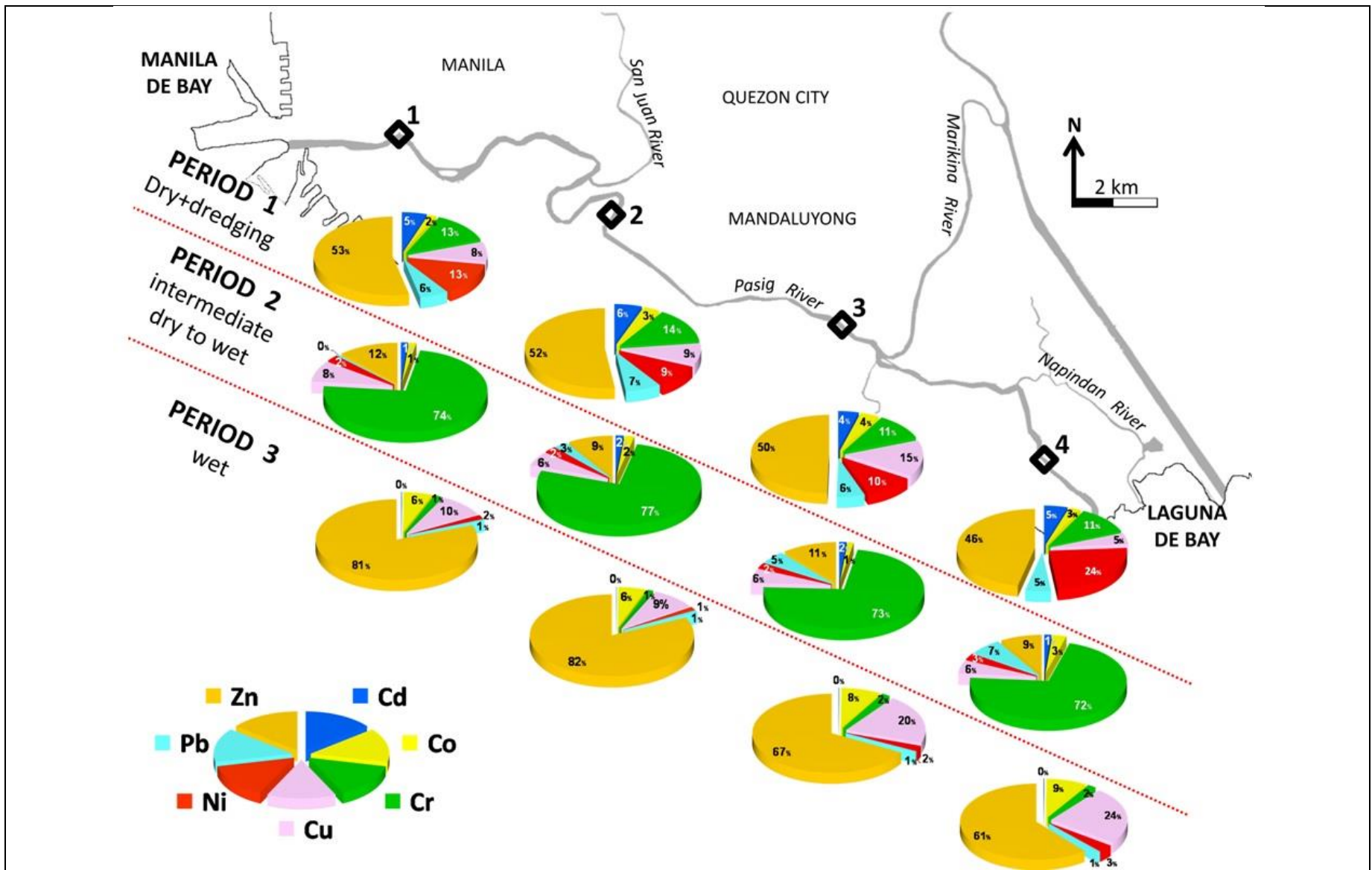
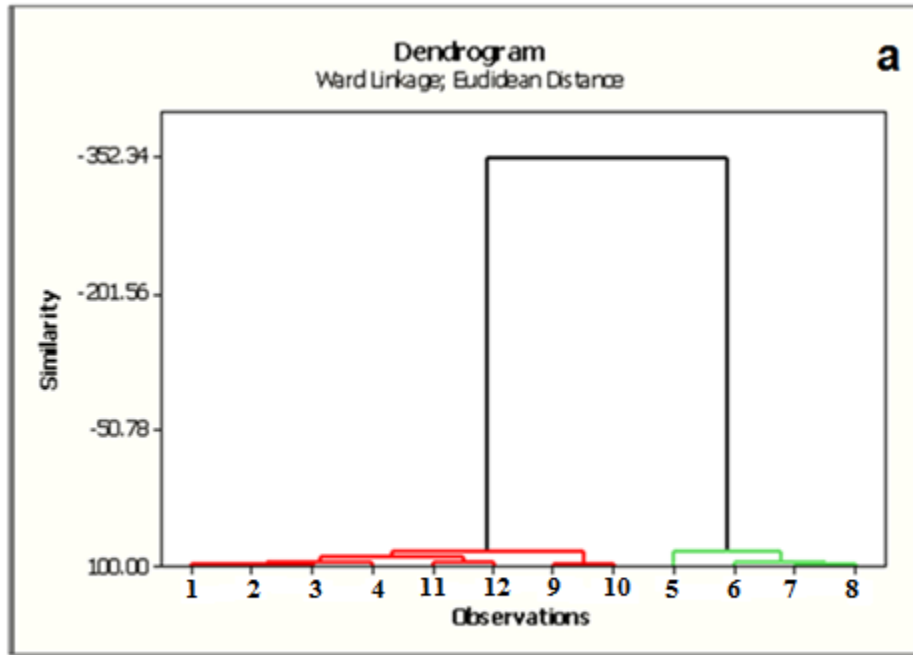
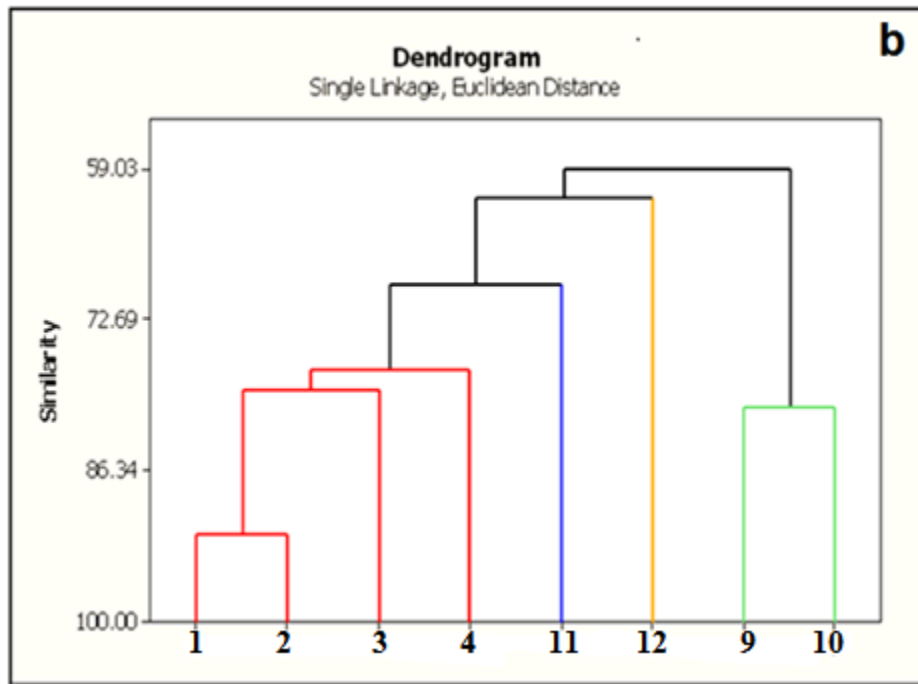


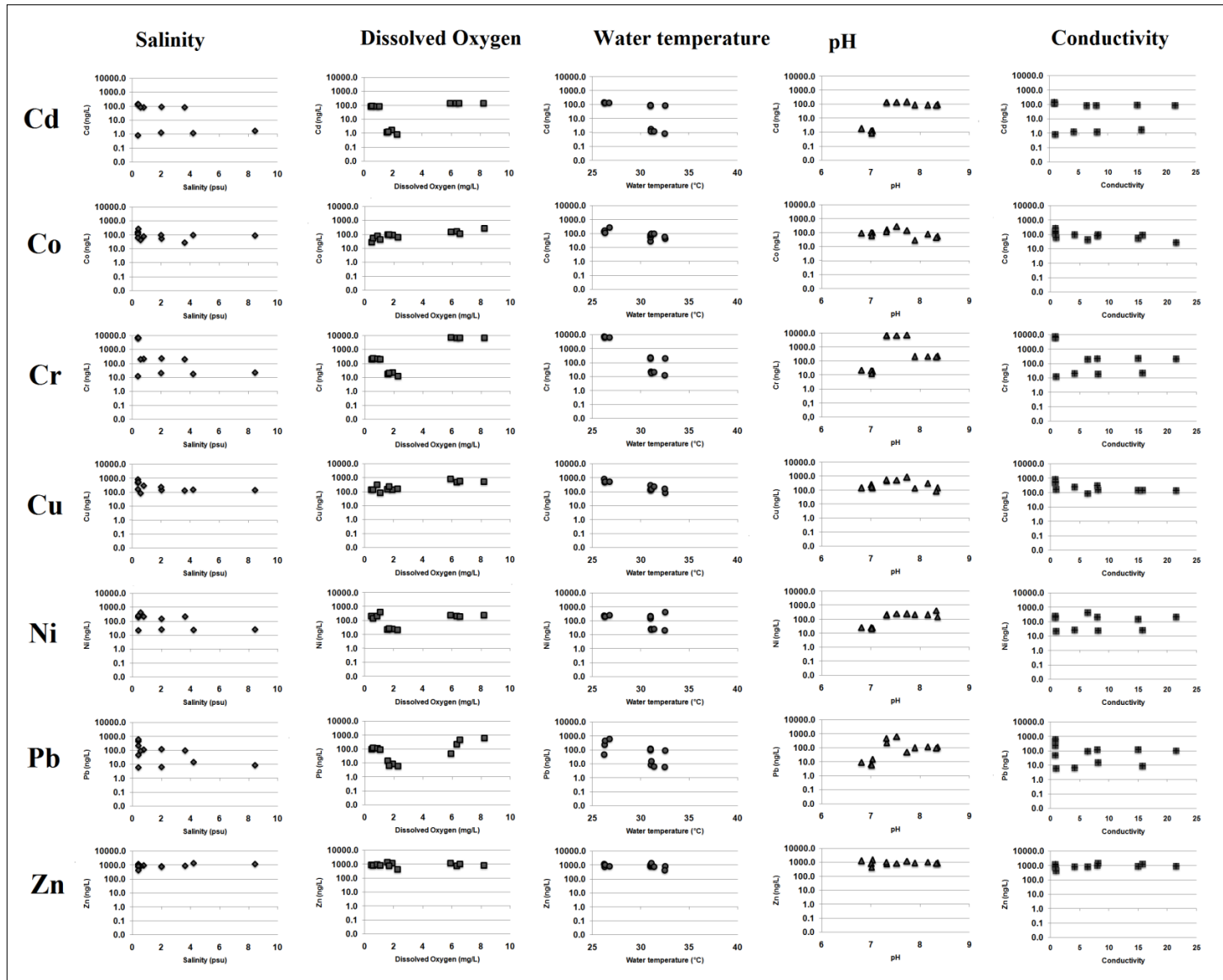
Fig. 3 Spatio-temporal variation of the trace metals among period



**1**– Period 1 Point 1      **9** – Period 3 Point 1      **5**– Period 2 Point 1  
**2**– Period 1 Point 2      **10**– Period 3 Point 2      **6**– Period 2 Point 2  
**3**– Period 1 Point 3      **11**– Period 3 Point 3      **7**– Period 2 Point 3  
**4**– Period 1 Point 4      **12**– Period 3 Point 4      **8**– Period 2 Point 4



**Fig. 4** Generated dendrogram. Numbers indicate sampling regime (Period) and points. a: all the Periods and b: Periods 1 and 3 (Legend is provided in the middle)



**Fig. 5** Relationship of the physico-chemical parameters to the labile trace metal concentrations

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