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1 **River water pollution in developed and developing countries:**
2 **Judge and assessment of physicochemical characteristics and**
3 **selected dissolved metal concentration**

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8 **Abbreviations:** DOC, dissolved organic carbon; TDS, total dissolved solids; COD,
9 chemical oxygen demand; PO_4^{3-} , phosphate; NO_2^- , Nitrite ion; NO_3^- , nitrate ion; Cl^- ,
10 chloride ion.

11

12 **Keywords:** Pollution, water quality, metals, developing and developed countries,
13 principal component analysis

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1 **ABSTRACT**

2 To compare water quality in rivers of developed and developing countries, a study
3 based on physicochemical parameters and dissolved metals levels was conducted. Water
4 samples were collected from selected sites in Dhaka, Bangladesh; Hokkaido and Osaka,
5 Japan; Erdenet, Mongolia and West Java, Indonesia. Analysis of least significant
6 differences revealed that most water quality parameters were within comparable low
7 levels in both developed and developing countries. The dissolved metals concentrations
8 were found to be similar and below those of water standards except for manganese and
9 cadmium at every sampling point, and lead in Erdenet, Mongolia. Some metals showed
10 high enrichment factors in the rivers of Osaka, Japan and Erdenet, Mongolia, indicating
11 accumulation possibility of metals in the river-bed sediments. High concentrations of
12 dissolved organic carbon, *Escherichia coli* and dissolved metals suggested greater water
13 pollution in some rivers of developing countries than in the rivers of Japan. Principal
14 component analysis showed strong correlations between “dissolved organic carbon
15 (DOC) and chemical oxygen demand (COD)” and “conductivity and total dissolved
16 solids (TDS)” at each sampling point, and *Escherichia coli*, nitrate (NO_3^-), nitrite (NO_2^-)
17 and pH levels were found to be higher in the rivers of Dhaka and Erdenet. In addition,
18 there were high levels of Al and Zn in West Java, Pb in Erdenet, and Mn, Fe and Cr in
19 the rivers of Dhaka and Japan. Based on pressures and impacts, it is evident that
20 dissolved metal, organic and fecal pollution in the rivers of developing countries are in
21 somewhat dreadful condition in comparison with the rivers of developed country.

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1. Introduction

A great variety of chemicals is present in water and sediment, which can easily become polluted as a result of rapid population growth; land development along river basins; urbanization; unplanned industrialization and impromptu agricultural operations in the rivers of both developed and developing countries [1]. Rivers are the main sources of both drinking water and irrigation for agriculture. They also play vital roles in transportation, maintaining soil fertility, the development of forest resources and conservation of wild life.

Most of the rivers in urban areas of developing countries are the end point of effluents discharged by industries [2]. Process industries such as tanneries, steel plants, battery producers, and thermal power plants, along with indiscriminate mining operations that discharge toxic metal-containing effluents, and fertilizers and pesticides, pose a severe threat to the environment by deteriorating water quality [3-6]. Toxic materials and metals are mostly disposed of in rivers in both developed and developing countries.

Industrialized countries have well implemented monitoring and remediation programs to reduce the environmental hazards and associated risks of industrial operations. On the other hand, there are few such programs in developing countries [7]. Tremendous amounts of organic compounds, metals and untreated sewage are discharged every day into the Buriganga, Shitalakshyaa, Turag and Bongshi rivers of Dhaka, Bangladesh. Domestic wastewater including human waste flows directly into the Ciliwung, Cisadane and Cikaniki rivers in Jakarta, Indonesia, and some accidental leakages of drinking water pipes into the sewerage system are everyday phenomena in

1 Dhaka, Bangladesh, resulting in severe health risks [8]. In Erdenet, Mongolia, the Tuul,
2 Hangol and Orkhon rivers are undergoing severe environmental deterioration due to
3 unregulated mining activities [9]. Even in Japan, a developed country, there is
4 degradation of water quality due to industrial activities, despite precautionary measures
5 taken before discharging the effluents into the rivers.

6 Assessments of general water quality and dissolved metals concentrations in aquatic
7 ecosystems have been extensively conducted [8, 10-14]: however, there are few
8 publications comparing the general water quality and metal pollution in developed and
9 developing countries [11]. The principal aims of the present study were to determine the
10 physicochemical characteristics and dissolved metal concentrations of rivers of
11 developing countries in comparison with those of developed countries and the standard
12 values recommended by the WHO [15].

13 **2. Materials and Methods**

14 **2.1. Study areas**

15 The Buriganga River, a tide-influenced river in Bangladesh flowing west and then south
16 of Dhaka, originates from the Dhaleshwari river near the Kalatia region. Its average
17 width and depth are 400 m and 10 m, respectively, and it is only 27 km long. The Turag
18 River joins the Buriganga River at Kamrangirchar in Dhaka. In fact, the main flow of
19 the Buriganga River comes from the Turag river. The Buriganga is one of the most
20 polluted rivers in Bangladesh. Most of the industries and factories in Dhaka are situated
21 on the banks of this river or very close to the river system. The Turag River, an upper
22 tributary of the Buriganga, originates from the Bangshi River, flows through the
23 Gazipur district and joins the Buriganga at Mirpur in Dhaka. The Shitalakshyaa River
24 links with the Buriganga on the northwestern side of the capital and is considered the

1 second most polluted river in Bangladesh (Fig. 1a).

2 The Shiribetsu River, considered one of the cleanest in Japan, originates from Lake
3 Shikotsu in Hokkaido. The river has a very narrow channel with a fast current and
4 passes through a mountainous area. The Ishikari River, the third longest river (268 km)
5 in Japan, originates from Mount Ishikari and flows through the cities of Ashahikawa and
6 Sapporo. The Dotonbori, Yodo and Aji rivers are considered the most economically
7 important rivers in Osaka, Japan. The problems of urbanization and industrialization are
8 well managed in all areas of Japan (Fig. 1b).

9 The Tuul, Hangol and Orkhon rivers provide most of the water for mining operations
10 in Erdenet, Mongolia (Fig. 1c). The Ciliwung, Cisadane and Cikaniki Rivers are
11 important rivers in West Java, where the capital city, Jakarta, is located (Fig. 1d).

12 Bangladesh is a low-lying, riverine country along the equator characterized by a
13 tropical monsoon climate. Indonesia is a tropical country, whereas Mongolia possesses a
14 continental climate. They are all developing countries with severe environmental threats
15 caused by the development activities. Hokkaido, Japan is in the cool temperate zone.
16 Osaka has a humid and temperate climate, and is the major industrial port and economic
17 center in the Kansai region of the main island of Honshu, Japan.

18

19 **2.2. Sample collection and preservation**

20 A total of 39 sampling sites, 9 in Dhaka, Bangladesh; 9 in Hokkaido and 3 in Osaka,
21 Japan; 8 in Erdenet, Mongolia; and 10 in West Java, Indonesia were chosen as shown in
22 Fig. 1. All sampling points had extensive industrial, mining and agricultural operations
23 with several point and non-point pollution sources, which were the main reason for the
24 selection of sampling sites (Table 1). It is evident that the pressures and impacts in the

1 rivers of developing countries due to the above mentioned activities are significantly
2 high in compare with the rivers of Japan. All sampling points along with the obtained
3 data were confirmed as representative data for each river and each region. In
4 Bangladesh, water was collected on December 27, 2010 from 4 rivers, the Buriganga,
5 Shitalakshyaa, Turag and Bongshi, surrounding the capital Dhaka, the fastest growing
6 industrial city in South Asia. These rivers are characterized by sluggish flow throughout
7 the year, except during the monsoon, when rainfall causes a manifold increase in the
8 runoff. In Hokkaido, water samples were collected from the Shiribetsu River on May 25,
9 2010 and from the Ishikari on June 28, 2010. In the Osaka area, water was obtained
10 from the Dotonbori, Aji and Yodo rivers on July 2, 2010. In Erdenet, water was
11 collected from the Tuul, Hangol and Orkhon rivers from July 18 to 23, 2010. In West
12 Java, water from the Ciliwung, Cisadane and Cikaniki rivers was collected from
13 September 8 to 15, 2007. Water samples were collected in sterilized containers with
14 caps (500 ml) by the method of the APHA-AWWA [16]. Briefly, each container was
15 washed carefully with river water to remove any contaminants in the bottle before
16 collecting water. The water samples were filtered using Millipore membrane filters
17 (OmniporeTM, Ireland) with 0.45 μ m pores and then stored in polystyrene bottles by
18 acidification with concentrated nitric acid (AR grade; 60-61% with a density of 1.38
19 kg/L) to pH < 2 for metal analysis. Sampling bottles were kept at 4°C.

20

21 **2.3. General water quality**

22 The physicochemical parameters (pH, conductivity, total dissolved solids [TDS],
23 temperature and salinity) of the samples were measured immediately at each sampling
24 point with a U-51 multiparameter water quality meter (HORIBA, Kyoto, Japan)

1 according to the instruction manual. The multiparameter water quality meter was
2 calibrated every time at each sampling point with two standard solutions of pH 4 and
3 pH 7. An ion selective pack test (Kyoritsu Chemical-check Lab, Corp, Tokyo, Japan)
4 was employed to measure chemical oxygen demand (COD), NO_2^- , NO_3^- , PO_4^{3-} and Cl^-
5 according to the instruction manual. The detection limits of the ion selective pack were
6 COD (2 mg/l), PO_4^{3-} (0.02 mg/l), Cl^- (0.1 mg/l), NO_2^- (0.02 mg/l), and NO_3^- (1 mg/l).
7 *Escherichia coli* (*E-coli*) were measured with simple detection paper (Shibata, Japan)
8 according to the instruction manual. Dissolved organic carbon (DOC) was measured
9 with a TOC analyzer (TOC-5000A, Shimadzu, Kyoto, Japan). For this procedure, 25 ml
10 of the filtrate was added to a 50 ml messflask and 5 ml of 0.1M HCl was mixed in.
11 Phthalic hydrogen potassium was used for TOC standard samples. Sodium carbonate
12 and sodium bicarbonate were used for inorganic carbon standard samples. The detection
13 limit of the TOC analyzer was 4 ppb.

14 Internal quality control was used in the measurement of the physicochemical
15 parameters and dissolved metals of the samples in each region. Analytical quality
16 control was assured by replicate analysis of samples. Three replicates of each sample
17 were prepared and their physicochemical parameters were analyzed simultaneously.

18

19 **2.4. Metal analysis**

20 For the dissolved metal analysis, river water samples were filtered using Millipore
21 membrane filters (OmniporeTM, Ireland) with 0.45 μm pores to remove the insoluble
22 materials followed by acid digestion with grade conc. HNO_3 for 1.5 h. The precise
23 concentration of HNO_3 was 60-61% with a density of 1.38 Kg/L. The pH of the samples
24 was measured to keep it below 2. The digested samples were transferred into a

1 volumetric flask to analyze metal ions with inductively coupled plasma–mass
2 spectrometry (ICP-MS, Seiko SPQ-6500, Tokyo, Japan), using the specific
3 measurement conditions for metals described by Hanada et al. [17]. This argon-based
4 method uses ICP as a highly efficient ion source. Most metals are ionized at 80 to 95%
5 efficiency and we used 1 ppb scandium (Sc), and indium (In) as internal standards. The
6 concentration of the target element can be determined from comparison with the target's
7 ion count and Sc or In ion count. This method was used due to the unavailability of
8 standard reference materials for the metals in water in every region [18]. The
9 concentrations of dissolved metals were detected at the ng/ml (ppb) level. The detection
10 limits of ICP-MS were Al (0.005 ng/ml), Mn (0.03 ng/ml), Fe (0.005 ng/ml), Cr (0.03
11 ng/ml), Zn (0.05 ng/ml), Cu (0.005 ng/ml), Cd (0.03 ng/ml), and Pb (0.005 ng/ml).
12 Standard solutions were prepared from 1,000 mg/l stock solutions of different metals of
13 interest (Wako Pure Chemicals Industries Ltd., Kyoto, Japan) by dilution with ultrapure
14 water. The glassware was washed with nitric acid followed by distilled water. All the
15 experiments were carried out in triplicate. The results were reproducible within an error
16 limit of $\pm 5\%$.

17

18 **2.5. Enrichment factor**

19 Contamination due to different metals was analyzed for the rivers of all sampling
20 regions according to the enrichment factor (EF). The EF (%) is usually used to
21 determine water and sediment chemistry in relation to natural and anthropogenic
22 pollution sources [19-21]. The EF was calculated using the following equation.

23

$$EF(\%) = \{(C - C_{\min}) / (C_{\max} - C_{\min})\} \times 100$$

1 where C refers to the mean concentration of dissolved metals in the water sample (ppb)
2 and C_{max} and C_{min} , refer to the maximum and minimum concentrations (range) in
3 (ppb), respectively, determined during the study.

4

5 **2.6. Statistical analysis**

6 To analyze differences among the sampling stations for different metal levels, one-way
7 ANOVA was applied followed by the student t-test to identify the type of the data sets.
8 Pearson's correlation matrix was also calculated for different metals to trace the
9 common sources of pollutants [20]. The significance level in this study was $P < 0.05$.
10 Multivariate principal components analysis (PCA) was used to determine and interpret
11 the variables of water quality and to measure the characteristic features of each region.
12 XLSTAT statistical analysis software (Addinsoft, version-2011.1) was used for PCA.

13

14 **3. Results and discussion**

15 **3.1. Physicochemical parameters**

16 The pH values were within the recommended range 6.5–8.5 indicated by WHO for the
17 sampling points in all countries except for S-3 in Dhaka and S-22 to S-28 in Erdenet.
18 The pH maintained by a well-buffered river can be attributed to the fact that, normally,
19 running water is influenced by the nature of the deposits over which the water flows
20 [22]. Water temperatures ranged from 20.6 to 27.7°C, which was in the temperature
21 range recommended by the WHO [15] except for the the rivers of Hokkaido, located in
22 the temperate zone. TDS is the common indicator of polluted water. TDS can be
23 estimated by dividing the conductivity value (in mS/ cm) by a factor of 1.56 [23]. The
24 measured TDS values ranged from 1180 to 1430 ppm in the water of Erdenet. These

1 values exceeded the maximum level (500 ppm) for drinking water due to waste
2 discharge by several mining companies [15]. In Dhaka, the Shitalakshyaa River (S-3)
3 had a high TDS value (1118), as this river is the recipient of thousands of point sources
4 of pollution and in confluence with the polluted Buriganga River. High conductivity
5 values ranged from 503-1672 $\mu\text{S}/\text{cm}$ in Dhaka, 199-2230 $\mu\text{S}/\text{cm}$ in Erdenet, 70-400
6 $\mu\text{S}/\text{cm}$ in West Java and 47-108.1 $\mu\text{S}/\text{cm}$ in the rivers of Hokkaido and Osaka,
7 indicating high ionic pollution in Dhaka and Erdenet as compared with the rivers of
8 Japan and the WHO guideline. In Hokkaido, the Ishikari River (S-14) had a
9 conductivity value of 1932, as this sampling point was just beside the Sea of Japan.

11 Samples had remarkable concentrations of nitrate ions (NO_3^-) in sampling points
12 except S-1 in Dhaka, Bangladesh and S-13 in Hokkaido, Japan. The NO_2^-
13 concentrations greatly exceeded the WHO guideline in Erdenet (5-16 ppm). Non-point
14 pollution sources such as agriculture and livestock may have contributed to the
15 increased NO_2^- and NO_3^- in the rivers of developing countries since Bangladesh and
16 Indonesia are agriculture-based countries and Mongolia is the world's most pasture and
17 livestock-based country. The increased NO_3^- levels in the rivers of Osaka and Hokkaido
18 also may be explained by the study of Kido et al. [8], who reported high levels of NO_2^-
19 and NO_3^- in the Tokyo area due to acid rain and exhaust gases. COD mainly accelerated
20 with the urban runoff carries household wastes and wastes from streets and sidewalks;
21 nutrients from fertilizers; leaves, grass clippings, and paper from residential areas,
22 which increase oxygen demand. Oxygen consumed by the aerobic biological organisms
23 in the decomposition process of organics, make gradual oxygen deficiency in the water
24 threatened the lives of other aquatic organisms. Surprisingly, the values for Cl^- ions and

1 COD were lower than the recommended WHO values (255 and 200 ppm for COD and
2 Cl^- , respectively) in the sampling areas of every region. The highest COD value of 120
3 ppm was recorded in the Shitalakshyaa River in Dhaka (S-3 and 4). In the Cu Lake of
4 Erdenet (S-22), and rivers of Hokkaido and Osaka (S-10 to 21), high levels of Cl^- were
5 found. Dissolved organic carbon (DOC) in aquatic ecosystems is one of the Earth's
6 largest actively cycled reservoirs of organic matter. The dissolved organic carbon
7 (DOC) and the soluble COD are parameters for the inert or persistent compounds in the
8 water, which cannot be eliminated easily. The DOC levels in this study were higher in
9 sampling areas except West Java, Indonesia (not determined) (Table 2). The main
10 source of DOC in these rivers is precipitation and leaching of industrial effluents and
11 decomposition of house hold waste water along with dead animals and plants primarily
12 in the form of dissolved fulvic and humic acids [24]. So, this study strongly
13 recommends developing and using easy and effective working treatment systems like
14 constructed wetlands.

15 All sampling locations, especially in the rivers of the developing countries, had
16 markedly high levels of phosphate as compared with the WHO guidelines (Table 2).
17 Phosphates generally enter water from phosphorus-rich bedrock and from human and
18 animal waste, including that from laundry, cleaning, industrial effluents, and fertilizer
19 runoff.

20 The results attained from the microbial study indicated that the microbial water
21 quality in the rivers of developing countries was not so good compared with the rivers
22 of Japan. Microbial pollution was widespread in maximum sampling points. However,
23 elevated level of *E-coli* was found in the rivers of Dhaka, Osaka and Erdenet. The rivers
24 of Dhaka and West Java are the major outlets of treated and untreated sewage waste and

1 industrial effluents. Mongolia is the livestock based country and the catchment of every
2 river is mostly the pasture land. Enormous amount of biological waste are mixing
3 everyday in the river water and therefore significant number of *E-coli* is present. The
4 presence of *E-coli* in water is a strong indication of recent sewage or animal waste
5 contamination. Coliform concentrations in this study were found amazingly higher in all
6 sampling areas except Shiribetsu River, Hokkaido, Japan (Table 2). The Shiribetsu
7 River is one of the cleanest rivers in Japan and also undergoes high level of purification
8 and expectedly the coliform level is satisfactory. These results indicated fecal pollution
9 caused by human activities and livestock, as domestic and agricultural waste as well as
10 human excreta were directly discharged into rivers. When these are used as sources of
11 drinking water and the water is not treated or inadequately treated, *E-coli* may end up in
12 drinking water and may cause severe health damage to the people. Moreover, these
13 pathogenic bacteria can survive for up to one year at temperatures from 4° to 25°C with
14 no loss of viability [25]. So, extensive care must be taken before discharging the
15 industrial, agricultural and household waste into the water. Moreover, effective
16 sewerage and drainage system should be established and maintained as soon as possible.
17 In this current scenario of fecal pollution, it can be highly recommended to arrange
18 alternative safe drinking water. Besides, there is some risk of infectivity of the food web
19 when vegetables are eaten raw [26]. Kido et al. [8] and Dallas [9] also reported severe
20 fecal pollution in rivers of Indonesia and Mongolia.

21 The general water quality of the rivers in both developed and developing countries
22 suggested that there was little pollution on the basis of the observed healthy
23 physicochemical status, although higher pollution was expected to be found in the rivers
24 of developing countries than those in Japan. The morphological attributes of rivers may

1 cause them to visually appear polluted, but in reality they undergo continual natural
2 remediation [27]. For example, dilution of contaminated river water by uncontaminated
3 water could be observed in the Buriganga River, Shitalakshyaa River and Turag River,
4 with the last one being relatively uncontaminated. The confluence of river water may
5 dilute the pollution level of the entire river system in Dhaka. Second, soil, sediment and
6 climatic variability may reduce the original concentrations of pollutants in these rivers
7 ([http://www.ecofriends.org/main/eganga/images/Critical%20analysis%20of%20GAP.p](http://www.ecofriends.org/main/eganga/images/Critical%20analysis%20of%20GAP.pdf)
8 [df](http://www.ecofriends.org/main/eganga/images/Critical%20analysis%20of%20GAP.pdf)).

9

10 **3.2. Metal ions**

11 The ranges of the dissolved metal concentrations, their means, standard errors, medians,
12 standard deviations, variances and confidence levels are given in Table 3.
13 Concentrations of Al, Mn, Cu, Zn and Cd in West Java, Fe in Dhaka, and Pb and Cr in
14 Erdenet were found as maximum levels depicting the overall metal pollution in the
15 rivers of developing countries. In contrast, dissolved metal levels were low in the rivers
16 of Hokkaido and Osaka, Japan. Mn in all sampling regions, Pb in Erdenet, and Cd in the
17 rivers of West Java exceeded the standard level recommended by the WHO [15].
18 Statistically significant differences were calculated among all sampling regions for Al
19 ($P < 0.001$ and $F-9.03 > F_{crit}-2.96$), Cu ($P < 0.001$ and $F-15.31 > F_{crit}-2.65$), Zn ($P < 0.001$
20 and $F-41.19 > F_{crit}-2.96$), Pb ($P < 0.001$ and $F-76.42 > F_{crit}-2.64$) and Cd ($P < 0.001$ and
21 $F-1947 > F_{crit}-2.64$). These results indicated the discrete metal status (source and
22 distribution) in both developed and developing countries, except for Mn, Fe and Cr,
23 which had common features. The pH value plays a key role for metal pollution and
24 higher pH keeps low concentration of dissolved metals especially in the rivers of Dhaka

1 and Erdenet. To determine the common sources of dissolved metals in the rivers of
2 Bangladesh and Japan, a correlation matrix was calculated for the metals in the water.
3 Table 4 shows significant correlations among Mn, Fe and Zn in the rivers of Bangladesh,
4 and among Al, Mn, Fe, Cd in the rivers of Japan. Cu and Cd in Bangladesh and Mn and
5 Fe in Japan showed close relationships with each other whereas Pb negatively correlated
6 with Cr. Alternatively, poor correlation was noted between Al and other metals in the
7 rivers of Bangladesh, suggesting that the attribute of Al contamination was different
8 from other metals. We do not have firm hypothesis of why that may happen. Correlation
9 of the metals in the same water body may be due to an interaction between the different
10 metals in the same water body in the same country. The sources of these metals may be
11 the industrial operations on the banks of rivers. Urban runoff could be a source of
12 metals for river water, especially in the rainy season, as all sampling regions had high
13 annual rainfall except for Erdenet, which has an extreme continental environment.

14

15 **3.2.1 Analysis of metal enrichment factors**

16 The EF% was calculated for different metals from all study sites to estimate both natural
17 and anthropogenic metal sources in relation to the tendency to accumulate in river
18 sediments. The analysis showed that the rivers in each region had identical EF (Al),
19 whereas EF (Mn), EF (Zn) and EF (Pb) were highest in the rivers of Osaka. The rivers
20 of Erdenet had the highest EF (Fe) and EF (Cr), whereas the maximum Cd and Cu
21 enrichment factors were 55.56 and 76.81 in Dhaka and West Java, respectively (Table
22 5). These results suggested the scale of particular dissolved metal pollution in the
23 regions having the maximum EF (%). Lower EF values indicate unpolluted river water.
24 These results suggested great accumulation of dissolved metals in river bed sediments,

1 presenting a further threat to the water quality since sediment pollution is an
2 important long-term marker for pollution [20]. Besides, high pH values stimulate
3 accumulation of dissolved metals in riverine sediments (geoaccumulation) [28]. The
4 rivers of Hokkaido in mountainous regions may pick up metals and these metals have
5 low possibility to deposit into the bottom sediment due to the rapid currents of these
6 rivers and ends up into the ocean and do not affect the surrounding environment.

7

8 **3.2.2 Principal component analysis**

9 PCA provided quick visualization and showed correlations among the initial water
10 quality variables (Fig. 2) [8]. To make the graph easily readable, a representative data
11 set was chosen. The first 4 sampling points in Dhaka (S-1 to 4), Hokkaido (S-10 to 13),
12 Erdenet (S-22 to 25) and West Java (S-30 to 33), and 3 sampling points in Osaka
13 (S-19-21) were selected for PCA. When two variables are far from the center and close
14 to each other, they are significantly positively correlated (r close to 1). If they are
15 orthogonal, they are not correlated (r close to 0). When they are on opposite sides of the
16 center, then they are significantly negatively correlated (r close to -1). Accordingly,
17 “DOC and COD” and “conductivity and TDS” were strongly correlated, and *E-coli*,
18 NO_3^- , NO_2^- and pH were weakly correlated with each other. The fact that fecal coliform
19 bacteria and DOC were not significantly correlated might be due to the different sources
20 from whence DOC originates. Only Cl^- correlated negatively with every other parameter,
21 and was present at high levels in the rivers of Japan, Mongolia and Bangladesh except
22 West Java (not determined). The levels of the remaining parameters were high in the
23 rivers of Dhaka and Erdenet (Fig. 2A and Table 2). Figure 2B shows that there were
24 high levels of Al and Zn in West Java, Pb in Erdenet, and Mn, Fe and Cr in the rivers of

1 Dhaka and Japan.

2

3 The major anthropogenic pollution was a big problem in the sampling water as some
4 rivers polluted with *Escherichia coli*, NO_3^- , NO_2^- , PO_4^{3-} , Mn, Pb and Cd from domestic
5 and industrial sources in developing countries. Therefore, the typical water chemistry
6 for all rivers may be considered to be a fairly good average for the respective country.
7 The mean metal concentrations in all rivers were generally lower than the estimated
8 world averages [15] and background concentrations except Cd in respect to
9 environmental health. None of the observed concentrations of others metal seemed to be
10 alarmingly high from a toxicological point of view. Also after filtration of the raw river
11 water, the dissolved cadmium exceeds in more than 50% of all investigated samples in
12 compare with the WHO guideline for drinking water quality excluding the sampling site
13 in Erdenet (Table 3). Cadmium is believed to enter into these rivers through the usage of
14 manures and pesticides in the agricultural land and largely from industrial by-product.
15 By entering into the food web through drinking water, Cd may severely damage the
16 immune system of humans and the bio-accumulation of Cd into the aquatic flora and
17 fauna may affect the whole aquatic ecosystem. So, steps should be taken to lower the
18 dissolved Cd concentration below the WHO guideline. Nearly all of the observed
19 elemental concentrations may be explainable by natural sources and processes. The
20 rivers of Hokkaido pass through areas with hot springs and other natural geologic
21 formations, receiving tremendous amounts of dissolved metals from nonanthropogenic
22 sources. No typical point of pollution was viewed during sampling of the Ishikari and
23 Shiribetsu Rivers in Hokkaido. In a similar manner, the rivers of Dhaka, West Java and
24 Erdenet have depositional characteristics and it is likely that most of the pollutants (e.g.

1 metals) were deposited in bottom sediments. It is believed that bottom sediments in
2 these areas would have elevated dissolved metal concentrations, so that some additional
3 sampling (i.e. river bottom sediments in the area) will be necessary to assess the extent
4 as well as the potential remobilization of this contamination [29, 30].

5 Organic carbon has a tendency to bind with some metals in rigid forms, and thus it's
6 content in water and consequently in sediment may influence the metal enrichment rates
7 of rivers [20]. It can be assumed that the metal accumulation in sediments is low in the
8 rivers of Japan as the DOC levels were comparatively low. On the other hand, high
9 DOC levels in the rivers of Erdenet and Dhaka may indicate high metal accumulation in
10 river sediments. Kido et al. [8] reported that the water bodies of Indonesia have high
11 levels of organic substances and agricultural chemicals as compared with those in Japan
12 because sewage is less treated in Indonesia. The same can also be assumed for the rivers
13 of Dhaka and Erdenet as they have inadequate sewage treatment facilities. Low pH may
14 increase the solubility of metals both in water and sediments of rivers [31], whereas
15 high pH may result in the reduction of metals toxicity [32]. At the maximum sampling
16 points in this study with high pH the metals might precipitate into their insoluble higher
17 oxides, hydroxides and carbonates, resulting in lower concentrations of metals in the
18 river water of developing countries. Similar results were also reported by Wasim et al.
19 [33] in their study investigating the metal levels in the Ganges River in India. The levels
20 of dissolved metals in both developing and developed countries were, in most cases,
21 below the permissible limits for irrigation and drinking recommended by the EU [34].
22 In this respect, the metal levels were not a matter of concern.

23

24

1 **4. Conclusion**

2 This study was designed to determine whether there was a significant difference of
3 pollution between developed and developing countries. From the results, it is concluded
4 that the overall situation of the pollution in the rivers of all sampling countries is still
5 under the threshold limit. West Java, Indonesia seems to have high pollution as
6 compared with Dhaka, Bangladesh and Erdenet, Mongolia, whereas no significant
7 difference in the pollution level was observed between the rivers of Hokkaido and
8 Osaka, Japan and the rivers of the developing countries. The dissolved metal levels did
9 not exceed the international background values, though there were some exceptions in
10 West Java and Erdenet. However, the high enrichment factors also suggest elevated
11 accumulation of metals in riverbed sediments. The general water quality met the
12 international standard in all regions. This may be explained by geochemical factors,
13 geographical and geological influences and natural reclamation abilities in each region.
14 However, fecal pollution was found at almost all points in the developing countries and
15 at a few in Japan. Such fecal pollution indicates the urgent need for sewage treatment
16 plants, drainage systems and monitoring criteria, especially in developing countries. The
17 pressures and impacts on the rivers of developing countries due to high population
18 density and industrial and agricultural activities exert organic, inorganic and microbial
19 pollution to a higher level. Whereas, low pressures and impacts along with the
20 sustainable water quality management keep harmless the water bodies of developed
21 country. So, this study suggests proper implications of water quality management in the
22 developed countries. Further synoptic monitoring study is required to trace the direct
23 sources of pollution along with seasonal variations and temporal effects in
24 contamination and to develop a global river quality database to better compare data in

1 developed/developing countries. Additionally, identification of metal sources is required
2 to trap particulate metals at or close to the source in order to protect water uses and
3 ecosystem in the downstream.

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14
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Table 1. Catchment characteristics of the major rivers studied^a.

River	Length (km)	Population density (km ²)	Wastewater purification level	Industrial activity	Mining activity	Land use (% agricultural)	Natural weathering processes	Catchment area (km ²)
Developed country								
Ishikari (Hokkaido, Japan)	268	5730	High	Little	Little	8	High	14330
Shiribetsu (Hokkaido, Japan)	126	12	High	Little	Little	13	High	1640
Yodo (Osaka, Japan)	75	335	High	High	Little	9	Slight	21340
Developing countries								
Buriganga (Bangladesh)	27	23029	Low	High	Little	46	Slight	253
Shitalakshyaa (Bangladesh)	110	2815	Low	High	Little	41	Slight	-
Tuul (Mongolia)	704	235	Low	High	High	1	High	49840
Orkhon (Mongolia)	1124	10	Low	High	High	2	High	11 860
Ciliwung (Indonesia)	97	8584	Medium	High	Medium	48	High	476
Cisadane (Indonesia)	137	4039	Medium	High	Medium	49	High	1366

^aOnly the representative rivers of each region,- = Not known.

Table 2. General water quality in the samples of river water from Dhaka, Bangladesh and Hokkaido and Osaka, Japan.

Sample number	Sampling point	pH	Temp. (°C)	Conductivity (µS/cm)	COD (mg/l)	Cl ⁻ (mg/l)	NO ₂ ⁻ (mg/l)	NO ₃ ⁻ (mg/l)	PO ₄ ³⁻ (mg/l)	Salinity (mg/l)	TDS (mg/l)	<i>E-coli</i> (CFU ³ /ml)	DOC (mg/l)
Dhaka, urban area of Bangladesh.													
1	Buriganga 1	7.3	20.7	620	40	55	0.2	0.2	2	296	440	216	9
2	Buriganga 2	7.3	21.5	619	40	60	0.02	1	1.5	299	440	360	8
3	Shitalakshyaa 1	9	26.4	1672	120	70	0.1	1	2	838	1118	180	33
4	Shitalakshyaa 2	7.2	23.9	503	120	65	0.02	1	0.15	244	357	180	51
5	Turagh 1	7.4	21.8	566	25	5	0.1	2	1.5	274	402	220	9
6	Turagh 2	7.5	21.3	593	45	10	0.1	1	2	284	419	340	5
7	Bongshi 1	7.6	20.8	605	40	8	0.03	1	1	292	429	120	5
8	Bongshi 2	7.9	20.6	632	45	10	0.02	1	1.45	305	448	276	7
9	Bongshi 3	6.8	21.2	545	20	12	0.02	5	0.5	261	384	0	2
Hokkaido, rural area of Japan													
10	Ishikari 1	7.6	16.1	47	2	110	0.01	2	0	30	34.2	9	2.3
11	Ishikari 2	7.6	21.7	59.5	7	110	0.01	1	0.2	25.5	70	44	3.2
12	Ishikari 3	7.6	21.5	80	8	110	0.01	1	0.05	93.5	66.5	11	1
13	Ishikari 4	7.4	21.4	108.1	7	110	0.02	0.2	0	54.5	77.7	34	2.5
14	Ishikari 5	7.3	22.8	1932	8	200	0.02	2	0.02	980	137	15	1.6
15	Shiribetsu 1	6.6	7.9	47.1	7	-	0.01	1	0.1	21.6	33.5	0	1.7
16	Shiribetsu 2	7.2	8.3	63.5	6	-	0.01	1	0.1	28.6	45.1	0	2.2
17	Shiribetsu 3	7.5	6.5	103	6	-	0.01	1	0.1	21	73	0	1.8
18	Shiribetsu 4	7.5	6.8	37.5	4	-	0.01	1	0.1	17	26.7	0	2
Osaka, urban area of Japan													
19	Dotonbori	7.1	25.5	281	11	100	0.3	2	0.3	136	199	240	1.5
20	Aji	7.2	26.4	258	8	100	0.2	10	0.5	125	183	170	3.1
21	Yodo	7.7	26.8	240	8	100	0.03	1.5	0.35	117	170	91	5
WHO standard ^b		6.5-8.5	20-30	250	255	200	0.5	0.45	0.01	-	500	0	-

Sample number	Sampling point	pH	Temp. (°C)	Conductivity (µS/cm)	COD (mg/l)	Cl ⁻ (mg/l)	NO ₂ ⁻ (mg/l)	NO ₃ ⁻ (mg/l)	PO ₄ ³⁻ (mg/l)	Salinity (mg/l)	TDS (mg/l)	<i>E-coli</i> CFU ^a /ml	DOC (mg/l)
Erdenet, mining area in Mongolia													
22	Cu lake 1	9.9	26.5	1860	120	50	16	20	0.1	-	1180	-	33.4
23	Cu lake 2	10	25	2190	50	50	5	15	0.1	-	1400	384	26.8
24	Cu lake 3	10.1	22.9	2230	30	50	5	10	0.5	-	1430	-	17.8
25	Cu lake 4	9.4	27.7	1930	50	20	16	1	1.5	-	1230	-	26.7
26	Tuul river	8.1	23.1	308	15	10	16	0.5	0.05	-	200	57	8.8
27	Hangol 1	7.9	21.8	1010	30	50	10	10	0.1	-	693	552	14.5
28	Hangol 2	8	24.9	1010	30	50	16	5	0.1	-	647	36	13.5
29	Orkhon	7.7	24.9	199	30	20	10	2	1.5	-	130	240	23
West Java, urban area in Indonesia													
30	Ciliwung 1	7.6	-	70	-	-	0.01	1	0.	-	-	26	-
31	Ciliwung 2	7.4	-	140	-	-	0.02	2	0.2	-	-	24	-
32	Ciliwung 3	7.2	-	230	-	-	1	45	0.7	-	-	56	-
33	Ciliwung 4	6.9	-	230	-	-	0.5	20	0.7	-	-	98	-
34	Cisadane 1	7.3	-	400	-	-	0.05	1	2	-	-	126	-
35	Cisadane 2	7.7	-	340	-	-	0.02	1	2	-	-	144	-
36	Cisadane 3	7.2	-	70	-	-	0.02	1	0.1	-	-	52	-
37	Cisadane 4	7.4	-	110	-	-	0.3	15	0.2	-	-	60	-
38	Cikaniki 1	7.7	-	130	-	-	0.15	3	0.2	-	-	67	-
39	Cikaniki 2	7.4	-	110	-	-	0.05	2	0.2	-	-	90	-
WHO standard^b		6.5-8.5	20-30	250	255	200	0.5	0.45	0.01	-	500	0	-

^aCFU= Colony forming unit, ^bWHO = World Health Organization, - =No data, n.d. = Not detected.

1 **Table 3.** Metal concentration in river water samples collected from different regions.

	Al (ng/ml)	Mn (ng/ml)	Fe (ng/ml)	Cu (ng/ml)	Zn (ng/ml)	Pb (ng/ml)	Cd (ng/ml)	Cr (ng/ml)
Dhaka								
Mean	6.85	31.2 ^b	42.1	14.7	1.94	4.11	4.67 ^b	23.3
Median	5.84	1.09	16.9	10.7	2.00	4.00	5.00	20
SD	3.39	39.9	75.4	14.8	1.70	0.78	0.87	13.4
Variance	11.4	1599	5688.8	219	2.88	0.61	0.75	181.2
Range	2.49-14.6	0-98.4	10.31-24	3.09-51.5	0.15-5.67	3.00-5	3-6	0-50
CL	2.60	30.7	57.9	11.3	1.31	0.60	0.67	10.3
Hokkaido								
Mean	23.1	11.1 ^b	33.9	9.67	7.74	2.69	4.89 ^b	13.8
Median	22.8	10.7	26.2	9.56	7.53	2.24	5.00	10
SD	16.2	0.81	28.0	0.32	0.57	1.13	0.78	6.51
Variance	264.0	0.66	787	0.10	0.32	1.28	0.61	42.3
Range	4.03-55	10.2-13.9	11.7-105.7	9.31-10.4	7.20-8.8	2.19-5.6	4-6	10-25
CL	12.4	0.63	21.56	0.25	0.44	0.87	0.60	5
Osaka								
Mean	8.54	10.9 ^b	18.83	10.8	11.2	2.34	4 ^d	15
Median	5.39	10.9	17.01	10.6	11.8	2.31	4	15
SD	6.79	0.14	4.51	0.35	2.71	0.10	1	5
Variance	46.1	0.02	20.34	0.12	7.33	0.01	1	25
Range	3.90-16.3	10.8-11	15.52-23.9	10.5-11.2	8.34-13.6	2.26-2.4	3-5	10-20
CL	16.8	0.34	11.2	0.87	6.73	0.26	2.48	12.4
Erdenet								
Mean	-	-	16.2	10.8	-	39.6 ^b	n.d.	27.5
Median	-	-	20	11	-	38	n.d.	35
SD ^c	-	-	10.6	4.55	-	11.1	n.d.	24.9
Variance	-	-	112.5	20.7	-	124.2	n.d.	621.4
Range	-	-	0-30	1.00-16	-	27-60	n.d.	0-50
CL	-	-	8.87	3.80	-	9.32	n.d.	20.8
West Java								
Mean	44.2	108.4 ^b	-	37.5	42.0	6.91	23.5 ^b	-
Median	29.8	32.7	-	37.9	35	6.62	23.4	-
SD	23.9	161.2	-	1.77	14.7	0.51	0.30	-
Variance	572.6	26001.5	-	3.12	218.4	0.27	0.09	-
Range	24.4-83.5	32.3-457	-	32.7-39	31.7-75.8	6.4-7.79	23.2-24.2	-
CL	17.1	115.3	-	1.26	10.5	0.37	0.22	-
WHO^a	50	10	50	2000	3000	10	3	50

2 ^aWorld Health Organization (2011), SD =Standard deviation, CL= Confidence Level, ^bExceeds maximum
3 permissible limit, - = No data, n.d. = Not detected

1

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Table 4. Correlation analysis of metals at all sampling points in Bangladesh and Japan.

	Al	Mn	Fe	Cu	Zn	Pb	Cd	Cr
Bangladesh								
Al	1	0.056	0.158	0.471	0.269	0.338	0.260	0.235
Mn		1	0.682	0.319	0.555	0.400	0.399	-0.180
Fe			1	-0.008	0.264	0.425	0.192	-0.075
Cu				1	-0.035	0.021	0.595	0.246
Zn					1	0.160	-0.218	-0.047
Pb						1	0.062	-0.574
Cd							1	0.214
Cr								1
Japan								
Al	1	0.686	0.888	-0.376	-0.491	-0.224	0.620	0.023
Mn		1	0.903	0.124	-0.052	-0.114	0.327	-0.056
Fe			1	-0.175	-0.273	-0.156	0.576	0.035
Cu				1	0.621	-0.011	-0.427	-0.166
Zn					1	0.049	-0.275	0.181
Pb						1	0.054	-0.282
Cd							1	-0.057
Cr								1

3

4

^aValues in boldface are different from 0 with a significance level of alpha = 0.05

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Table 5. Metal enrichment factors (%) in all sampling areas.

Area	EF (Al)	EF (Mn)	EF (Fe)	EF (Cu)	EF (Zn)	EF (Pb)	EF (Cd)	EF (Cr)
Dhaka	35.98	31.72	13.73	23.98	32.39	37.04	55.56	46.67
Hokkaido	37.42	29.09	23.66	31.47	33.68	14.50	44.44	25.93
Osaka	37.33	51.85	39.21	37.50	55.16	41.67	50.00	50.00
Erdenet	- ^a	- ^a	54.17	65.83	- ^a	38.26	- ^a	55.00
West Java	33.55	17.89	-	76.81	23.42	35.11	29.60	- ^a

3

^aNo data

4

Figure Legends

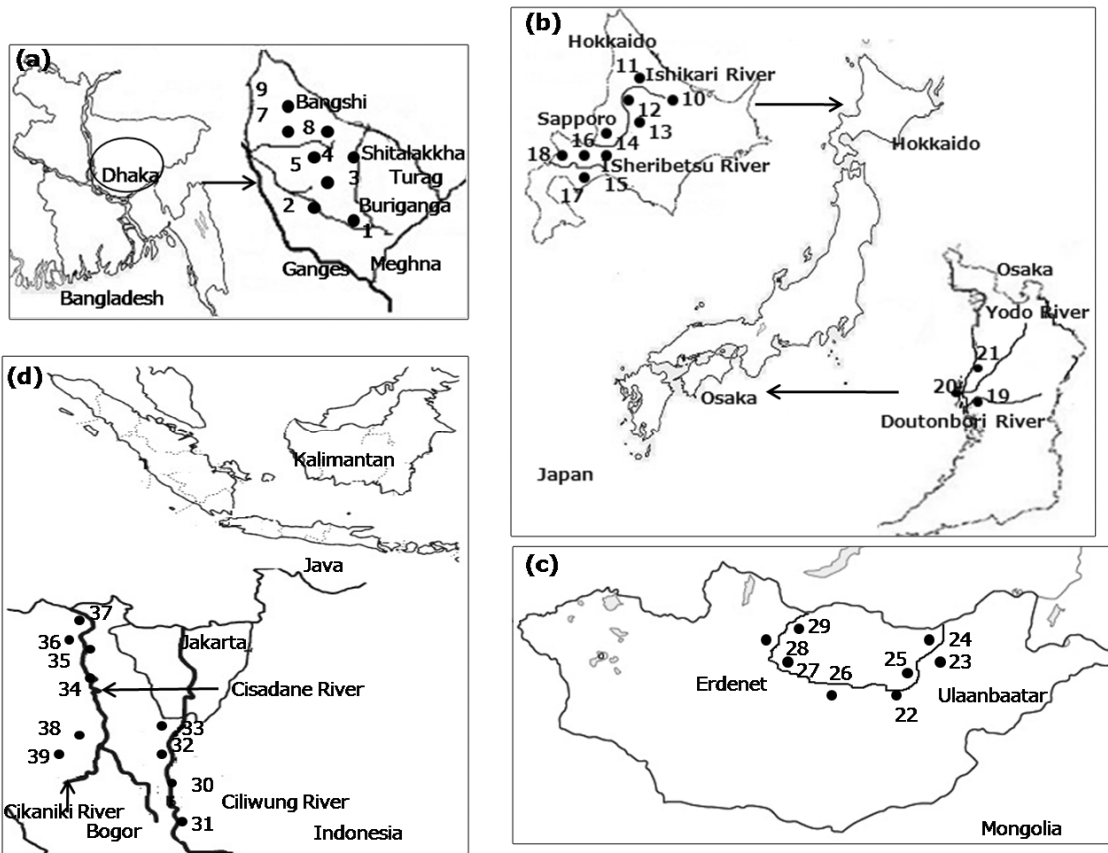
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4 **Figure 1.** Sampling points in Dhaka, Bangladesh (1 to 9) (a); Hokkaido and Osaka,
5 Japan (10 to 21) (b); Erdenet, Mongolia (22 to 29) (c) and West Java, Indonesia (30-39)
6 (d).

7

8 **Figure 2.** PCA to project general water quality (a) and metals (b) in river water from
9 Dhaka (Bangladesh), Hokkaido and Osaka (Japan), Erdenet (Mongolia) and West Java
10 (Indonesia) in a biplot frame. The circle represents each location of observations for two
11 principal factors, F1(X axis) and F2 (Y axis), and the vector sign shows the loading of
12 the original variable on the computed factor.

13



1 Fig. 1

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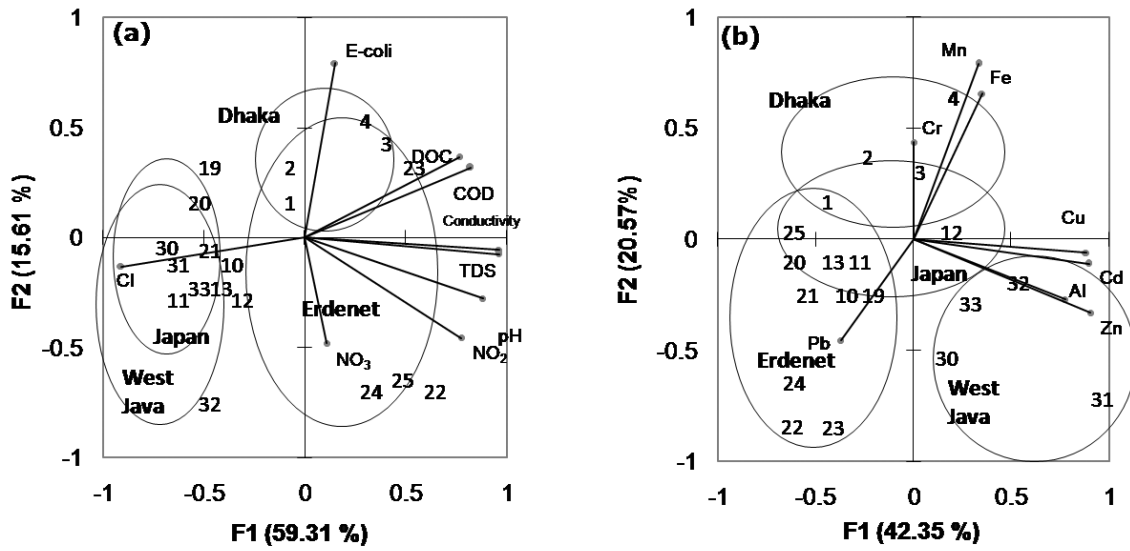
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2 Fig. 2

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