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

Md. Tajuddin Sikder[1], Yusuke Kihara[1], Masaomi Yasuda[1], Yustiawati[1], Yoshihiro Mihara[2], Shunitz Tanaka[3], Dalkhjav Odgerel[4], Badamtsetseg Mijiddorj[4], Suhaemi M. Syawal[5], Toshiyuki Hosokawa[6], Takeshi Saito[7], Masaaki Kurasaki[3*]

[1]Environmental Adaptation Science, Division of Environmental Science Development, Graduate School of Environmental Science, Hokkaido University, 060-0810, Sapporo, Japan

[2]Biomaterals Chemistry, Division of Environmental Materials Science, Graduate School of Environmental Science, Hokkaido University, 060-0810, Sapporo, Japan

[3]Group of Environmental Adaptation Science, Faculty of Environmental Earth Science, Hokkaido University, 060-0810, Sapporo, Japan

[4]Professional Inspection Agency of City, Ulaanbaatar, Mongolia

[5]RC for Limnology, Indonesian Institute for Sciences, Indonesia

[6]Higher Education Research and Development, Division Institute for the Advancement of Higher Education, Hokkaido University, 060-0817, Sapporo, Japan.

[7]Environmental Health Sciences, Faculty of Health Sciences, Hokkaido University, 060-0812, Sapporo, Japan

* Correspondence: Dr. Masaaki Kurasaki, Group of Environmental Adaptation Science, Faculty of Environmental Earth Science, Hokkaido University. Kita 10, Nishi 5, Kita-ku, Sapporo 060-0810, Japan.

Tel: +81-11-706-2243; fax: +81-11-706-4864

E-mail: kura@ees.hokudai.ac.jp

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

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

ABSTRACT

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

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

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

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

2. Materials and Methods

2.1. Study areas

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

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

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

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

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

2.2. Sample collection and preservation

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

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

2.3. General water quality

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

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

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

2.4. Metal analysis

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

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

2.5. Enrichment factor

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

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

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

2.6. Statistical analysis

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

3. Results and discussion

3.1. Physicochemical parameters

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

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

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

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

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

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

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

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

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

3.2. Metal ions

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

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

3.2.1 Analysis of metal enrichment factors

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

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

3.2.2 Principal component analysis

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

Dhaka and Japan.

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

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

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

4. Conclusion

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

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

Acknowledgements

The research was supported by Grants-in-Aid from the Japan Society for the Promotion (JSPS) of Science (No. 18404004 and No. 23406021 for Kurasaki) and the JSPS-UGC Joint Research Project for FY between Bangladesh and Japan for Tanaka. The authors are grateful to Mr. Kim Barrymore for his careful English editing. The authors are grateful to Ms. Sun Yongkun, Mr. Tanvir Hossain and Ms. Nahid Akter for their kind assistance and support during sampling in Japan and Bangladesh. We are also grateful to the Erdenet Mining Corporation (EMC) for assistance in sampling and the Professional Inspection Agency of the City of Ulanbaatar for assistance in analysis of metals in Mongolia.

The authors have declared no conflict of interest.

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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

[a]Only 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)	*E-coli* (CFU[a]/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)	*E-coli* 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	-

[a]CFU= Colony forming unit, [b]WHO = World Health Organization, - =No data, n.d. = Not detected.

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

[a]World Health Organization (2011), SD =Standard deviation, CL= Confidence Level, [b]Exceeds maximum permissible limit, - = No data, n.d. = Not detected

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

[a]Values in boldface are different from 0 with a significance level of alpha = 0.05

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]

[a]No data

Figure Legends

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

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

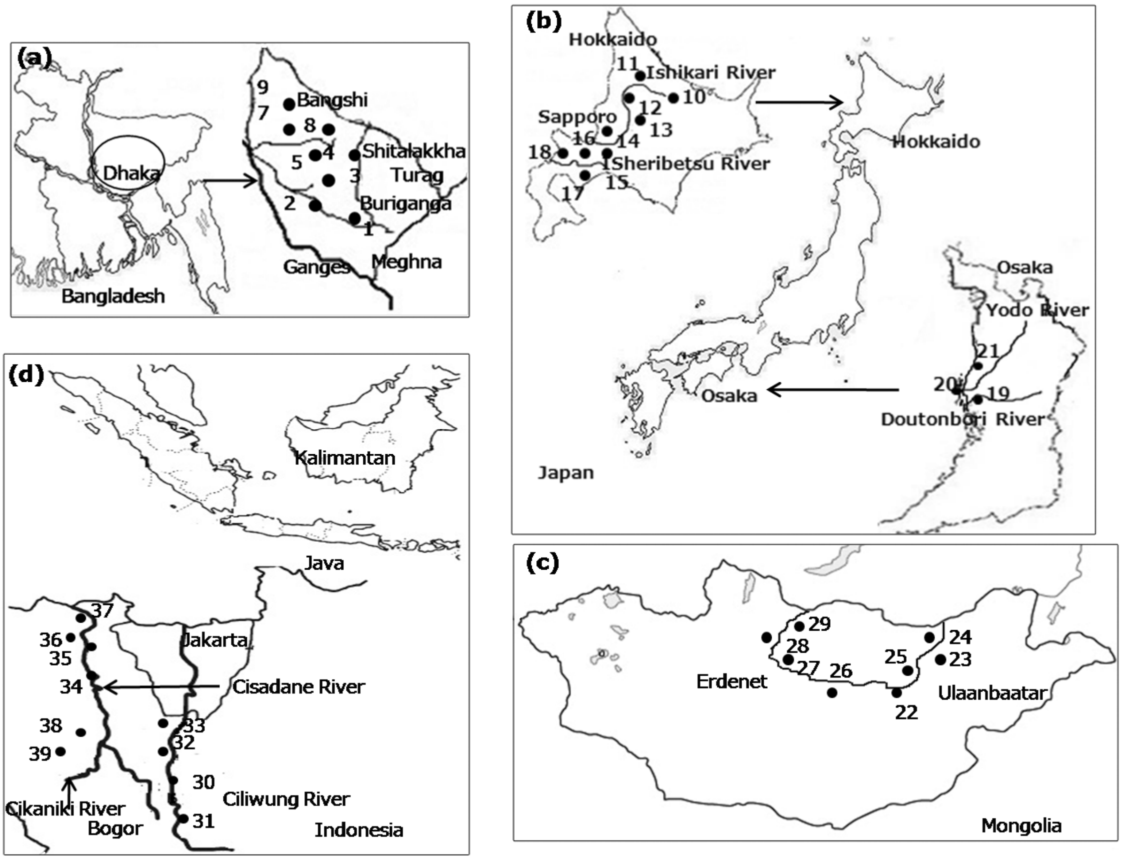
(a)
Dhaka
Bangladesh
Bangshi
Shitalakkha
Turag
Buriganga
Ganges
Meghna
(b)
Hokkaido
Ishikari River
Sapporo
Sheribetsu River
Hokkaido
Osaka
Yodo River
Doutonbori River
Osaka
Japan
(c)
Erdenet
Ulaanbaatar
Mongolia
(d)
Kalimantan
Java
Jakarta
Cisadane River
Cikaniki River
Bogor
Ciliwung River
Indonesia

Fig. 1

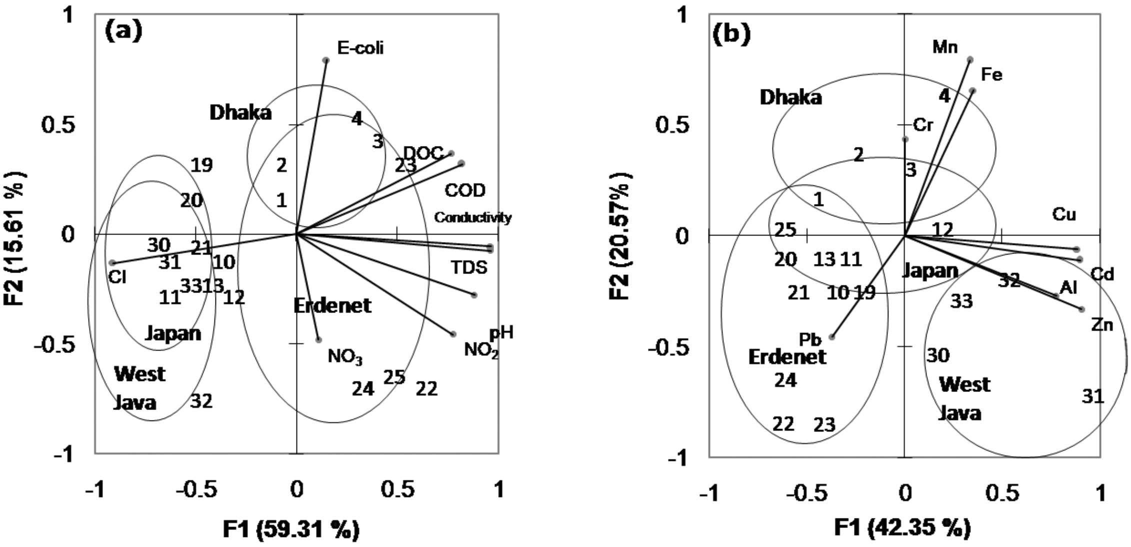
(a)
E-coli
Dhaka
4
3
DOC
23
2
COD
1
Conductivity
19
20
30
21
31
10
Cl
33
13
12
11
Japan
TDS
Erdenet
pH
NO_2
NO_3
West
Java
32
25
24
22
F2 (15.61 %)
F1 (59.31 %)
(b)
Mn
Fe
Dhaka
4
Cr
2
3
1
Cu
25
12
20
13
11
Japan
Cd
32
Al
21
10
19
33
Zn
Pb
Erdenet
30
24
West
Java
31
22
23
F2 (20.57%)
F1 (42.35 %)

Fig. 2