Quantitative comparison of forests and other areas with dry weather input loading in the Lake Biwa catchment area

S. Fujii*, H. Tanaka** and I. Somiya*

* Dep. of Environmental Engineering, Graduate School of Engineering, Kyoto University, Yoshida-honmachi, Saky-ku, Kyoto, 606–8501, Japan
** MKK Co. Ltd., Nisshoiwai Building 2–5–8, Imabashi, Chuo-ku, Osaka 541–0042, Japan

Abstract

For the evaluation of pollutants loading to Lake Biwa, comprehensive river surveys on river mouths and forest sites were conducted 9 times from 1996 to 1999, on 25–40 main rivers in the Lake Biwa watershed. The main results obtained are as follows. (1) River water quality reflects regional characteristics of their catchment areas, and the concentration difference among rivers ranged between 2–3 fold. (2) Concentration variation shows different patterns with time and location depending on water quality indices used. (3) Indices related to organic matter and nutrients have lower correlation between forests and river mouths, but those related to ionic species showed strong correlation. (4) Flux comparison of forest and river mouth sites suggests that pollutants from catchment areas are conveyed to the lake not only through rivers but also underground. (5) In dry weather conditions, forests contribute 30% to the whole pollutants (TN, TP, and TCODMn) loading, and the remainder is derived mainly from paddy fields and residential/commercial zones. (6) Unit loading factors from forests are estimated as 640, 57 and 1200 kg/km²/y, respectively for TN, TP and TCODMn, while those from other areas are estimated as 2,500, 208 and 4,200 kg/km²/y.

Keywords

Dry weather; forests; Lake Biwa; nutrients loading; regional properties; river mouths; unit loading factor

Introduction

Lake Biwa is the largest lake in Japan in terms of the volume (27.5 km³) and surface area (674 km²), and works as a reservoir for more than 14 million people. The importance of the lake has been always emphasized, but its quality has deteriorated in recent decades due to population increase and industrial development around the lake (Nomura et al., 1993). Since the deterioration is mainly followed by cultural eutrophication, the control of input nutrients (N and P) loading must be the most effective and fundamental measure to conserve the lake water quality. However, the control is not easy, because various kinds of non-point sources are related to the input loading, and their pollutants reach the lake through many rivers in its whole watershed (3,848 km², including its surface area, Water resources agency, 1993). For example, Masuda (2000) showed that the Lake Biwa watershed consists of 111 river basins and 94 shore zones. In his estimation, even the biggest river (Yasu-River) basin only occupies 12% of the whole watershed (excluding the lake surface). Thus, we recognize that a comprehensive survey is required to understand the input loading to the lake, which may suggest to us the most effective control measure.

The objectives of this study are to understand the pollutants loading characteristics in the Lake Biwa watershed through comprehensive river surveys, and to discover unit loading factors for main pollutants in dry weather conditions. Since the majority of the watershed consists of forests (73.4%, Ichiki et al., 1996), forests are the key sources for input pollutants loading even though their pollutant concentrations are usually low. Therefore, we conducted river surveys at many forest sites as well as at river mouths.
Materials and methods
Lake Biwa river surveys were conducted 9 times from 1996 to 1999, on 25–40 main rivers that occupy 75–85% of the whole lake watershed. Table 1 summarizes the dates and sampling points for these surveys. In Surveys I-V, water samples were collected only at river mouth sites to evaluate whole pollutants loading in each river basin. On the other hand, samples were collected at forest sites in Surveys VI and VII to evaluate the contribution of forests, the majority of land use. In the remaining two surveys of VIII and IX, sampling was simultaneously conducted at a river mouth site and a forest site(s) in each river basin, to quantitatively compare forests and other areas on input loading. In the surveys except VI and VIII, all water samples were collected within one or two days (practically 10 or 34 hours) so that each sampling point might receive similar meteorological influences such as temperature and rainfall. In Surveys VI and VIII, three to fifteen water samples were collected in a day, and such collection was repeated six times (VI) or three times (VIII).

In each river basin, a downstream point near to the lake, but without any influence of the lake water was appointed as its river mouth sampling site, while an upstream point having only forests in its catchment area was selected as the forest sampling site. Figure 1 gives the location of the sampling points in the Lake Biwa watershed, and catchment areas of upstream sites.

At each point, a water sample was collected and used for the measurement of more than 50 water quality items related to organic matter, nutrients, ions and elements. In the filtrated sample, anion species such as Cl\(^-\) and SO\(_4^{2-}\) were measured with ion-chromatography (Dionex DX-AQ), and metal elements such as Na\(^+\), Ca\(^{2+}\) and Si were analyzed with the ICP (Seiko SPS-4000). TOC, DOC and IC (inorganic carbon) were measured by a TOC analyzer (Shimadzu TOC-5000), and the others were analyzed following the Standard Methods (1995). In addition, flow rates at sampling points were measured in surveys VI to IX.

Results and discussion
Regional characteristics of river quality
The results of river surveys were summarized as median concentrations of main water quality indices. Figure 2 shows these values and their regional variations. Median values of nutrient concentrations (including both forests and river mouths) were 0.70 mg/L for TN and 0.060 mg/L for TP. These values seem to be low for river quality, but they are still 3 times higher for TN and 6 times higher for TP, compared with the administrative goal values determined for Lake Biwa (Okada et al., 2000).

Concentrations varied with river basins and stream sites, but had some similarity within

<table>
<thead>
<tr>
<th>No.</th>
<th>Date</th>
<th>No. of sampling points</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Aug. 26, 1996</td>
<td>30 (River mouths)</td>
</tr>
<tr>
<td>II</td>
<td>Apr. 2, 1997</td>
<td>40 (River mouths)</td>
</tr>
<tr>
<td>III</td>
<td>Jun. 24, 1997</td>
<td>40 (River mouths)</td>
</tr>
<tr>
<td>IV</td>
<td>Oct. 7, 1997</td>
<td>40 (River mouths)</td>
</tr>
<tr>
<td>V</td>
<td>Jan. 15, 1998</td>
<td>40 (River mouths)</td>
</tr>
<tr>
<td>VI</td>
<td>Jun.–Aug., 1998*</td>
<td>30 (Forests)</td>
</tr>
<tr>
<td>VII</td>
<td>1998.10. 5–6</td>
<td>28 (Forests)</td>
</tr>
<tr>
<td>VIII</td>
<td>Aug., 1999**</td>
<td>25 (R. mouths) .27 (Forests)</td>
</tr>
<tr>
<td>IX</td>
<td>Oct. 4–5 1999</td>
<td>27 (R. mouths) .27 (Forests)</td>
</tr>
</tbody>
</table>

* different 8 days in the period
** different 3 days in the period
neighboring sites. Fujii and Somiya et al. (2001) proposed that the Lake Biwa watershed should be divided into four regions of WS (western south), WN (western north), NE (Northern east) and ES (Eastern South) on the basis of a cluster analysis of river water quality variations. The range of these regions is given in Figure 1 and regional properties of their basins (corresponding to the downstream sites) are shown in Figure 3. Information on upstream sites can be found in our previous study (Fujii et al., 2001). ES is a narrow area sandwiched between the lake and mountains, and mainly consists of forests, containing a small area of residential zones. The region is relatively developed, and 80% of residents receive public sewerage service. WN is a mountainous area and has a low population density of 1.3 ca/ha. NE and ES rural areas have a high percentage of paddy fields. In both regions, a high percentage of household wastewater is discharged directly into many streams.

Such regional characteristics may influence water quality in their rivers. As shown in Figure 2, concentrations in forests corresponded to 50–80 percent of medians in all the data, and had less differences among the four regions. Relatively large differences were observed in Ca$^{2+}$ and SS. Ca$^{2+}$ concentrations may be related to bedrock types, while SS may be affected by stream conditions such as gradient. On the other hand, water quality in river mouths exhibited obvious regional characteristics. In WS and WN, most of the concentrations were increased about 1.5 times on the journeys from forests to river mouths, while these were increased 3–5 times in NE and ES. This means water quality changes in rivers highly depend on the strength of human activities downstream. These influences were seen in many water quality indices, but the causes of them might not be the same. For example, increase of household wastewater may raise the chloride ion concentration, but
increase of nitrogen and phosphorus may be more related to agricultural activities. The above results suggest that river water quality upstream is affected by natural conditions, but downstream it is affected by human activities. To confirm this idea, the regression analysis was conducted between water quality concentrations and regional properties. In the case of forest sites, their concentrations were compared with natural conditions such as bedrock types and average gradient of the catchment area, while for river mouths, their concentrations were compared with social statistics such as land use properties and population density. Figure 4 shows some examples, producing relatively high correlation coefficient values, where each sampling point makes one plot on the graphs, and its concentration is given with a median value of all the surveys.

In the case of forest sites high correlation values were mainly found in ionic species except for River Yano where golf links occupy 20% area. Ca$^{2+}$ concentration seems to be related to bedrock types, and higher values were observed in forests containing limestone or volcanic basic rock. Limestone is made of CaCO$_3$, while volcanic basic rock contains plagioclase that is made of NaAlSi$_3$O$_8$ and CaAl$_2$Si$_2$O$_8$ (Nagakura et al., 1998). In consequence, high linearity was observed between Ca$^{2+}$ concentration and a function of \( G_1 \) (limestone %) + 0.2 \( G_2 \) (volcanic basic rock %). In the case of nitrate, many different types of bedrocks seem to be related to its concentrations. Then, the multivariate regression analysis was applied to the nitrate with bedrock types. As a result, four kinds of rocks were selected as statistically meaningful predictor variables with a statistical risk level less than
These were sandstone, limestone, volcanic basic rock and clay slate. Kunimatsu et al. (2000) insisted that main nitrate sources for forest streams would be sedimentary rocks, and our results supported their opinion to some extent.

In the case of river mouths, water quality indices related to nutrients and organic matter had relatively high correlation coefficient values with statistics on regional properties. Statistics expressing human activities such as population density and land use percentage for paddy fields, had positive correlation with these indices in general, while those related to natural conditions such as percentage of forests, had negative correlation with the indices. This may suggest nutrients and organic matter are mainly derived from agriculture, and human daily life, although the influence of the latter source can be reduced with the spread of public sewerage services, as shown in low concentrations in WS region.

**Figure 4** Effects of regional properties on river water quality at river mouths and forest discharges. \(G_1, G_2, G_3, G_4\): area percent (%) of bed-rock types for limestone \(G_1\), volcanic basic rock \(G_2\), sandstone \(G_3\) and clay slate \(G_4\). \(R\): correlation coefficient value, \(R^*\): \(R\) calculated without R. Yano’s data (where golflinks are 20% of area), $: Population density for people who do not treat (directly discharge) their household wastewater

0.5%. These were sandstone, limestone, volcanic basic rock and clay slate. Kunimatsu et al. (2000) insisted that main nitrate sources for forest streams would be sedimentary rocks, and our results supported their opinion to some extent.

In the case of river mouths, water quality indices related to nutrients and organic matter had relatively high correlation coefficient values with statistics on regional properties. Statistics expressing human activities such as population density and land use percentage for paddy fields, had positive correlation with these indices in general, while those related to natural conditions such as percentage of forests, had negative correlation with the indices. This may suggest nutrients and organic matter are mainly derived from agriculture, and human daily life, although the influence of the latter source can be reduced with the spread of public sewerage services, as shown in low concentrations in WS region.

**Relationship between forest streams and river mouths, and their temporal variation characteristics**

The next analysis focuses on the relationship of water quality between upstream (forests) and downstream (river mouths). Then data from Surveys XIII and IX were used to express the concentration relationship between river mouths and forest sites in each river basin on the same day. The results are shown in Figure 5 (a) as scatter graphs, giving the effects of sampling sites. In Figure 5 (b), the effects of sampling date for forests streams and river mouths were analyzed by comparing two different surveys conducted in the same season. In this analysis, Surveys IV and IX were used for river mouths, and Surveys VII and IX were used for forest rivers.

The relationships of both effects showed many different patterns with various water quality indices, and seemed to be related to their main sources. In the case of nitrate, the relationship between forests and river mouths was weak in terms of correlation coefficient values, but its forest concentration gave the minimum level of its mouth water. This means forest nitrate makes the base of river quality, and additional increase is brought with human activities downstream. Forest nitrate concentration was temporally stable, although each river had its own concentration level. On the other hand, river mouth nitrate concentration was not so stable probably due to gaps between river flow rate change and nitrate loading from its sources. Ca\(^{2+}\) showed a similar variation pattern.

An opposite pattern was observed for the chloride ion. Chloride concentrations were temporally changeable in forest streams, but stable at river mouths. Correlation between forests and river mouths was hardly seen even in the simultaneous survey (IX). This means that downstream activities almost determine chloride concentration, and their effects are relatively stable with time. Organic indices made intermediate patterns between chloride
Figure 5  Concentration comparison for two surveys. (Values in parentheses indicate correlation coefficients.)
(a) Effects of sampling sites  (b) Effects of sampling dates
(X: R. mouths, Y: forests)  (X:1997(mouths) or 1998 (forests), Y:1999)
and nitrate, as shown in CODMn. Silica (Si) was quite unique from the other indices. This element had high correlation coefficient values for both forests and mouths, but its concentration levels were greatly changed day by day. For Si, a relationship was also observed between upstream and downstream. This may be interpreted by an idea that the Si discharge amount is regionally determined, but flow rate change makes its concentration variable. In the case of specific flow rate (= flow rate/catchment area), no relationship was observed spatially as well as temporally.

The three-way layout method, a statistical technique by ANOVA was introduced to quantitatively evaluate effects of river basin, stream site and date on concentration variations. Water quality data measured in Surveys XIII and IX were used for this analysis to make a matrix-type dataset of 25 (rivers) * 2 sites (forest and river mouth) * 2 (times). In the three-way layout, a concentration of $i^{th}$ river at $j^{th}$ site on $k^{th}$ day, $X_{ijk}$ is modeled with the following equation:

$$X_{ijk} = X_0 + a_i + b_j + c_k + (ab)_{ij} + (bc)_{jk} + (ca)_{ki} + e_{ijk}$$

Where $X_0$: average level of $X_{ijk}$; $a_i$, $b_j$, $c_k$: parameters for main effects concerning $i^{th}$ river, $j^{th}$ site and $k^{th}$ day, respectively; $(ab)_{ij}$, $(bc)_{jk}$ and $(ca)_{ki}$: parameters for interactions of their combinations; $e_{ijk}$: residual part of variation that these parameter values cannot explain.

ANOVA is a technique to statistically evaluate the influence of each factor (main effect and interaction) on the variation, and can give its contribution percentage. As shown in Figure 6, the contribution percentage was quite different among water quality indices. In the case of phosphate, nitrate and TN, effects of river, stream site and their combination were obviously high and the sum of their contributions exceeded 80%. This means concentrations of these indices are mainly determined with the sampling site, and are less influenced temporally. On the other hand, in the case of TOC, TP and specific flow rate, the other effects including residual variation were rather higher.

Comparison of loading rates between forests and the other areas

Since water samples of each river basin were simultaneously collected at upstream and downstream sites in Surveys VIII and IX, the effect of forests on the whole loading to Lake Biwa can be estimated quantitatively. In each river basin, its whole loading was calculated with a product of flow rate and concentration measured at the river mouth, while its forest loading was obtained from forest loading at the observed site multiplied by the ratio of observed forest area to whole forest area in the basin.

![Figure 6: Contribution proportion of each factor (3-way layout ANOVA)](https://iwaponline.com/wst/article-pdf/45/9/183/425714/183.pdf)
As shown in Figure 7, forest loading exceeds whole loading in many river basins. However, the contribution of forests was reported as 40% by Shiga local government, and 34% by Kunimatsu (Somiya, 2000). The reported values were based on pollutants production, while this study was based on river flux observation. We need to check how the pollutants reach Lake Biwa. Then flow rates at forests and river mouths were compared.

As shown in Figure 8, specific flow rates at forest ranged widely, but as an average rate they were scattering around 5 mm/d. Figure 9 illustrates yearly precipitation during 1997–1999 at meteorological stations around Lake Biwa (JAM, 1997–1999). As shown in this figure, yearly precipitation ranges from 1,500 to 2,500 mm/y (= 4 to 7 mm/d). Thus, we can conclude most of the rainwater in forests is discharged through river streams. On the other hand, specific flow rates at river mouths were at a lower level, ranging around 1–2 mm/d. In the Lake Biwa watershed, many rivers have thick and high riverbeds (these rivers are “ceiling rivers”), and convey their water to the lake not only in surface flows, but also in subterranean streams through their riverbed. In these rivers, surface streams may not
reflect actual flow rates, but underestimate them. Low specific flow rates in Figure 8 may indicate it.

Figure 8 also points out that the daily variation of flow rate is quite high, and shows that short-term loading does not express representative loading from the rivers. To overcome these difficulties, flow rates were evaluated with a mass-balance calculation. Jinnai (1988) estimated 67% of rainfall reaches the lake as river water or groundwater in the Lake Biwa watershed although 37% is lost with evaporation or transpiration. Then we assumed each region (WS, WN, NE and ES) receives rainfall with an average of precipitation values observed at meteorological observation stations in the region, and that 67% makes river streams, and reaches the lake. The concentrations observed at forest sites of each region were averaged for evaluation of forest areas, while those at river mouths were used for the whole loading. Finally, the loading rates (kg/y) were calculated with the products of rainfall (mm/y), discharge coefficient (= 0.67), area (km²) * concentration (g/m³).

Figure 10 shows the proportions of each region’s loading. In terms of area and flow rate, WN is the biggest region and occupies 38% and 43%, respectively. However, WN only contributed 25–31% of pollutants loading because of its high percentage of forest area. On the other hand, NE and ES had a high contribution to the pollutants loading especially from the land use other than forests. The other land use area (agriculture and residential zone) in NE and ES was 26% of the flow rate, but 48, 55, 59, 59, 47 and 65%, respectively for nitrate, TP, phosphate, TN, TCODMn and chloride loading.

As the last analysis, unit loading factors in dry weather conditions were obtained with the division of pollutants loading by area. As shown in Table 2, unit loading factors from
forests were one quarter to half of those from the other land uses except for chloride. Factors from forests were estimated to be 640, 57 and 1,200 kg/km²/yr, respectively for TN, TP and TCODMn, while those from other land uses were estimated to be 2,500, 208 and 4,200 kg/km²/yr. From Figure 10 and Table 2, we can learn that the effects of forests on the lake pollution are relatively low, but they are not at a negligible level. For the further control of the lake conservation, forests would also be one of the important targets.

Conclusions
Based on comprehensive surveys at river mouths and forest sites, pollutants loading characteristics in the Lake Biwa watershed were discussed. The main conclusions obtained in this study are as follows.
1. River water quality reflects regional characteristics of their catchment areas, and the concentration difference among rivers ranged between 2–3 fold.
2. Concentration variation shows different patterns with time and location depending on water quality indices used.
3. Indices related to organic matter and nutrients have lower correlation between forests and river mouths, but those related to ionic species showed strong correlation.
4. Flux comparison of forest and river mouth sites suggests that pollutants from catchment areas are conveyed to the lake not only through rivers but also underground.
5. In dry weather conditions, forests contribute about 30% to the whole pollutants (TN,

Figure 10  Contribution percentage of each region to input loading to Lake Biwa

Table 2  Unit loading factors for main pollution indices (kg/km²/yr)

<table>
<thead>
<tr>
<th></th>
<th>Forests</th>
<th>Others*</th>
</tr>
</thead>
<tbody>
<tr>
<td>TN</td>
<td>640</td>
<td>2,500</td>
</tr>
<tr>
<td>NO₃⁻-N</td>
<td>450</td>
<td>980</td>
</tr>
<tr>
<td>TP</td>
<td>57</td>
<td>208</td>
</tr>
<tr>
<td>PO₄³⁻-P</td>
<td>12</td>
<td>81</td>
</tr>
<tr>
<td>TCODMn</td>
<td>1,200</td>
<td>4,200</td>
</tr>
<tr>
<td>TN</td>
<td>1,900</td>
<td>6,900</td>
</tr>
<tr>
<td>CI</td>
<td>5,100</td>
<td>32,900</td>
</tr>
</tbody>
</table>

* mainly paddy fields and residential areas
TP, and TCOD\textsubscript{Mn} loading, and the remainder is derived mainly from paddy fields and residential/commercial zones.

6. Unit loading factors from forests are estimated to be 640, 57 and 1,200 kg/km\textsuperscript{2}/y, respectively for TN, TP and TCOD\textsubscript{Mn}, while those from other land use areas are estimated to be 2,500, 208 and 4200 kg/km\textsuperscript{2}/y.

References