Classifying Water Quality of Wando and Tamari According to the Characterization of H_2O Stable Isotope and Ionized Type in the Middle and Lower Kiso River*

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Abstract. *Wando* and *tamari* are water bodies in the floodplain of a river and play an important role in maintaining valuable ecosystems. There are over 100 wando and tamari in the middle and lower basin of the Kiso River. An *Acheilognathus longipinnis,* Itasenpara Bitterling, which is designated as an endangered species, has been identified in these areas. The habitat of these valuable wando and tamari species is endangered by the development of large land plants around these reservoirs caused by river dredging for flood protection. Therefore, it is essential to collect detailed data about the habitat, hydraulic water flow, physical structures and landscape in order to preserve this species, but so far little attention has been given to water quality. The purpose of our research was to classify the water quality of wando and tamari water, especially ions, and to determine the water type based on its origin. Samples were collected at 10 wando sites and 15 tamari sites from August 2011 to February 2013 along the Kiso River. As our analysis by trilinear diagram shows, the waters of wando and tamari almost all belong to the category of Type I (Ca-HCO_3), which forms in shallow aquifers. The two reservoirs that do not belong to Type I are presumably contaminated by drainage water from human activities.

Keywords: *hexa-diagram; ions; stable isotope; trilinear diagram; wando and tamari.*

1 Introduction

Floodplains, which are flooded when water levels in a river are high, are an important biodiversity landscape element for the habitat of freshwater organisms [1]. Wando and tamari are reservoirs existing in the floodplain beside a main river. Each reservoir has a different connecting frequency with the main river determined by hydrological phenomena. Many species of organisms that

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inhabit these areas are in danger of extinction [2] and it is imperative that the preservation and recovery of these are undertaken.

There are over 100 wando and tamari in the middle and lower basin of the Kiso River, which runs from a central highland area (the highest elevation of the catchment is 3,067 m) to the Pacific Ocean through the Chubu region, the central part of Japan. In this area, *Acheilognathus longipinnis*, Itasenpara Bitterling, which is designated as an endangered species, has been identified. The wando and tamari habitats have been reduced by the development of large land plants around these reservoirs caused by river dredging for flood protection. Mori, *et al*. [3] did not find the existence of Itasenpara Bitterling in wando and tamari along the Kiso River in 1998. However, Sagawa, *et al*. [4] reported that they found the existence of this species in 15% of 105 wando and tamari reservoirs in the area. Judging from these previous researches, this species does not exist continuously and it is a rare occasion to find them.

Investigations of the mussel and fish [5,6] and the physical structure of the river landscape, with the purpose to identify the annual ecological cycle of Itasenpara Bittering, have been carried out as part of a flood plain research in the middle and lower Kiso River. Takatsu, *et al*. [7] proposed that the environment is the total system affected by three main factors, i.e. physical structures, water quality and biota, which strongly interact with each other. Therefore, continuous water quality investigation and clarifying water quality formation processes are necessary to devise the preservation and recovery of the habitat of Itasenpara Bitterling. Matsumoto, *et al*. [8] have elucidated the levels of concentration of dissolved organic carbon (DOC) in each reservoir and the grouping of the DOC fluctuations throughout the year. They classified the reservoirs as having a higher or lower DOC concentration by taking samples once every two months. Spring water supply reservoirs that contain a higher DOC concentration and reservoirs with a lower DOC concentration are supplied by the Kiso river water, as analyzed by the H_2O stable isotope technique (δD and $\delta^{18}O$). The fluctuation of DOC concentration in each reservoir can fall into four groups. In two of these groups the fluctuation of DOC concentration is strongly related to water depth. This relationship indicates that the hydrological factor is affected by the fluctuation of the DOC concentrations in wando and tamari.

In the next step of this research, our purpose was to classify the water quality, especially ions, of wando and tamari and to determine the water type based on its origin. In a previous study, the characteristics of the DOC concentrations were classified by water type based on its origin: river water or spring water. Accordingly, we also used the stable isotopes of water to categorize the characteristics of the ions.

2 Investigation and Sampling Methods

2.1 Survey Area

This Investigation started in June 2011. We took water samples from wando and tamari in the middle and lower Kiso River, which are located between 39 km to 27 km from the river mouth. Wando are connected to the Kiso River and river water circulates inside of them continuously. Tamari are connected with the Kiso River only when the water level rises due to heavy rainfall and not when the water level of the river is low.

We investigated 10 wando and 15 tamari. We devided the investigation area into seven regions, A to G, along 12 km. There were more than two reservoirs in each area and we sampled both the right and left side of the river (Table 1). We sampled water from the reservoirs once every 2 months from August 2011 to February 2013. In choosing the water-sampling days we avoided days following heavy rain that caused flooding of the river. Each sampling reservoir was given a designation in the form of a capital letter, representing the region (A-G); a number, the reservoir's number within each region; and another capital letter, indicating reservoir type (tamari or wando), respectively. For example, region A, number 3, reservoir type Tamari was named A3-T.

Table 1 Region distribution of investing area.

Region	Right or Left Bank Distance from River Mouth (km)	Number of Reservoirs	
		Wando	Tamari
A	Left, 39.0 to 41.0	0	2
B	Left, 37.0 to 39.0	2	7
C	Left, 33.0 to 35.0	2	0
D	Left, 31.0 to 33.0	0	3
E	Right, 28.0 to 30.0	2	0
F	Right, 33.0 to 36.0	2	3
G	Right, 27.0 to 30.0	2	0

2.2 Water Quality Analysis

We sampled 1,000 ml of water from each reservoir for an ion analysis and 20 ml for a stable isotope analysis using plastic bottles. Samples were preserved in a cooling bag from the field to the laboratory and put in the refrigerator immediately. Samples were filtered through a 45 μm glass fiber filter and ions were analyzed by suppressed ion chromatography using a Dionex Chromatograph at Toyohashi University of Technology. The analyzed ions were, anions: Cl^-, NO_2^-, NO_3^-, SO_4^{2-} and cations: Na^+, K^+, Mg^{2+}, Ca^{2+}, NH_4^+. Bicarbonate (HCO_3^-) was calculated by the difference of total cations and total anions. We analyzed a total of 265 samples that were collected from August 2011 to February 2013.

In addition, we analyzed the hydrogen stable isotope (δD) and the oxygen stable isotope ($\delta^{18}O$) of the water. After collecting the samples, we preserved them in the dark and at room air temperature before analysis. We analyzed a total of 73 samples that were collected from June 2011 to October 2011 for δD and $\delta^{18}O$ by PICARRO WS-CRDS-based Analyzer at ICRE, University of Yamanashi.

3 Results and Discussion

3.1 Water Source of Wando and Tamari

The values of δD and $\delta^{18}O$ reflect phase transition, evaporation, and water freezing phenomena. This means that these values are affected by the history of meteorological and hydrological processes. Thus, estimating the δD and $\delta^{18}O$ of wando and tamari provides information about the origin of the water contained in a reservoir.

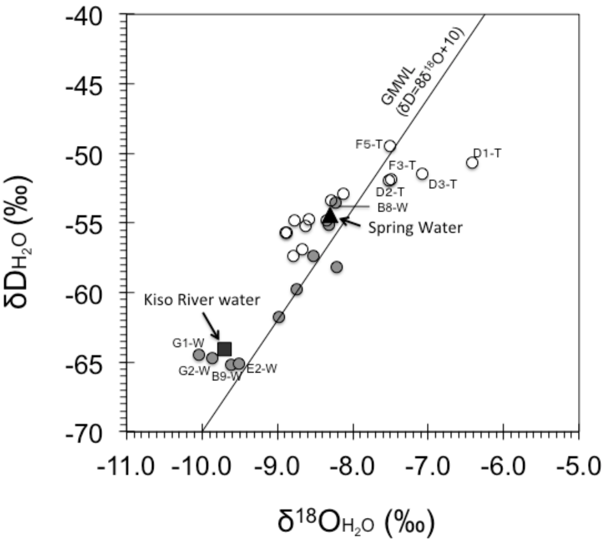

Figure 1 Relationship between δD and $\delta^{18}O$ for each reservoir ●Wando, ○ Tamari.

Matsumoto, *et al.* [8] calculated the average and standard deviation of δD and $\delta^{18}O$ for each reservoir. Figure 1 shows the values of δD and $\delta^{18}O$ of wando and tamari and the meteoric water line, $\delta D = 8\delta^{18}O + 10$. The values were -64.1‰ and -9.7‰ of δD and $\delta^{18}O$ for Kiso River water and -54.4‰ and -8.3‰ of δD and $\delta^{18}O$ for spring water that emerges from underground in Region B. Four samples belonged to the category of the River Group, coming from wando nearby the Kiso River (B9-W, E2-W, G1-W, and G2-W), as can be seen in Figure 1. Thirteen samples of wando and tamari belonged to the category of the Spring Group, coming from nearby springs. Four samples (C1-W, C2-W, E1-W and F1-W) belonged to the category of the Middle Group, being a mix of Kiso River water and spring water. Most water samples from wando, tamari, springs and river were arranged along the meteoric water line, but some samples from tamari (D1-T, D2-T, D3-T and F3-T) were plotted underneath this line, as can be seen in Figure 1. These samples were defined to belong to the category of the Evaporation Group.

3.2 Grouping of Ions by Trilinear Diagram

Figure 2 shows a trilinear diagram with the average ion values for each reservoir. Trilinear diagrams are normally used for the water quality formation processes of groundwater [9], but we used it for the analysis of the characteristics of the water quality.

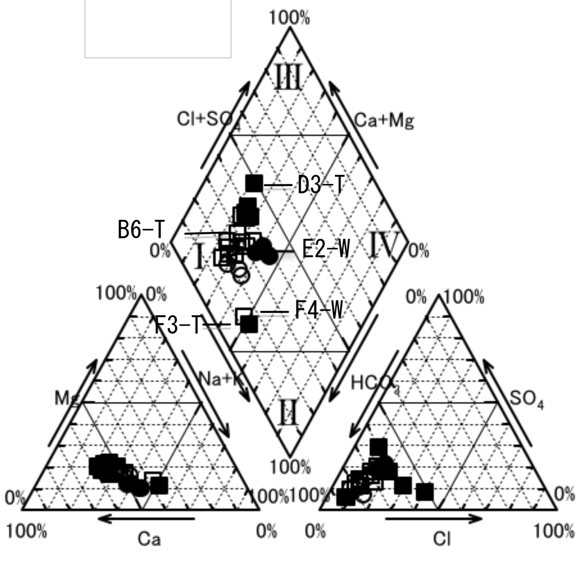

Figure 2 Trilinear diagram of each reservoir. □ : Spring Group, ● : River Group, ■ : Evap. Group, ○ : Middle Group.

Firstly, Type I is characterized as Ca-HCO_3 type; most Japanese circulating groundwater belongs to this type. 22 reservoirs were grouped into this type, regardless of being wando or tamari. The samples categorized as River Group, Spring Group or Middle Group were included in this type.

Then, D3-T was classified as Between Type I (Ca-HCO_3 type) and Type III (Ca-SO_4 or Ca-Cl type). Type III is characterized as a stable groundwater, which means that the water flows deeper underground or through a limestone area. Only D3-T, belonging to the Evaporation Group, was included in this type.

Finally, F3-T and F4-W were classified as Between Type I (Ca-HCO_3 type) and Type II (Na-HCO_3 type). Type II is characterized as contaminated hot spring water or industrial drainage water. F3-T, belonging to the Evaporation Group, and F4-W, belonging to the Spring Group, were included in this type.

3.3 Ions Characteristic of Each Water Quality Type

Figure 3 shows hexa-diagrams of typical examples of the reservoirs that were classified by trilinear diagram.

The diagram of Type I forms a nearly regular hexagon, with larger amounts of Ca^{2+} and HCO_3^- and smaller amounts of other ions. However, the size of the diagram differs between reservoirs. Concentrations of each water quality index in 11 reservoirs (A1-T, A2-T, B5-T, B6-T, B7-T, B8-W, C1-W, C2-W, F1-W, F2-T and F5-T) were larger and spread wider. On the other hand, the same concentrations in E2-W, G1-W, G2-W, B3-T, B4-T, B9-W were smaller and shrunken. The size of the diagram reflects the amount of ion content. Hence, a larger diagram size means many ions and a smaller size means fewer ions. Four wandos of six reservoirs had a smaller diagram. Conversely, seven tamaris of 11 reservoirs had a larger diagram.

As for the characteristics of Between Type I and Type III, the concentration of Cl^- in the reservoir was larger than that of Type I. The diagram of this type was medium-sized.

As for the characteristics of Between Type I and Type II, the concentrations of Na+K and HCO_3^- in these reservoirs were larger than those of Type I. Especially in K the concentration was larger than in the other reservoirs. This means that the water was contaminated by human activities [10]. The diagram size of this type was larger than that of the other types.

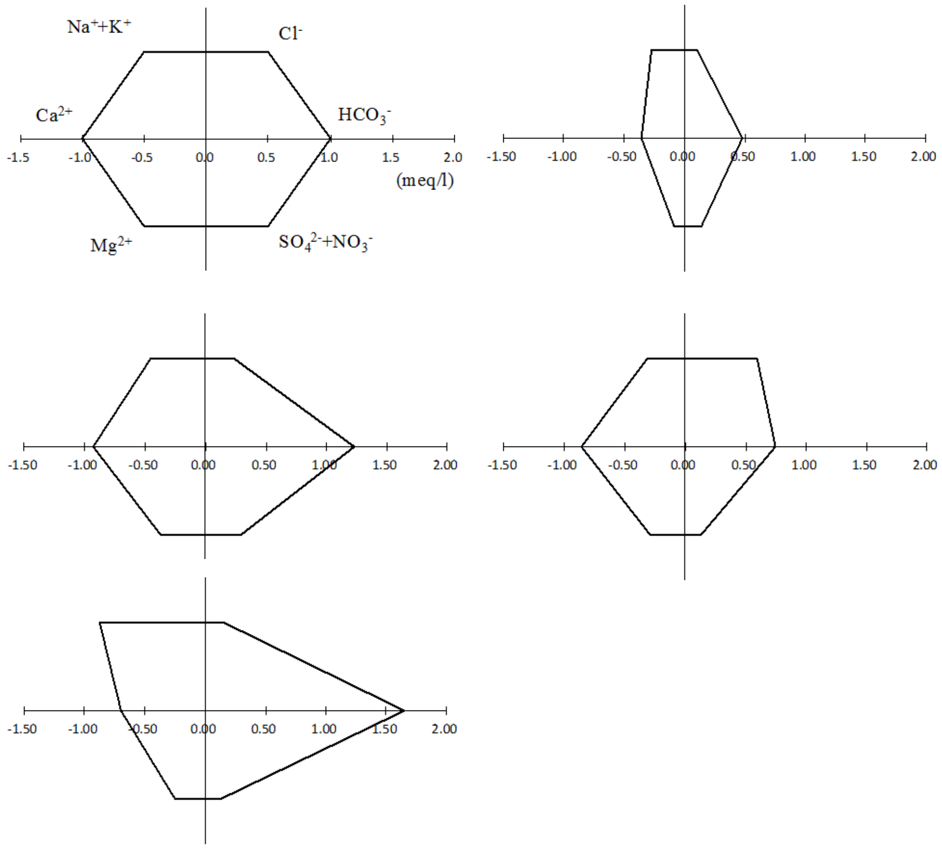

Figure 3 Hexa-diagrams of typical examples of reservoirs classified by trilinear diagram. Upper left: explanatory note, upper right: E2-W, Type I; middle left: B6-T, Type I; middle right: D3-T, between Type I and Type III; bottom left: F4-W, Between Type I and II. The diagram's shape of Type I shows larger amounts of Ca^{2+} and HCO_3^- and smaller amounts of other ions. The diagram size of the River Group, at the upper right, is smaller than that of the Spring Group, middle left. Waters classified as Between Type I and Type III contained a higher Cl^- concentration. The water classified as Between Type I and Type II had large amounts of Na^++K^+ and HCO_3^-.

3.4 Water Quality Characteristics

In the first place, most reservoirs classified as belonging to the River Group and the Spring Group also belong to Type I in the trilinear diagram based on stable isotope analysis. However, the sizes of the hexa-diagrams of each reservoir vary with the difference in concentrations of Ca^+ and HCO_3^-. Water from reservoirs belonging to the River Group are filled by rainwater falling on the upper area of the catchment because the δD and $\delta^{18}O$ of these were lower than those of the rest. The water quality characteristics of the River Group show a similar tendency in its trilinear diagram, since the geological conditions that determine the water quality are uniform in the catchment.

In the second place, the reservoirs that were classified as Between Type I and Type III are filled with spring water and affected by evaporation. The water from D1-T and D2-T, which exist in the same area as D3-T, is also more affected by Type III compared with the other reservoirs that are filled with spring water. The concentrations of Cl^- in these reservoirs are characteristically higher than in the others, which are classified into the Evaporation Group based on stable isotope analysis. Water from the Kiso River that does not flow into these reservoirs exits from Region D continuously, while spring water does not supply enough water to fill them, which puts them in the Evaporation Group. Spring water showing a high concentration of Cl^-, which emerges in reservoirs in Region D, presumably come from deep-seated groundwater. On the other hand, the spring water that fills the other reservoirs comes from a shallow aquifer, as revealed by the trilinear diagram. These results indicate that water quality formation processes of tamari and wando in middle and lower Kiso river are not only related to the origin of the water (river water or spring water), but also to the process of spring water flowing through.

Furthermore, the water from both reservoirs that are affected by Type II water (F3-T and F4-W), is filled with spring water. The water classified as Type II would be considered contaminated by human activities according to the high K^+ concentration [10]. In addition, Matsumoto, *et al*. [8] reported that both reservoirs had higher concentrations of DOC than other reservoirs. The average DOC concentration was 4.1 (mg/L) in F3-T and 4.2 (mg/L) in F4-W. Therefore, these reservoirs have presumably been affected by drainage water from human activities.

4 Conclusion

We classified the water quality of wando and tamari along the middle and lower Kiso River according to the characterization of H_2O stable isotope and trilinear and hexa diagram. We found the following conclusions by water quality investigations and analyses.

22 wando and tamari reservoirs were classified as Type I ($Ca\text{-}HCO_3$ type) by trilinear diagram. These reservoirs contained Type I water, regardless of whether the source of the water was a spring or the river. However, the size of the hex diagram for river water was smaller, which means that the ion amount contained in these reservoirs was low. On the other hand, the diagrams of the

reservoirs that were filled with spring water were larger because it contains more minerals than river water. The reservoir that was influenced by Type III ($Ca-SO_4$ or Ca-Cl type), contained a high concentration of Cl^-. And the reservoirs that were affected by Type II ($Na-HCO_3$ type) contained a high K^+ concentration. Most of the reservoirs were grouped into Type I ($Ca-HCO_3$ type), which originates from river water or a shallow aquifer. Two reservoirs, located in Region F, are assumed to have been contaminated by drainage discharged from human activities, having high DOC and K^+ concentrations. And the reservoirs in Region D are presumed to be filled by deep-seated groundwater that has different characteristics from the spring water emerging in other reservoirs. The water quality characteristics of wando and tamari in the middle and lower Kiso river were concerned to be affected by the source of the water. In addition, the characteristics would also be reflected the process, which pass through underground or contaminates by a human activity in these area.

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