Bulletin of Glaciological Research 26 (2008) *1–8*

Water balance and mass balance in a mountainous river basin, Northern Japan Alps

Keisuke SUZUKI[1,2], **Takayuki KURAMOTO**[1], **Motoki TANAKA**[2] **and Shailendra Kumar SHAH**[3]

1 Department of Environmental Sciences, Faculty of Science, Shinshu University Matsumoto, 390–8621 Japan
2 Institute of Mountain Science, Shinshu University, Matsumoto, 390–8621 Japan
3 Interdisciplinary Graduate School of Science and Technology, Shinshu University Matsumoto, 390–8621 Japan

(Received April 4, 2008; Revised manuscript accepted May 7, 2008)

Abstract

We have investigated the water balance and mass balance for four years in Maekawa River basin on the eastern slope of Mt. Norikura-dake. In this region, the precipitation frequency is high from the rainy season to the autumn. The maximum base-flow discharge occurs in the spring snowmelt season. The pH and electric conductivity of the river water decline rapidly with the beginning of the snowmelt runoff and temporarily decrease when the discharge increases temporarily in the rainy season or during a typhoon event. The Cl^- concentration of the river water increases in the early stage of snowmelt season since there is a considerable amount of sea salt in the snow. In addition, the NO_3^- concentration of the river water increases when the rainfall increases the discharge. The major ion concentration of the river water, except Cl^- and NO_3^- almost synchronizes with the change in the electric conductivity. In the mass balance of cations, the runoff rate from the river basin considerably exceeds the atmospheric deposition rate to the river basin. This is because there is extremely much elution of ions from new volcanic rocks and soils. Further, the atmospheric deposition rate of NO_3^- is larger bigger with the biological consumption in the river basin than the runoff rate from the basin.

1. Introduction

For heavy-snow regions such as Japan Sea-side area, the quantity of water precipitated by a snowfall is extremely more important than rainfall as a water resource. Moreover, snow also plays a role of natural dams since it accumulates in river basins during winter time. The snowfall in mountainous regions is more than that in the lowlands; however, it is difficult to determine quantitatively. The snowfall measurement using a regular precipitation gauge requires a heater and therefore an electrical power supply. Moreover, the measurement accuracy is low because of a low capture rate of snowfalls in windy mountainous regions (Yokoyama *et al.*, 2003). For these reasons, snowfall is rarely measured using a precipitation gauge in mountainous regions during the winter season. Precipitation-gauge stations are set up by the Japan Meteorological Agency in mountainous regions only during warm periods; moreover, the number of stations is extremely small. It is crucial to elucidate the water balance by quantitatively comprehending the amount of precipitation and also including the snow in mountainous regions from the aspect of water resources.

Further there are reports that state that the snowfall in Japan decreases in accordance with global warming (Inoue and Yokoyama, 2003). However, this result is from research based on data mainly from lowlands; therefore, it is uncertain whether this data applies to mountainous areas at high altitudes. In a snowy temperate area, where rain or temporary warming can cause frequent melting at the surface of snow cover, the snow melts due to an increase in the air temperature and the temperature determines whether the precipitation will be in the form of snow or rain. At such places, the snow turns to rain or vice versa depending on increases and decreases in temperature. In addition, it is likely that the snowfall decreases if the climate becomes warmer since snow particles melt while falling and turn into rainfall; thus, the precipitation amount is the same. However, it is also conceivable that the snowfall will increase in mountainous regions at high altitudes. This is because the saturation vapor pressure in the atmosphere increases with temperature. Therefore, snowfall will increase if the precipitable water is increased in amount and dose not turn into rain. Inoue and Yokoyama (1998) predicted that the snowfall will not increase for the next hundred years with the hypothesis of global warming in Hokkaido (northern Island of Japan) above 41.5° north latitude. However, from the map provided in this paper, it can be observed that the snowfall along the coast of Hokkaido has decreased, while that in the mountainous regions of Hokkaido has increased.

In mountainous regions at high altitudes, even the snow depth is rarely measured and the amount of snow is entirely unknown. Only recently, National Research Institute for Earth Science and Disaster Prevention of Japan started the snow depth observation in mountainous areas (Shimizu and Abe, 2001; Yamaguchi *et al.*, 2007). However, the highest altitude is 1,310 m for this measurement. For the snow, as the water resources of Japan and natural dams, it is essential to promptly build the network of meteorological observations including the snowfall and accumulation of snow in high altitudes regions in order to predict the snowfall fluctuation.

Further, to some extent, it is possible to evaluate the amount of snow by hydrologically reviewing the water balance based on even deficient data of precipitation amount at the basins of mountains. Therefore, we can report on the research results regarding the hydrological cycle and material cycle of the mountainous watershed on the eastern slope of Mt. Norikura-dake, Northern Japan Alps.

2. Methods

The study basin is the alpine watershed area that spreads out on the eastern slope of Mt. Norikura-dake (Fig. 1). The surface geology of this basin mainly consists of granite. Mt. Norikura-dake is a Konide volcano with scattered crater lakes and it is the quaternary volcano that constitutes the Norikura volcanic chain distributed along the Northern Japan Alps. The Norikura volcano is a compound volcano with six volcanic bodies, which were formed by volcanic activities that have been occurring since approximately 100000 years, and it has a gentle shape as young stage with the plateau formed by the objects of volcanic eruptions. At the study location on the eastern slope, there is a lava plateau of a novel volcanic body. The climate in this region is normal: a precipitation amount of 2000.8 mm, an annual mean temperature of 8.1℃, the mean temperature in the coldest months (January and February) of −3.5℃, and the mean temperature in the warmest month (August) of 20.3℃ according to the data from the neighborhood of Nagawa where the Automated Meteorological Data Acquisition System (AMeDAS) substation is set up by the Japan Meteorological Agency.

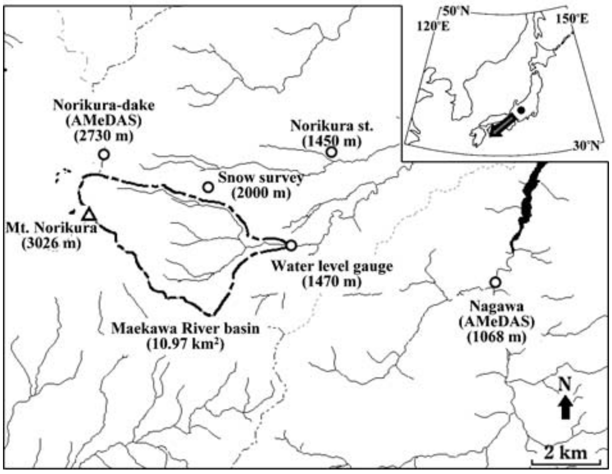

Fig. 1. Maekawa River basin and related points.

The observation was started in May 2002 and the data until June 2006 was used. The measurement point was at an altitude of 1470 m in Maekawa River basin, which runs through the eastern slope of Mt. Norikura-dake, and a water level gauge was setup at this point to continuously measure the water level of the river. The measurement of discharge was conducted at different water levels and the runoff rate was calculated by using a discharge rating curve. Further, an automatic water sampler was set up and the river water was collected periodically. In addition, meteorological observations were conducted and the atmospheric deposition amounts (wet and dry) were measured at a point located at an altitude of 1450 m from Norikura station of Institute of Mountain Science, Shinshu University. Its location was approximately 2 km north of the lower end of this basin. The atmospheric deposits were collected approximately once a week in a bulk sampler using a funnel of 20 cm diameter, a filter, and polyethylene bottle. Then, the volume of the collected water was calculated from its weight and the sample was brought to the laboratory. After filtering the sampled river water and atmospheric deposits, its electrical conductivity and pH were measured and ionic concentration was measured using ion chromatography. Also the HCO_3^- concentration was measured by the sulfuric acid titration method on the river water.

3. Results and discussion

3.1 Seasonal change of precipitation and runoff

The daily amount of precipitation at the Norikura station and daily runoff at Maekawa River basin during the period of observation are shown in Fig. 2. Every year, the amount of precipitation and its frequency are increasing between the rainy season (Baiu) and autumn. The runoff is increasing in response to these precipitations; however, the maximum base flow discharge occurs during the snowmelt season. On July 4, 2005, the largest daily runoff of 59.5 mm was recorded; however, it was the result of both rainfalls associated with the passage of a warm front and snow melt caused by the increase in temperature on that

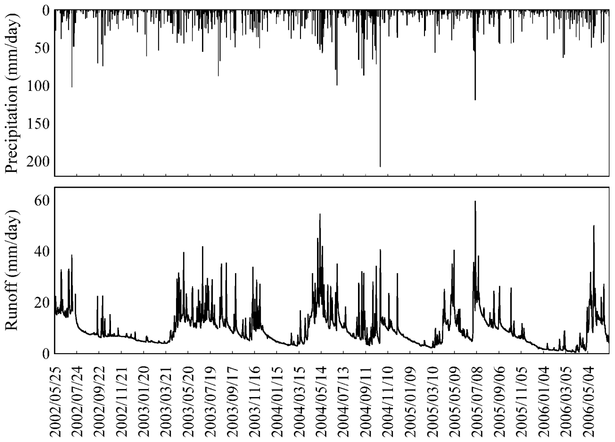

Fig. 2. Daily precipitation at Norikura station and daily runoff in Maekawa River basin.

Table 1. Correlation matrix of river water chemistry (Q: discharge, EC: electric conductivity).

	Q	pH	EC	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	NO_3^-	SO_4^{2-}
pH	-0.608									
EC	-0.752	0.766								
Na^+	-0.711	0.735	0.946							
K^+	-0.662	0.648	0.888	0.906						
Mg^{2+}	-0.715	0.767	0.961	0.941	0.852					
Ca^{2+}	-0.707	0.692	0.921	0.882	0.815	0.924				
Cl^-	-0.073	0.158	0.195	0.297	0.316	0.224	0.122			
NO_3^-	*-0.009*	-0.079	*0.023*	*-0.052*	*0.039*	*-0.021*	0.112	-0.107		
SO_4^{2-}	-0.643	0.629	0.870	0.887	0.853	0.822	0.779	0.250	*0.021*	
HCO_3^-	-0.731	0.768	0.947	0.908	0.807	0.952	0.893	0.210	-0.065	0.739

$P < 0.01$ exept italic letters

day. By the influence of low rainfall during summer to autumn 2002, the base flow discharge was continuously decreasing after the snowmelt season in 2002 until increasing again in the next snowmelt season in 2003. For other years, the runoff was temporarily decreased after the increase in base flow discharge in the snowmelt season; however, it increased again in the autumnal rainy season and the base flow discharge in wintertime continuously decreased until the next snowmelt season.

3.2 *Seasonal change of river water chemistry*

All samples of the river water were used during the period of observation. For each sample, the correlation matrix between the chemical characteristics and variables including the discharge at the sampling time are shown in Table 1. With an increase in discharge, the pH, electrical conductivity, and the concentrations of all the ions decreased. It can be observed that the NO_3^- concentration barely shows a positive correlation with the concentrations of other ions and exhibits a peculiar variable trend. Further, the Cl^- concentration exhibits no correlation with the concentrations of other ions. It was discovered that the concentrations of ions excluding Cl^- and NO_3^- have an extremely high mutual correlation coefficient and also show an almost analogous variable trend.

The pH, electrical conductivity, and ion concentrations in the river water during the period of observation along with the discharge at the time of sample collection are shown in Fig. 3. The concentrations of only Cl^-, NO_3^-, and SO_4^{2-} anions are shown: Cl^- and NO_3^- were selected because of their low correlation coefficient with the fluctuation in the concentrations of other ions and peculiar fluctuation of Cl^- and NO_3^- concentrations; SO_4^{2-} was selected as a representative for the variable trend exhibited by ions other than Cl^- and NO_3^-, because of a positive mutual correlation excluding these two ions. In winter season, the discharge decreases and the recharge of river water by the base flow will be articulated. In this season, the pH and electrical conductivity of the river water indicated high values; they showed a gradual increase until the snowmelt runoff started and drastically decreased thereafter. Then, if the trends are repeated, both pH and electrical conductivity gradually increased as a whole until the start of the next snowmelt season and temporarily decreased with the flow increase during rainy season (Baiu) and by typhoons. It is known that there is a considerable amount of sea salt in the snow at the snowy basins in Japan (Suzuki and Endo, 1994, 1995). It was also recognized that there was an increase in the Cl^- concentration in the river water at the beginning of a snow melt season (Suzuki and Kobayashi, 1987; Suzuki, 1995; Yamazaki *et al.*, 2005). As shown in Table 1, the NO_3^- concentration in the river water, which showed only a small correlation coefficient with the discharge of river water, was low at the time of the base flow; however, it was found to increase with an increase in the flow particularly caused by rainfalls. This increase is attributed to NO_3^- that was produced in the soil by nitrobacteria and conveyed by shallow subsurface flows at the time of rainfall runoff (Suzuki, 1996). Of all the ion species in the river water, HCO_3^- has the maximum ion concentration, followed by SO_4^{2-}. From Fig. 3, it is clear that the fluctuation of the SO_4^{2-} concentration in the river water is simultaneous with that of electrical conductivity.

3.3 *Mass balance in the study basin*

We will discuss the water balance and mass balance for each month at the study basin. Regarding the water balance, the monthly precipitation amount at the Norikura station and the monthly runoff at Maekawa River are reflected without modification. As for the atmospheric deposition amount of each ion in the basin, the measurements of atmospheric deposition amount at the Norikura station will be used. Since the measurement of atmospheric deposition amount was implemented weekly, the deposition amount of each ion species per precipitation amount is prorated from the time of the measurements. The runoff volume of each ion species from the Maekawa River basin is calculated as follows. First, the daily average concentration of each ion species in the river

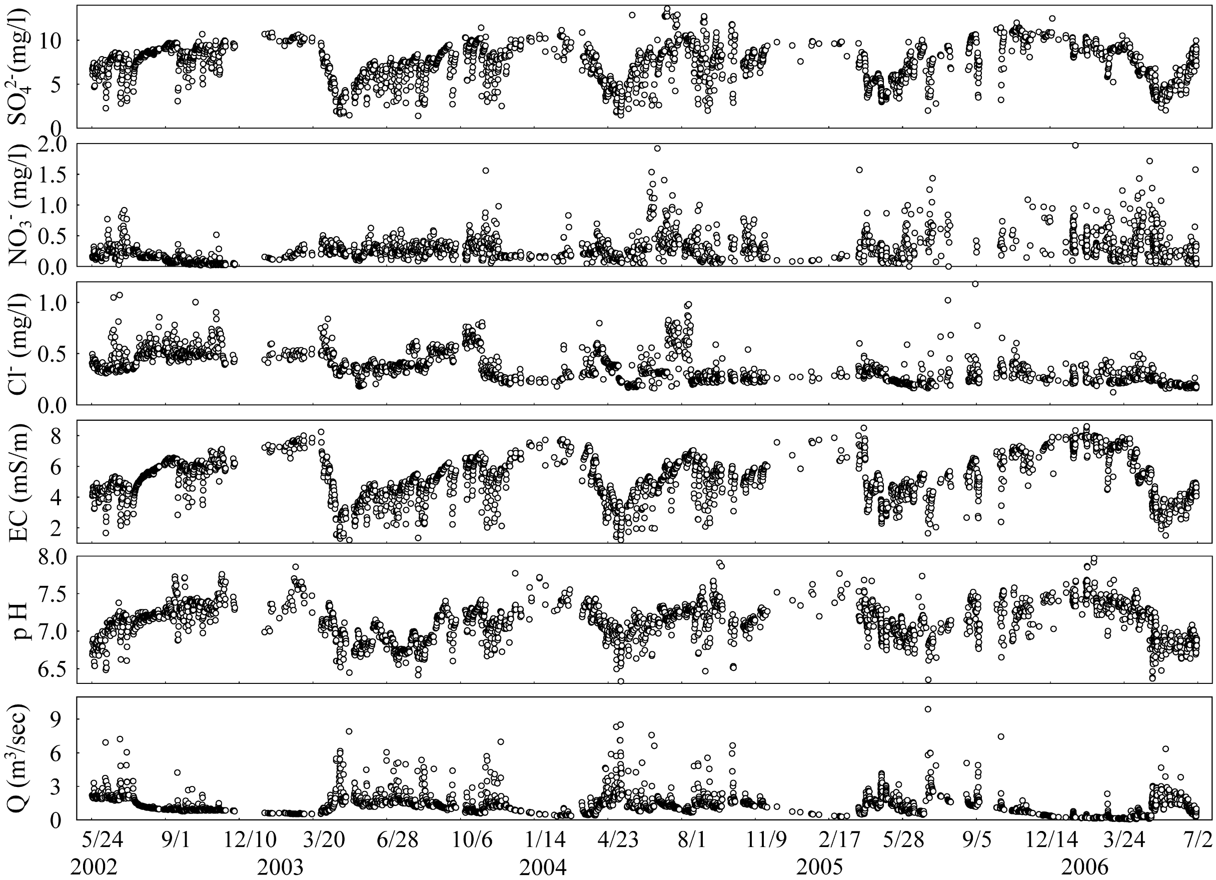

Fig. 3. Electric conductivity (EC), pH, and anion concentration in river water and discharge (Q) when river water samples are collected.

water was calculated. As clearly shown in Fig. 3, the river water was collected multiple times per day and analyzed in a warm period during which the flow exhibits a large fluctuation. The river water was collected less frequently in a cold period during which the flow exhibits only a small fluctuation, and hence only a small fluctuation of ion concentrations in the river water. Next, the daily runoff volume of each ion species from the basin was calculated using its daily average concentration and daily discharge. The total daily runoff volume of each month was deemed as the monthly runoff volume of each ion species from the basin. On some days in a month, such as December 2002, no sample of the river water was collected; for such days, the daily average runoff volume of that month was used to calculate the daily runoff volume of each ion species.

The water balance and mass balance at the Maekawa River basin, which were calculated as above, are shown in Fig. 4. As for the water balance, runoff exceeded the precipitation amount for most months. This result is inconsistent with evapotranspiration. This is because only values from the Norikura station obtained at the altitude of 1450 m were used for the precipitation amount, although the runoff was from the entire basin at the altitudes from 1470 to 3026 m. Further, the above result also contradicts the general expectation that the precipitation amount would increase with altitude. This problem will be considered later.

As for the mass balance of each ion species, the runoff value from the basin was overwhelmingly larger than the atmospheric deposition amount in the basin. Regarding cations, the contribution made by an extremely large elution from new volcanic rocks and soil was more than the atmospheric deposition amount derived from precipitation and dry deposition. Similarly, the runoff volume of the river water exceeded the atmospheric deposition amount with regard to SO_4^{2-} which is peculiar to volcanic bodies (Asai *et al.*, 2001). As for the cations, the runoff volume is extremely larger than the atmospheric deposition amount, particularly that of Ca^{2+}; however, the atmospheric deposition amount of Na^+ progressively increased mainly in the winter season. Further, the atmospheric deposition amount of K^+ was found to clearly increase in a warm season when the eluviation volume from plant leaves also increases (Kuramoto and Suzuki, 2005). On the other hand, the atmospheric deposition amount of Cl^- in the basin and its runoff volume from the river water were balanced; Cl^- is thought to be barely eluted from the basin rocks and soils due to the geological condition of this basin, considering the underestimation of the precipitation

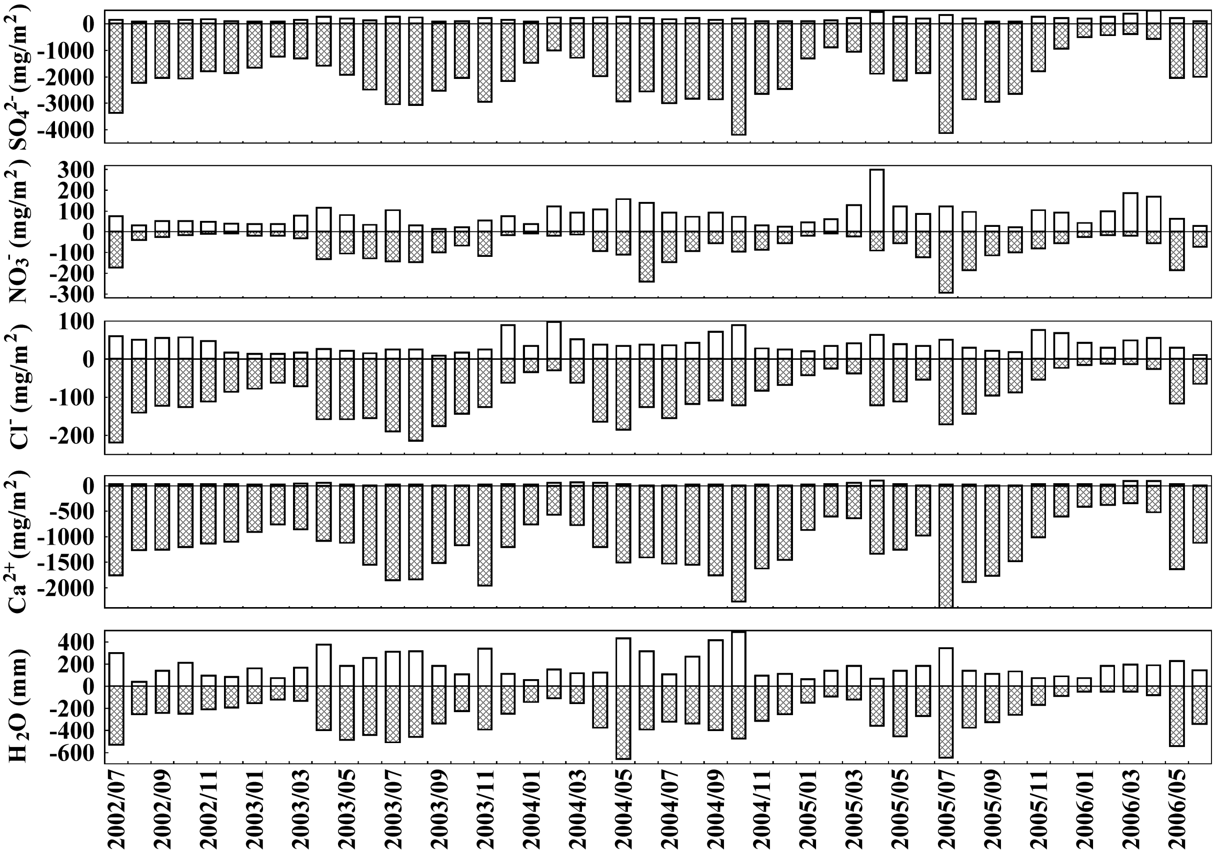

Fig. 4. Monthly atmospheric deposition at Norikura station (white column) and monthly runoff of water and ions from Maekawa River basin (gray column).

amount as stated above. The underestimation of the atmospheric deposition amount will be discussed later. Further, the atmospheric deposition amount of Cl^- was relatively large during the cold season, same as Na^+. Moreover, the atmospheric deposition amount of NO_3^- in the basin exceeded its runoff volume from the river water. Among all the analyzed ion species, only NO_3^- exhibited positive values in the mass balance of the basin. This is attributed to the nitrogen accumulation and its elimination by the internal circulation of microorganisms and vegetation in the basin.

3.4 *Discussion for water balance*

As already stated, the water balance will not be analyzed since the runoff would be larger than the precipitation amount if the runoff of the entire basin at the altitudes of 1470 to 3026 m was calculated, against the precipitation amount of only one level at the altitude of 1450 m. Monthly precipitation amounts at the Norikura station and monthly runoff at the basin are diagrammatically shown in Fig. 5. The annual mean precipitation amount over a 4 year period between June 2002 and May 2006 was 2186 mm and the annual mean of runoff was 3497 mm. Since it is said that the annual evapotranspiration at mountainous regions in the main island of Japan is 500 mm or less, there will be a shortage of approximately 2000 mm in the annual precipitation amount. We will examine whether it is possible to cover this underestimation of precipitation amount by the elevation effect of precipitation amount and the relationship between winter monsoon and topography.

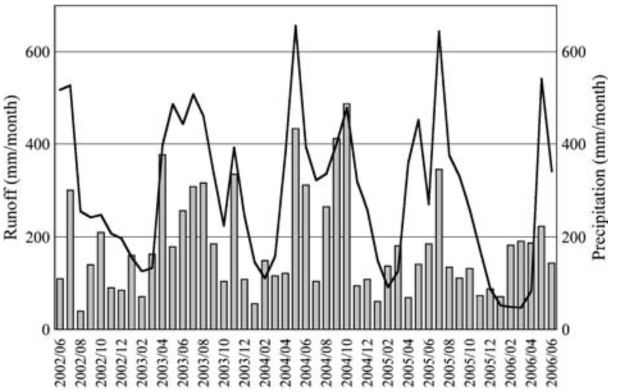

Fig. 5. Monthly runoff in Maekawa River basin (solid line) and monthly precipitation at Norikura station (gray column).

There is Nagawa substation where AMeDAS is located, which is near the Maekawa River basin, and Norikura-dake where the precipitation is measured only in warm periods. The measurements of the precipitation amounts at the Norikura station at the altitude of 1450 m started in May 2002 and the precipitation in Norikura-dake has only been measured until

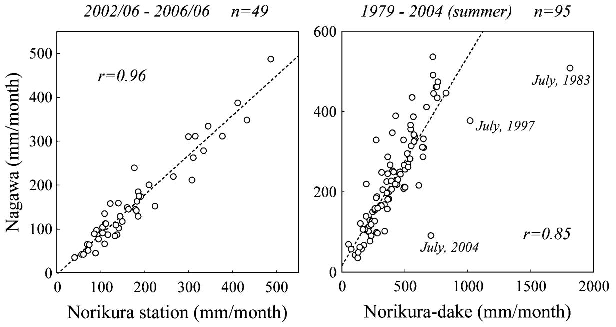

Fig. 6. Relationship between monthly precipitation at Norikura station and Nagawa (left) and that between monthly precipitation at Norikura-dake and at Nagawa (right).

September 2004. Due to the limited available data, it is not appropriate to directly compare the Norikura station with Norikura-dake, which is located at an altitude of 2730 m where the precipitation is recorded only during warm periods. Therefore, each precipitation will be compared for the Norikura station, Nagawa, and Norikura-dake. The relationships between the monthly precipitations are shown in Fig. 6 for the Norikura station and Nagawa (left) for Nagawa and Norikura-dake (right). The relational equation (1) was obtained for the Norikura station (Nk) and Nagawa (Ng) for 49 months between June 2002 and June 2006.

$$Ng = 0.902 \cdot Nk - 2.85 \ (r = 0.96) \quad (1)$$

The monthly precipitation at the Norikura station at the altitude of 1450 m is 10% larger than that at Nagawa at the altitude of 1068 m throughout the year. The relational equation (2) was obtained for Nagawa (Ng) and Norikura-dake (Nd) only for the warm periods of 95 months between 1979 to 2004.

$$Nd = 1.40 \cdot Ng + 88.8 \ (r = 0.85) \quad (2)$$

There were monthly precipitations that were extraordinarily high at Norikura-dake, such as in July 1983, July 1997, and July 2004. However, it is recognized as a positive correlation. Again, it is determined that the monthly precipitation at Norikura-dake at the altitude of 2730 m is more than 40% larger than that at Nagawa at the altitude of 1068 m for the warm periods only.

By comparing the relationships of the Norikura station and Norikura-dake with Nagawa using the relational equations (1) and (2), the relational equation (3) was obtained:

$$Nd = 1.26 \cdot Nk + 84.8 \quad (3)$$

This relational equation can only apply to the warm periods; however, the annual mean precipitation at Norikura-dake for 4 years between July 2002 and June 2006 is 3746 mm that is comparable to 3497 mm of the annual runoff at the study basin for the same period. Therefore, hypothetically, equation (3) can be applied throughout the year, and not only to warm periods. However, it can be said that it is underestimated for the precipitation in a cold period, considering the annual evapotranspiration of 500 mm or less and a wide range of altitudes from 1470 to 3026 m for the entire basin.

In general, it is believed that the precipitation in mountainous regions increases with altitude. Moreover, significant snowdrift is expected on the leeward side when it snows during the winter monsoon, since this basin is located on the eastern side of the mountain range stretching north to south. This can be corroborated by the snow patch at the upper part of this basin after summer. Consequently, the survey for water equivalent of snow cover was conducted within the basin in the winter season. This was a part of the snow chemical research of Japan Alps area; thus, the snow survey was also conducted within the basin. The details of the methods employed for snow layers survey will be stated in the next paragraph; here, only the water equivalent of snow cover is described. The water equivalent of the snow at the altitude of 2000 m on February 28, 2006 was 822 mm. In addition, it is known that the snow started to accumulate continuously in Norikura Plateau at an altitude of 1590 m from the first of December, 2005. Furthermore, samples were weekly collected from the atmospheric deposition at the Norikura station at the altitude of 1450 m since December 1, 2005: the precipitation at this point from December 1, 2005 to February 28, 2006 was 342 mm. Ignoring the difference of start time for the continuous accumulation of snow at an altitude of 2000 m and the basal snowmelt rate in wintertime, it is observed that the precipitation in a cold period at the altitudes of 2000 m is 2.4 times more than that at 1450 m.

The annual mean precipitation at the basin for 4 years between July 2002 and June 2006 was calculated as 3961 mm on the basis of the following assumptions:

(a) the monthly precipitation in the warm periods at the altitude of 2730 m (Nd) can be obtained using the above relational equation (3),
(b) the monthly precipitation of the basin in the warm periods can be obtained by averaging the precipitations at 1450 m (Nk) and 2730 m (Nd),
(c) by multiplying the monthly precipitation at 1450 m (Nk) by 2.4 yields the monthly precipitation at 2000 m in the cold periods, and the monthly precipitation at 2000 m (which was about in the middle of the basin) can be regarded as the monthly precipitation in the basin in the cold periods.

It is considered that the water balance was obtained reasonably since the annual mean runoff at the basin for the same period was 3497 mm; thus, the annual evapotranspiration will be 464 mm.

3.5 Discussion for mass balance

It was stated that inexpediencies occur because of the elevation effect of precipitation and underestimating the amount of snow in wintertime if the water balance of the basin was obtained in a wide range of altitudes from 1470 to 3026 m by using the precipitation at the Norikura station at the altitude of 1450 m. This also applies to the mass balance which was previously described. In other words, the basin's ion content that is deposited from the atmosphere is also underestimated if the precipitation amount was underestimated even if the ion concentration was constant. Here, we will discuss the amount of ion deposition in the cold periods, which can be elucidated by the snow survey.

As stated in the preceding paragraph, the snow survey was conducted at the northern part of the basin at the altitudes of 2000 m on February 28, 2006 as a part of the snow chemical research of Japan Alps area. The snow layers were excavated until the ground surface was reached and the snow temperature and density were measured after observing the snow layers. Then, snow layers were collected at every 3 cm depth. Snow samples were put in spill-proof plastic bags and carried to the laboratory in a cooler and then kept in a freezer until the chemical analysis that was performed in a clean room. At the time of analysis, the snow was melted and filtered; then, pH and electrical conductivity were measured. Furthermore, the ion concentrations were measured using ion chromatography. The water equivalent of snow could be calculated from the density and depth and the ion loadings of all the snow layers could be calculated from the water equivalent of the snow cover at each layer and the ion concentrations. The anion loadings in the snow obtained from the above analysis are shown in Table 2. The water equivalent of snow cover and the precipitation at the altitude of 1450 m measured from December 1, 2005 to February 28, 2006 are also shown. Additionally, the atmospheric deposition amount for each ion species at the altitude of 1450 m for the same period is also shown. It was observed that the precipitation at the altitude of 2000 m is 2.4 times more than the one at the altitude of 1450 m; however, more atmospheric deposition amount was also recorded for each of the ion species: 1.5 times more for Cl^-, 1.75 times more for NO_3^-, and 1.09 times more for SO_4^{2-}. It was determined that the anion concentrations at the altitude of 2000 m were lower than that at the altitude of 1450 m. It is thought that this can be attributed to the difficulty in the transportation of snow particles at high altitudes, since the snow particles become heavy as their ion content increases.

The water balance results at the basin, considering the elevation effect of precipitation and the snow distribution at the basin, as stated above. A similar estimation was made for the mass balance of ions. It is believed that if the ion concentration at the altitude of 1450 m is used and the elevation correction is made only to the precipitation amount in the warm periods, and if the volume of the atmospheric deposition at the altitude of 1450 m is multiplied by the proportion indicated in Table 2, the basin would be correctly characterized in the cold periods. The annual total atmospheric depositions of Ca^{2+} and anions were calculated on the basis these hypotheses along with the annual runoff from the basin are shown in Table 3. Due to the characteristics of the volcano basin, the runoff volume from the basin overwhelmingly exceeds the atmospheric deposition amount for SO_4^{2-}. However, the runoff volume of NO_3^- from the basin is about half the atmospheric deposition amount in the basin due to the consumption and internal circulation inside the basin. There is more runoff volume from the basin than the atmospheric deposition amount of the Cl^-, considering that there was no consumption inside the basin and no elution from rocks and soils. However, this is on the agenda to be examined in the future including the possibility of increased atmospheric deposition in the past.

Table 2. Total atmospheric deposition at 1450 m and snowpack load at 2000 m.

	H_2O (mm)	Cl^- (mg/m^2)	NO_3^- (mg/m^2)	SO_4^{2-} (mg/m^2)
Total deposition at 1450m (2005/12/01 - 2006/02/28)	342	138	231	658
Snowpack load at 2000m (2006/02/28)	822	207	405	715
2000m / 1450m	2.40	1.50	1.75	1.09

Table 3. Annual total atmospheric deposion, annual outflow and estimated total deposition in river basin.

	H_2O (mm)	Ca^{2+} (mg/m^2)	Cl^- (mg/m^2)	NO_3^- (mg/m^2)	SO_4^{2-} (mg/m^2)
Annual total deposition at 1450m	2,186	321	465	945	2,167
Annual outflow from river basin	3,497	14,814	1,221	969	24,788
Estimated annual total deposition in river basin	3,961	212	683	1,521	2,697

4. Conclusions

As the result of examining the water balance and mass balance at the Maekawa River basin, which is an alpine watershed area and runs through the eastern slope of Mt. Norikura-dake, the following was discussed:

1) The precipitation frequency is high from the rainy season to fall and the runoff temporarily increases in response to this. However, the maximum base-flow discharge occur in the snowmelt season. The pH and electrical conductivity of river water gradually in-

crease in wintertime until the snowmelt runoff begins; however, both drop suddenly with the start of the snowmelt runoff. The pH and electrical conductivity of the river water temporarily decrease as the flow increases during the rainy season and during typhoons. At the beginning of snow melt, the Cl^- concentration in the river water increases. Further, the NO_3^- concentration in the river water increases when the flow increases due to rainfall. The primal ion concentrations in the river water, except these two, are nearly simultaneous with the fluctuation of the electrical conductivity.

2) As for the mass balance of cations at the study basin, the runoff volume of the river water overwhelmingly increases compared to the atmospheric deposition amount in the basin, which is caused by an extremely large elution from new volcanic rocks and soils. Conversely, the atmospheric deposition amount and the runoff volume of the river water are balanced reasonably for Cl^- ions since it was not necessary to consider the elution from rocks and soils. Furthermore, the atmospheric deposition amount of NO_3^- ions in the basin was higher than the runoff volume of the river water, due to the consumption and internal circulation inside the basin.

3) If the water balance at the study basin was obtained by only using the precipitation amount at the low altitudes, the runoff would be excessive. Therefore, it would be balanced with a water balance with evapotranspiration if the elevation correction is made to the precipitation amount of the AMeDAS observation in the warm periods and a correction is made to the precipitation amount from the water equivalent of snow survey in the cold periods.

From the above results, it is determined that the lack of observation of the amounts of precipitation and snow in the high altitude mountainous regions in Japan makes it very difficult to accurately predict increases or decreases in water resources; thus, it is imperative to promptly devise a measure to deal with this problem.

Acknowledgements

The authors would like to thank Mr. K. Yokoyama, Mr. H. Ichihara, Ms. M. Nara, Mr. Y. Yoshida, Ms. M. Muramoto and Mr. M. Namba for their help on the sampling and analysis. This research was supported by a Grant-in-aid for Scientific Research (No. 12480018, 17310007) of Japan Society for the Promotion of Science. This research was supported by the Global Environment Research Fund (C-6, C-052) of Japan Ministry of the Environment.

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