THE EANET CHALLENGES ON CATCHMENT-SCALE MONITORING IN ASIAN FORESTS

Sase, H.[1]*, N. Yamashita[1], J. Luangjame[1], H. Garivait[2], T. Visaratana[3], B. Kietvuttinon[3], B. Hongthong[3], S. Urban[4], K.P. Leong[4], Y.Y. Toh[4], Nik M. Majid[5], A. Sanusi[5], O.H. Ahmed[5], S. Gandaseca[5], S. Kasim[5], N. Chappell[6] S. Ohta[7], J. Shindo[8], K. Hayashi[8] and K. Matsuda[9]

[1]Asia Center for Air Pollution Research, Japan Environmental Sanitation Center, 1182 Sowa, Nishi-ku, Niigata, 950-2144, Japan
[2]Environmental Research and Training Center, Department of Environmental Quality Promotion, Thailand
[3]Royal Forest Department, Thailand
[4]Malaysia Meteorological Department, Malaysia
[5]Universiti Putra Malaysia, Malaysia
[6]Lancaster University, UK
[7]Kyoto University, Japan
[8]National Institute for Agro-Environmental Sciences, Japan
[9]Meisei University, Japan.
*Corresponding author: sase@acap.asia

***Summary*:** Atmospheric deposition is still one of the major environmental issues in Asia. The joint research projects for catchment-scale analysis have been conducted in a tropical rainforest (Danum Valley, Malaysia), tropical seasonal forest (Sakaerat, Thailand) and temperate coniferous forest (Kajikawa, Japan) for future monitoring in EANET. In Kajikawa site, the possibility of nitrogen saturation was suggested by the largest level of nitrogen deposition. In tropical forests, acid buffering capacity of the ecosystems was higher in Danum Valley site than in Sakaerat site. The data in different climates will be useful for biogeochemical model as it may contribute to atmospheric management.

***Keywords*:** atmospheric deposition, acid sensitive, seasonality, biogeochemical model

INTRODUCTION

Emissions of SO_2, NO_X and NH_3 from fossil fuel combustion and/or agricultural activities have been increased with rapid industrialization in Asia. According to Ohara *et al*. (2007), the increase rate from 1980 to 2003 was 119% for SO_2 and 176% for NO_X. Although the SO_2 emission in China peaked in 2006 and started decreasing afterwards, the emission level in the Asian region is still high. Moreover, after the nuclear power plant accident caused by the earthquake on 11 March 2011 in East Japan, the importance of thermal power plant is essential. Atmospheric deposition derived from fossil fuel combustion as well as agricultural activities is still one of the major environmental issues in Asia.

The Acid Deposition Monitoring Network in East Asia (EANET) started its regular phase activities in 2001 and has been monitoring atmospheric deposition and its impacts on ecosystems in the East Asian region including Northeast Asia and Southeast Asia. So far, monitoring on wet deposition, dry deposition, soil and vegetation, and inland aquatic environment has been mostly conducted independently. However, an integrated monitoring including atmosphere, vegetation, soil, and inland water is required to evaluate effects of atmospheric deposition on forest ecosystems qualitatively and quantitatively. Catchment-scale analysis of biogeochemical processes may be one of the solutions for this requirement.

Since the East Asian region is latitudinally wide from tropical to boreal zones, various types of ecosystems have been developed depending on the respective climatic zones. The Asia Center for Air Pollution Research (ACAP) as the Network Center for EANET (NC) has been promoting case studies of the catchment-scale analysis as joint research projects in cooperation with experts of the EANET countries, taking the climatic zones into account. The joint research projects are conducted in tropical rainforest, tropical seasonal forest, and temperate coniferous forest, namely, Danum Valley site, Sabah State, Malaysia, Sakaerat site, Nakhon Ratchasima Province, Thailand, and Kajikawa site, Niigata Prefecture, Japan. This paper introduces major outcomes from the joint research projects and the EANET's trial for catchment monitoring.

MATERIALS AND METHODS

The characteristics of the study sites are summarized in Table 1. Danum Valley site and Sakaerat site are similar in catchment area, soil type and geology, while vegetation is different depending on their climates. The catchment area of Kajikawa site was very small but the vegetation, soil type and geology are common in Japanese forests.

Table 1: Study sites in the joint research projects on catchment analysis in Malaysia, Thailand, and Japan

	Danum Valley (since 2008)	Sakaerat (since 2005)	Kajikawa (since 2002)
Catchment area	Approx. 44 ha	Approx. 35 ha	3.84 ha
Vegetation	Tropical rainforest	Tropical seasonal forest (dry evergreen forest)	Coniferous forest (Japanese cedar forest)
Soil type	Acrisols, Alisols	Orthic Acrisols	Dystric Cambisols
Geology	Mudstones, sandstone	Sandstone	Granodiorite
Climate	Tropical rainforest climate (Af)	Tropical savanna climate (Aw)	Humid subtropical climate (Cfa)

Water level of the streams was monitored continuously at 10-20 minutes intervals to estimate water discharge, while a weir was constructed in Danum Valley and Kajikawa sites. Stream water was collected basically biweekly or twice a month. The pH, electric conductivity (EC), alkalinity, anions, cations and SiO_2 were measured for the stream water. The ion fluxes by the stream were estimated as an output from the ecosystem based on the water flux and the ion concentrations.

Since electricity was not available in the forest areas of these sites, bulk sampling was applied for the surveys on input. In Sakaerat and Kajikawa sites, rainwater from rainfall outside forest canopy (RF), throughfall under forest canopy (TF), and stemflow (SF) were collected at the same interval as the stream water collection. The rainwater pH, EC, anions and cations were measured. The ion fluxes by atmospheric deposition were estimated based on precipitation amounts (from sample amounts or rain gauge) and the ion concentrations. However, in Danum Valley and Sakaerat sites, the resin sampling method using ion-exchange resin was applied (Fenn and Poth, 2004), since the experience in Sakaerat site suggested that nitrogen compounds were rapidly consumed by microbial activities during the sampling period in tropical hot and humid climate, especially for RF samplers in an open field. In the case of the resin sampling, the ions trapped by the resin from rainwater during several months were extracted and analyzed. Moreover, the EANET deposition data, which is collected in the same compound, can be referred to for Danum Valley and Sakaerat sites.

Additional surveys on soil, soil solutions, ion flux in soil and so on were conducted to discuss more detailed biogeochemical processes in the ecosystems. In particular, ion flux in soil layer was measured using the resin-ring method packed with ion-exchange resin (Yamashita *et al*., 2010).

RESULTS AND DISCUSSION

1) Possible nitrogen saturation in Kajikawa site

The annual deposition amounts of S and N were high (Table 2). These values were comparable or higher than those in Lake Ijira catchment that was considered as nitrogen-saturated; total depositions (wet + dry) of SO_4^{2-} and dissolved inorganic nitrogen (DIN, NO_3^- + NH_4^+) in Laka Ijira catchment were 0.57 kmol ha^{-1} $year^{-1}$ and 1.37 kmol ha^{-1} $year^{-1}$, respectively (Nakahara *et al*., 2010). The lower NH_4^+ deposition by TF+SF than by RF suggests uptake of N compounds on forest canopy (Sase *et al*., 2008).

Table 2: Mean input-output budget of ion constituents and water for eight water years in Kajikawa site, Japan

	SO_4^{2-}	NO_3^-	Cl^-	NH_4^+	Na^+	K^+	Ca^{2+}	Mg^{2+}	H^+	Alk	water
	$kmol_c$ ha^{-1} $year^{-1}$										mm
RF	1.31	0.52	3.23	0.72	2.81	0.14	0.53	0.71	0.43	-	2344
TF+SF	1.87	0.74	6.32	0.51	5.13	0.58	1.17	1.48	0.56	-	1994
Stream	1.42	0.62	5.28	0.01	4.94	0.29	4.61	2.71	0.00	5.03	1378

Note. RF, rainfall outside forest canopy; TF+SF, sum of throughfall and stemflow; Alk, alkalinity

The DIN deposition in Kajikawa site, 18.5 kg ha^{-1} $year^{-1}$ by RF, was greater than the threshold value in Europe, 10 kg N ha^{-1} $year^{-1}$, for enhancing N discharge to stream water (Kamisako *et al*., 2008). In fact, 50% of N from the atmospheric deposition seemed to have flowed out from the ecosystem (Table 2). The NO_3^- concentration was relatively high even in summer. Nevertheless, the NO_3^- concentration in the stream water seemed to be regulated by plant uptake, since the NO_3^- concentration negatively correlated with air temperature and decreased in summer (Kamisako *et al*., 2008). This suggests that the catchment of Kajikawa site is yet to be saturated with nitrogen. However, during high discharge periods in heavy rain events, the stream water pH in Kajikawa site decreased with increasing NO_3^- concentration (Kamisako *et al*., 2008). This observation was similar to that observed in Lake Ijira catchment (Nakahara *et al*., 2010). This may be the first symptom proceeding nitrogen saturation.

2) Acid sensitivity in two tropical forests

The pH, EC, and all ion concentrations expect for Cl^- in the stream water were higher in Danum Valley site than in Sakaerat site (Table 3). The alkalinity in Danum Valley site was ten times greater than that in Sakaerat site. Acid neutralizing capacity (ANC) of the stream water seemed to be higher in Danum Valley site. Moreover, the SiO_2 concentration, an indicator of weathering rate, was also higher in Danum Valley site. High weathering rate in Danum Valley site may be related to the higher ANC of the stream water.

Table 3: Volume-weighted mean concentration of the stream water at Danum Valley site, Sabah, Malaysia and at Sakaerat site, Nakhon Ratchasima, Thailand.

Catchment	pH	EC	SO_4^{2-}	NO_3^-	Cl^-	Ca^{2+}	Mg^{2+}	Alk	SiO_2

		mS m^{-1}	μmol_c L^{-1}						mg L^{-1}
Danum Valley (n=55)	7.1	4.7	38.0	9.8	36.4	168	148	373	5.8
Sakaerat (n=96)	5.7	2.1	7.8	4.4	99.1	35.8	58.7	41.3	2.6

Note. Alk, alkalinity.

The vertical fluxes in soil layer were higher than those by throughfall in Sakaerat site (Yamashita et al., 2010) and also in Danum Valley site (detail data not shown here). The internal material cycle in soil-plant system may be quite large compared with the deposition amounts in these tropical forests. Vertical fluxes in soil layer and fluxes by stream water for most ions were generally higher in Danum Valley site than in Sakaerat site. The large internal cycle in Danum Valley site also suggests high acid buffering capacity of the ecosystem. Annual flux of SiO_2 from the stream in Danum Valley site (86.9 kg ha^{-1} $year^{-1}$) was greater than that in Sakaerat site (7.8 kg ha^{-1} $year^{-1}$). This also supports the high acid buffering capacity of Danum Valley site. Actually, the stream water pH at Danum Valley site did not easily decrease even in high-discharge periods by heavy rains.

3) Perspective

The *Guideline for catchment-scale monitoring in East Asia* (EANET, 2010) was developed based on the experience gained through the projects. It is expected that catchment-scale monitoring will be conducted as regular monitoring in the EANET countries in the near future. Moreover, the catchment monitoring data can be utilized for biogeochemical models. This could be useful for atmospheric management.

There are many unknown parts in biogeochemical processes in tropical ecosystems. Rehabilitation forests are mostly natural and the histories are well recorded. This can be utilized for studying changes in biogeochemical processes with forest maturing or by different species composition, which will be informative for biogeochemical models. Further collaboration with tropical countries should be promoted.

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