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THE CHANGES IN STREAM WATER TEMPERATURE AND WATER QUALITY PARAMETERS DURING RAINFALL EVENTS IN FORESTED WATERSHEDS: SCALING OF OBSERVATIONS

Luki Subehi
luki@limnologi.lipi.go.id
Research Centre for Limnology, Indonesian Institute of Sciences, Cibinong 16911

Takehiko Fukushima
Yuichi Onda
Graduate School of Life and Environmental Sciences, University of Tsukuba
Tsukuba 305-8502

Shigeru Mizugaki
Watershed Environmental Engineering Research Team, Civil Engineering Research Institute for Cold Region
Public Work Research Institut, Sapporo 062-8602

Takashi Gomi
Graduate School of Agriculture, Tokyo University of Agriculture and Technology
Tokyo 183-8509

Ken'ichirou Kosugi
Graduate School of Agriculture, Kyoto University, Kyoto 606-8502

Shinya Hiramatsu
Hikaru Kitahara
Faculty of Agriculture, Shinshu University
Nagano 399-4598

Koichiro Kuraji
Graduate School of Agricultural and Life Sciences
University of Tokyo, Aichi 489-0031

Tomomi Terajima
Disaster Prevention Research Institute, Kyoto University
Kyoto 611-0011

ABSTRACT

We studied the changes in stream water temperature (Tw) and water quality (Wq) during rainfall events in forested watersheds. The parameters of Wq (SS, DOC, NO_3^--N, DTN, Na^+, Si and K^+) were observed in four regions of Japan *from June 2004 to December 2005. The R values between Tw and those Wq parameters and between specific discharge (Qs) and Wq were positive, except for the negative ones (Na^+ and Si). Similar to the relation between Qs vs. Tw, hysteretic loops in the relations between Qs vs. those Wq parameters were clockwise, except for Na^+ and Si as counter-clockwise loops. This indicates that the surface and subsurface flows contain higher concentrations of SS, DOC, K^+, NO_3^--N and DTN. To the contrary, the deeper pathways contain higher concentrations of Na^+ and Si. These results suggest that the changes in Tw and Wq could be used to interpret the flow paths.*

Keywords : stream water temperature, water quality, rainfall event,hysteretic loops

INTRODUCTION

Stream water temperature and water quality are important parameters in aquatic systems. They are key variables affecting the health, biodiversity, and productivity of freshwater ecosystems [*Karr and Schlosser*, 1978; *Vannote and Sweeney*, 1980; *Hawkins et al.*, 1997; *Webb et al.*, 2008]. Information on, and control of, water quality and temperature are great importance for a wide range of purposes, including water supply and public health, agricultural and industrial uses. In addition, in many areas of the world, the use of water is limited more by its quality than by its quantity [*Caissie,* 2006].

The land use, geology and topology influenced the hydrology and water quality. They control the water quality and thermal patterns in the stream water [*Meybeck,* 1982; *Hakamata et al.,* 1992; *Bolstad and Swank,* 1997; *Harding et al.,* 1999; *Clinton and Vose,* 2005; *Young et al.,* 2005]. Headwater catchments characterized by shallow soils and steep topography are most susceptible to chronic surface water acidification because water has insufficient residence time to neutrallize acidic inputs from the atmosphere [*Shanley and Peters,* 1988]. In addition, there are strong links between geology and stream water temperature regimes via geological differences in run-off mechanisms and surface-subsurface water interactions [Sugita, 1983; *Jones and Holmes,* 1996; *Ward and Robinson,* 2000; *Poole and Berman,* 2001; *Subehi et al.*, 2010].

The previous studies have described the changes in water quality parameters in stream watersheds. Using both hydrometric observations and geochemical tracers, [*Gomi et al.,* 2009] pointed out that overland flow can occur in Japanese cypress at the steep slope, indicated by potassium concentrations. Another research shows that the concentrations of K^+ and DOC are closely related to surface runoff and shows a clockwise hysteresis with higher concentrations on the rising limb compared to the falling limb of the hydrograph at the steep topography [*Stott and Burt,* 1997; *Hood et al.,* 2006]. In the case of NO_3^--N concentrations, subsurface layer contains these parameters and contributes to the stream water at lower slope watersheds, depicted by counter-clockwise loops from correlation between specific discharge and NO_3^--N concentrations [*Ebise,* 1984; *Takeuchi and Sakamoto*, 1986; *Hirata and Muraoka,* 1988]. In addition, [*Muraoka and Hirata,* 1988] said that runoff may be separated into three components: surface runoff, subsurface runoff or interflow and groundwater runoff. The solute concentrations in each component are different according to the runoff source.

Nowadays, water quality research is one of the most rapidly expanding aspects of hydrology. The hydrologists have paid much attention to the importance of water quality, including both chemical characteristics, due to dissolved material, and physical characteristics, such as temperature, color, etc [*Ward and Robinson,* 2000]. In addition to the chemical consideration of the thermodynamics and kinetic of reactions, hydrology plays an important role in determining solute composition and concentrations. Moreover, the climate change impacts can be attributed to hydrological changes in either discharge, which controls dilution, flow velocity and residence times, or in stream water temperature [*Latron and Gallart,* 2008]. They may lead to the longer summer periods of low flow in streams which will reduce the dilution of pollutants. In addition, the different dominant runoff generation processes depend on the seasonality of catchment water reserves and rainfall characteristics.

Detailed observation to describe the water quality change corresponding to the time series of discharge and stream water temperature is useful to understand the hydrological processes. The lack of studies concerning stream water temperature and water quality parameters changes in various topological watersheds suggests the necessity of its investigation. Because the stream water temperature is one of the indicators to trace the processes of the changes in water quality, the objectives of this study are (1) to analyze the relationship between stream water temperature and water quality changes during rainfall events and (2) to analyze the patterns of the changes in stream water temperature and water quality those describes the flow paths in the various watershed conditions.

THE METHODS

Site description

Study areas are located over a wide range of longitude (~6°) from 133°08'E to 139°19'E and latitude (~2°) from 33°12'N to 35°47' N in Japan [*Subehi et al.,* 2009]. We selected 12 streams with various forested watersheds in four regions. They are Aichi (A3), Kochi (K3, K4 and K5), Mie (M1, M2, M3 and M4) and Tokyo (T1, T4, T5 and T6). The watershed areas ranged from 0.1 ha to 56.0 ha with various slope gradients from 0.12 to 0.57.

The Aichi sites are located in the Aichi Research Forest of The University of Tokyo, east of Inuyama in Aichi Prefecture. The Kochi sites are located in the Tsuzura River watershed, which is part of the left tributary of the Shimanto River, southeast of Taishouchou in Kochi Prefecture. The Mie sites are located in Taikichou, Mie Prefecture. The Tokyo sites are located in the Joubanzawa watershed, a tributary of the Arakawa River, and in the headwater of Nariki River.

Data collection at 12 sampling points

The data on stream water temperature (*Tw*) and water depth were taken in intervals of 5 minutes from June 2004 to December 2005. These measurements used *Tw* sensors with a range of -30°C to 70°C, with an accuracy of 0.3°C, and water depth with an accuracy of 1 mm (TruTrack WT-HR, Intech Instruments Ltd, New Zealand). These sensors were set in the Parshall flumes in the streams. In addition, water discharge was calculated from the formulas based on the given size of the Parshall flume and observed water depth [*Herschy,* 1985].

Next, the precipitation was measured by a tipping bucket rain gauge (Davis Instruments Company, Rain collector Metric Standard #7852 M) located in open areas adjacent to the monitored watersheds. A total of 18 rainfall events at 12 sites were selected for analysis with the rainfall intensity more than 5 mm/hour for each event. The water samples were obtained by using automatic water samplers (American Sigma Company, 900 portable). The sampling and analyzing methodology used in this study for water quality was described in detail by [*Zhang et al.,* 2007]. Further, the geological, topological, meteorological, and vegetation information for each site is summarized, based on the data for two years (Table 1).

Analysis of stream water temperature and water quality parameters

In order to investigate the changes in water quality during rainfall events as well as stream water temperature analysis, we selected the water quality parameters: SS (suspended sediment, mg/L), DOC (dissolve organic carbon, mg/L), NO_3^--N (nitrate-nitrogen, μg/L), DTN (dissolve total nitrogen, μg/L), Na^+ (sodium, mg/L), Si (silicon, mg/L) and K^+ (potassium, mg/L) concentrations at those sites in Period I (larger rainfall amounts) and Period II (smaller rainfall amounts) as relatively wet and dry seasons, respectively [*Subehi et al.,* 2010].

Table 1. Description of geological, topological, meteorological and vegetation information at 12

Site	Location	Precipitation (mm/year)	Mean Ta (°C)	Mean Elevation of Watershed (m)	Meteorological Station (Met. Sta)	Headwater Catchment and Distances to the Met. Sta.	Geology	Code	V	A	SG
Aichi	136°57.9' E 35°10.0'N	1,285.7	14.3	165.5	Nagoya	Kiso River Watershed 21.0 km	Sedimentary bedrock (Pleistocene sandstones)	A3	Hinoki (bad managed)	3.0	0.12
Kochi	133°07.7' E 33°12.4'N	2,820.4	13.4	483.8	Kubokawa	Tsuzura River Watershed 14.5 km	Sandstone and pelitic rock (Mesozoic sandstones and shales)	K3 K4 K5	Broadleaf Sugi Hinoki (well managed)	4.9 2.4 56.0	0.33 0.50 0.40
Mie	136°23.4'E 34°26.9'N	1,589.4	13.5	180.0	Kayumi	Miyagawa River Watershed 11.5 km	Metamorphosed shale and crystalline schist, gneiss rock	M1 M2 M3 M4	Mixing Hinoki (well managed) Hinoki (well and bad managed) Hinoki (bad	4.9 1.2 3.5 0.1	0.31 0.56 0.48 0.57
Tokyo	139°18.7'E 35°47.3'N	1,441.5	12.4	705.5	Oume	Nariki River Watershed 13.0 km	Sandstone, pelitic and chert rock (Mesozoic sediment)	T1 T4 T5 T6	Mixing Sugi and Hinoki Sugi and Hinoki Broadleaf	34.0 0.6 1.3 1.3	0.20 0.33 0.30 0.30

V: Vegetation; A: Area (ha); SG: Slope gradient

After the stream hydrograph and time series of water quality and stream water temperature (*Tw*) were observed, the correlation and hysteretic loops analysis were done at those sites during rainfall events. The correlations between *Tw* vs. water quality parameters (SS, DOC, NO_3^--N, DTN, Na^+, Si and K^+) and those between specific discharge defined as discharge divided by area (*Qs*) vs. those parameters, were investigated. In the next place, the clockwise (C) or counter-clockwise (CC) changes in the patterns were also determined from the relations between *Qs* and those parameters.

Based on storm hydrograph and runoff pathways analysis from small catchment and hill slope runoff [*Montgomery,* 2002; *Lane et al.,* 2004; *Onda et al.,* 2008], four types of runoff components should be considered. They are hortonian overland flow (surface flow), saturation surface flow, subsurface flow and groundwater flow (Fig.1). In addition, most likely, stream water temperature response to rainfall/storm events resulted from advective energy inputs (primarily from surface and subsurface hill slope pathways and groundwater), rather than from a direct heat flux from falling precipitation [*Brown et al.,* 2006].

RESULTS AND DISCUSSION

The correlations and hysteretic loops analysis at all sites

Based on the relations between *Tw* vs. SS, *Tw* vs. DOC, *Tw* vs. NO_3^--N, *Tw* vs. DTN, *Tw* vs. Na^+, *Tw* vs. Si, *Tw* vs. K^+ parameters and *Qs* vs. those water quality parameters, we obtained 67 and 61 significant correlations (> 45%), respectively. We selected the clear loops with the values of $|R| > 0.515$ as significant correlations ($p < 0.01$, $n = 24$) which are expressed by blue characters in Tables 2 and 3.

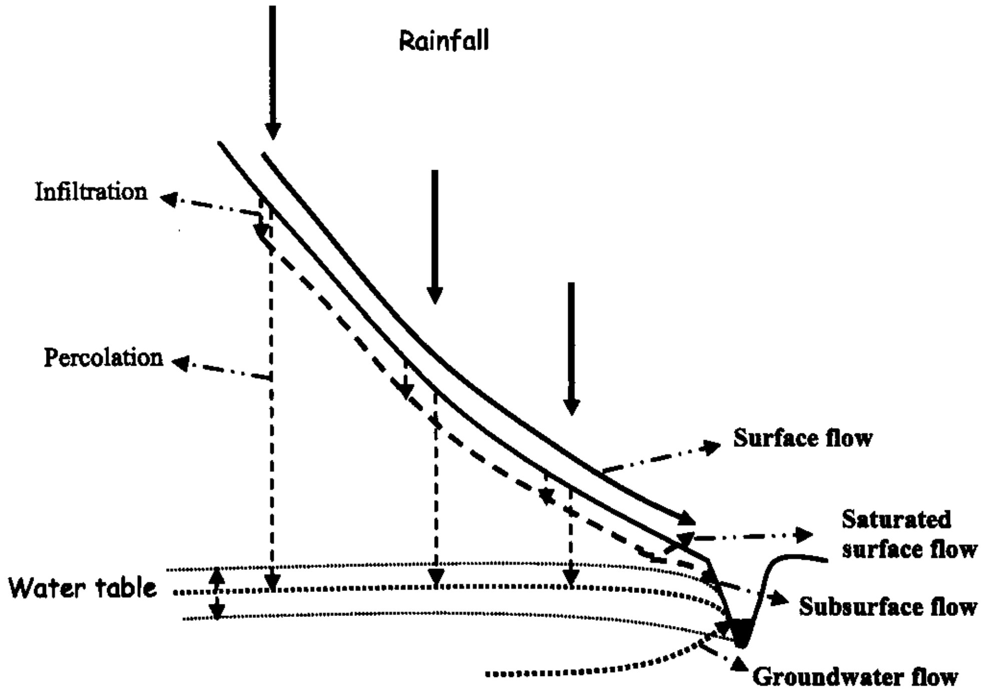

Figure 1. Schematic illustration for runoff components during rainfall events

The correlations between *Tw* vs. SS, *Tw* vs. DOC, *Tw* vs. NO_3^--N, *Tw* vs. DTN and *Tw* vs. K^+ parameters were positive in both periods at all sites, except for the negative ones in the cases of the concentrations of NO_3^--N and DTN at Mie 2 on October 20, 2004. Moreover, the relationships between *Qs* and those parameters were also positive in both periods at all sites, except the negative ones for the concentrations of SS and K^+ at Kochi 5 on June 11, 2004, for the concentration of DOC at Kochi 3 on August 30, 2004, and for the concentrations of DOC at Tokyo 4 and Tokyo 6 on July 25, 2005. Based on stream hydrograph and time series analyses, the exceptional cases could be explained by the higher concentrations of those parameters in the initial part of observation. On the other hand, the correlations of *Tw* vs. Na^+, *Tw* vs. Si parameters and *Qs* vs. those parameters were negative in both periods at all sites.

Table 2. Correlation analyses (*R* values): *Tw* vs. SS, *Tw* vs. DOC, *Tw* vs. NO_3^--N, *Tw* vs. DTN, *Tw* vs. Na^+, *Tw* vs. Si and *Tw* vs. K^+

R	Aichi		Kochi				Mie								Tokyo			
	PI	PII	PI				PI							PII	PI			
	A3	A3	K5	K4	K4	K3	M1	M2	M1	M4	M2	M3	M2	M2	T5	T1	T4	T6
	5-Sep-04	8-Oct-04	11-Jun-04	21-Jun-04	2-Aug-04	30-Aug-04	21-Jun-04	21-Jun-04	31-Jul-04	31-Jul-04	31-Jul-04	30-Aug-04	30-Aug-04	20-Oct-04	29-Sep-04	23-Jul-05	23-Jul-05	23-Jul-05
Tw vs. SS	0.195	0.178	0.501	0.738	0.604	0.733	0.789	0.712	0.541	-0.264	0.444	0.858	0.212	0.518	-0.228	0.516	0.372	0.675
Tw vs. DOC	0.205	-0.105	0.346	0.884	0.417	0.578	0.797	0.696	0.834	0.240	0.846	0.934	0.637	-0.283	-0.175	0.804	0.595	0.750
Tw vs. NO_3^--N	0.691	0.953	0.832	0.618	0.771	0.605	0.682	0.563	0.965	0.520	0.753	0.704	0.903	-0.652	0.537	-0.325	0.059	0.075
Tw vs. DTN	0.604	0.959	0.609	0.875	0.838	0.597	0.531	0.560	0.963	0.415	0.319	0.801	0.916	-0.516	0.505	-0.329	0.088	0.186
Tw vs. Na^+	0.066	-	-0.522	-0.188	-0.801	-0.076	-0.592	-0.888	-0.305	0.114	0.004	-0.607	-0.049	-0.352	-0.394	-0.024	-0.501	-0.040
Tw vs. Si	-0.313	-0.181	-0.869	-0.961	-0.903	-0.820	-0.974	-0.977	-0.800	-0.105	-0.753	-0.848	-0.808	-0.419	-0.033	-0.269	-0.788	-0.286
Tw vs. K^+	-	0.254	0.151	-0.188	-0.163	-0.182	0.669	0.792	0.381	0.424	0.247	0.488	0.746	-	-	-	0.171	0.604

Table 3. Correlation analyses (*R* values): *Tw* vs. SS, *Tw* vs. DOC, *Tw* vs. NO_3^--N, *Tw* vs. DTN, *Tw* vs. Na^+, *Tw* vs. Si and *Tw* vs. K^+

R	Aichi		Kochi				Mie								Tokyo			
	PI	PII	PI				PI							PII	PI			
	A3	A3	K5	K6	K4	K3	M1	M2	M1	M4	M2	M3	M2	M2	T5	T1	T4	T6
	3-Sep-04	8-Oct-04	11-Jun-04	21-Jun-04	2-Aug-04	30-Aug-04	21-Jun-04	21-Jun-04	31-Jul-04	31-Jul-04	31-Jul-04	30-Aug-04	30-Aug-04	20-Oct-04	29-Sep-04	23-Jul-05	23-Jul-05	23-Jul-05
Qs vs. Tw	0.916	0.626	0.197	-0.058	0.502	0.091	0.750	0.730	0.574	0.010	0.530	0.640	0.929	0.950	0.550	0.524	0.476	-0.464
Qs vs. SS	0.232	0.704	-0.584	-0.103	-0.287	0.276	0.786	0.550	0.123	-0.044	0.502	0.582	0.119	0.673	-0.196	0.150	-0.330	-0.383
Qs vs. DOC	0.103	0.569	-0.505	-0.456	-0.192	-0.560	0.344	0.174	0.285	0.102	0.354	0.565	0.501	-0.127	-0.501	-0.506	-0.694	-0.688
Qs vs. NO_3^--N	0.595	0.712	0.282	0.309	0.699	-0.440	0.087	-0.014	0.393	0.537	0.060	0.861	0.965	-0.483	0.698	0.705	0.624	0.583
Qs vs. DTN	0.501	0.679	-0.211	-0.068	0.636	-0.491	0.015	0.064	0.501	0.194	0.198	0.788	0.952	-0.338	0.694	0.898	0.597	0.503
Qs vs. Na^+	-0.082	-	-0.502	-0.533	-0.307	-0.773	-0.712	-0.760	-0.553	-0.365	-0.680	-0.568	-0.194	-0.516	-0.208	-0.636	-0.272	-0.710
Qs vs. Si	-0.307	-0.707	-0.052	-0.001	-0.285	-0.541	-0.788	-0.680	-0.501	-0.444	-0.777	-0.910	-0.830	-0.607	0.030	-0.511	0.118	-0.409
Qs vs. K^+	-	0.373	-0.613	0.135	-0.190	0.145	0.516	0.392	0.020	0.298	0.216	0.217	0.595	-	-	-	0.633	0.082

The hysteretic loops between *Qs* vs. *Tw* were clockwise (C) and counter-clockwise (CC) in Period I and II, respectively (Table 4). In addition, clear hysteretic loops could not be observed in some cases in Table 4 because of data incompleteness in describing the whole change during a rainfall event.

Next, the hysteretic loops between *Qs* vs. SS, *Qs* vs. DOC, *Qs* vs. NO_3^--N, *Qs* vs. DTN, *Qs* vs. Na^+, *Qs* vs. Si and *Qs* vs. K^+ parameters are also shown in Table 4. The clockwise loops were observed for concentrations of SS, DOC, NO_3^--N, DTN and K^+ in both periods. On the other hand, the counter-clockwise loops were observed for concentrations of Na^+ and Si in both periods. Some exceptional patterns were observed at Aichi 3 as explained below.

Analysis of the changes in stream water temperature and water quality during rainfall events at Kochi 4, Mie 2 and Tokyo 6 sites

In order to gain insight into the hydrological dynamics, we have also depicted the stream hydrograph and time series of stream water temperature and water quality at all sites. The representative examples of all events without Aichi could be observed at Kochi 4 on June 21, 2004 (Fig. 2), at Mie 2 on October 20, 2004 (Fig. 3) and at Tokyo 6 on July 25, 2005 (Fig. 4). From stream hydrograph and time series analysis, the variations of *Qs*, *Tw* and the water quality parameters were nearly proportional, except for the concentrations of Na^+ and Si in inverse relations.

According to the hysteretic loop analysis, the relation between *Qs* vs. *Tw* at Kochi 4 and Tokyo 6 in period I were clockwise loops. To the contrary, that at Mie 2 in Period II was counter-clockwise. Moreover, the relations between *Qs* vs. those water quality parameters were clockwise, except for the concentrations of Na^+ and Si as counter-clockwise loops in both periods (Figs. 2, 3 and 4).

Table 4. Hysteretic loop analyses: *Qs* vs. *Tw*, *Qs* vs. SS, *Qs* vs. DOC, *Qs* vs. NO_3^--N, *Qs* vs. DTN, *Qs* vs. Na^+, *Qs* vs. Si and *Qs* vs. K^+

R	Aichi		Kochi				Mie								Tokyo			
	PI	PII	PI				PI							PII	PI			
	A3	A3	K5	K4	K4	K3	M1	M2	M1	M4	M2	M3	M2	M2	T5	T1	T4	T6
	5-Sep-04	8-Oct-04	11-Jun-04	21-Jun-04	2-Aug-04	30-Aug-04	21-Jun-04	21-Jun-04	31-Jul-04	31-Jul-04	31-Jul-04	30-Aug-04	30-Aug-04	20-Oct-04	29-Sep-04	25-Jul-03	25-Jul-03	25-Jul-03
Qs vs. Tw	-	CC	C	C	C	C	C	C	C	C	C	C	C	CC	C	C	C	C
Qs vs. SS	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Qs vs. DOC	-	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	-	C
Qs vs. NO_3^--N	CC	CC	C	C	C	C	C	C	C	C	C	C	C	C	-	C	C	C
Qs vs. DTN	CC	CC	C	C	C	C	C	C	C	C	C	C	C	C	-	C	C	C
Qs vs. Na^+	-	-	CC	CC	CC	-	CC	CC	CC	CC	-	CC	CC	CC	CC	CC	CC	CC
Qs vs. Si	-	CC	CC	CC	CC	CC	CC	CC	CC	CC	-	CC	CC	CC	CC	CC	CC	CC
Qs vs. K^+	-	C	-	-	-	-	C	C	-	-	-	C	C	-	-	-	-	C

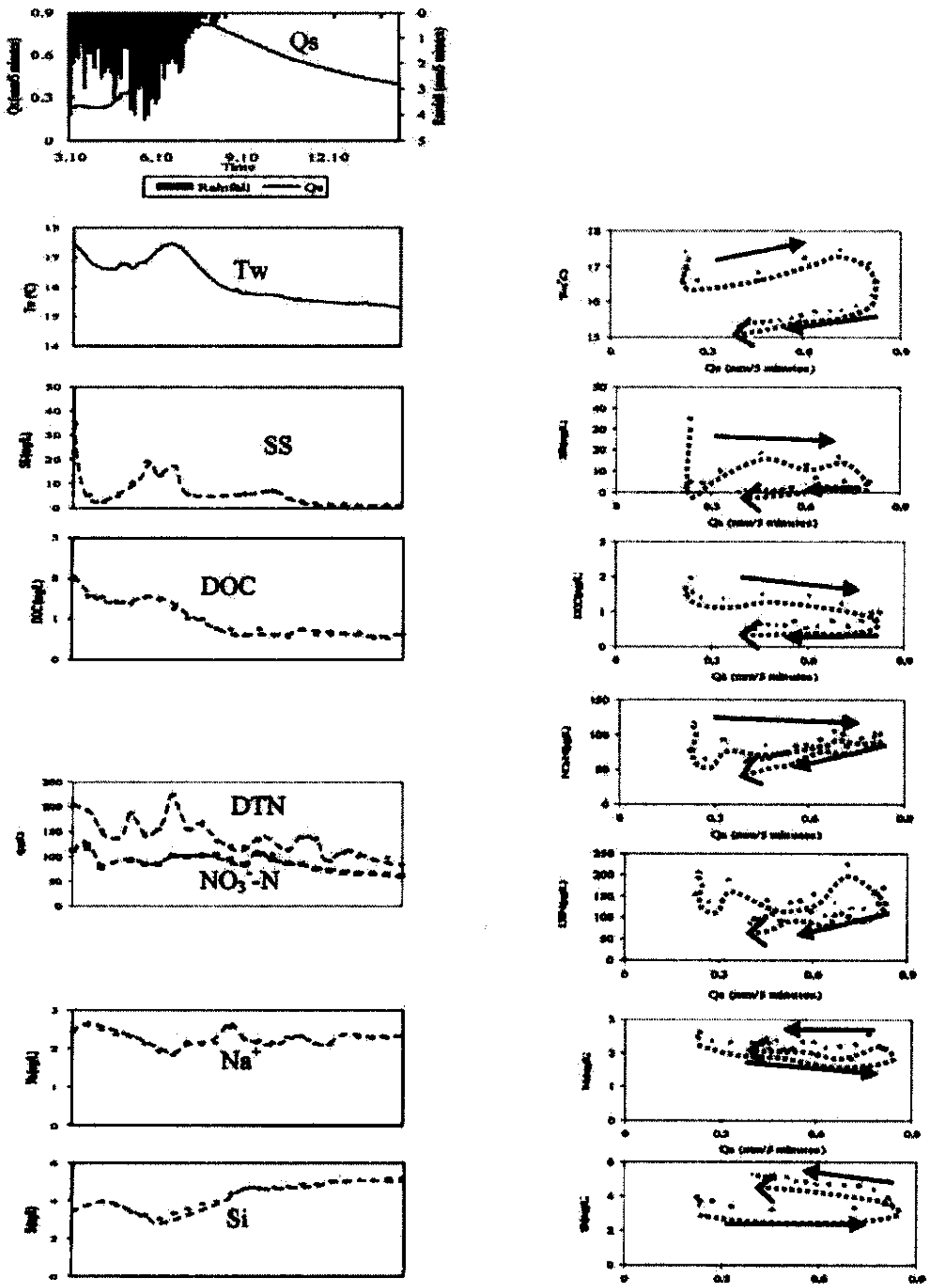

Figure 2. Stream hydrograph and time series of Tw, SS, DOC, NO_3^--N, DTN, Na^+, Si and hysteretic loops at Kochi 4 (June 21, 2004)

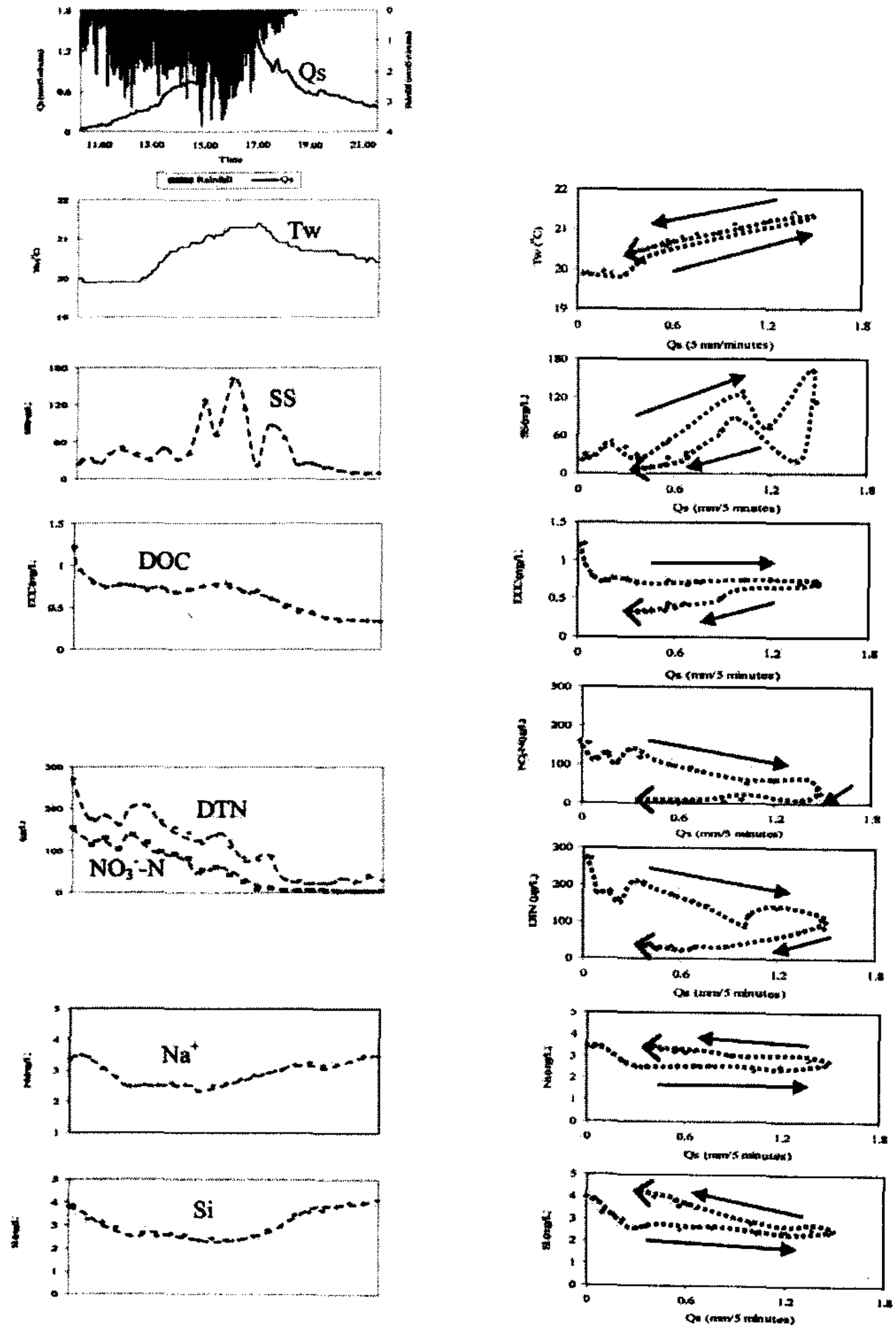

Figure 3. Stream hydrograph and time series of Tw, SS, DOC, NO_3^--N, DTN, Na^+, Si and hysteretic loops at Mie 2 (October 20, 2004)

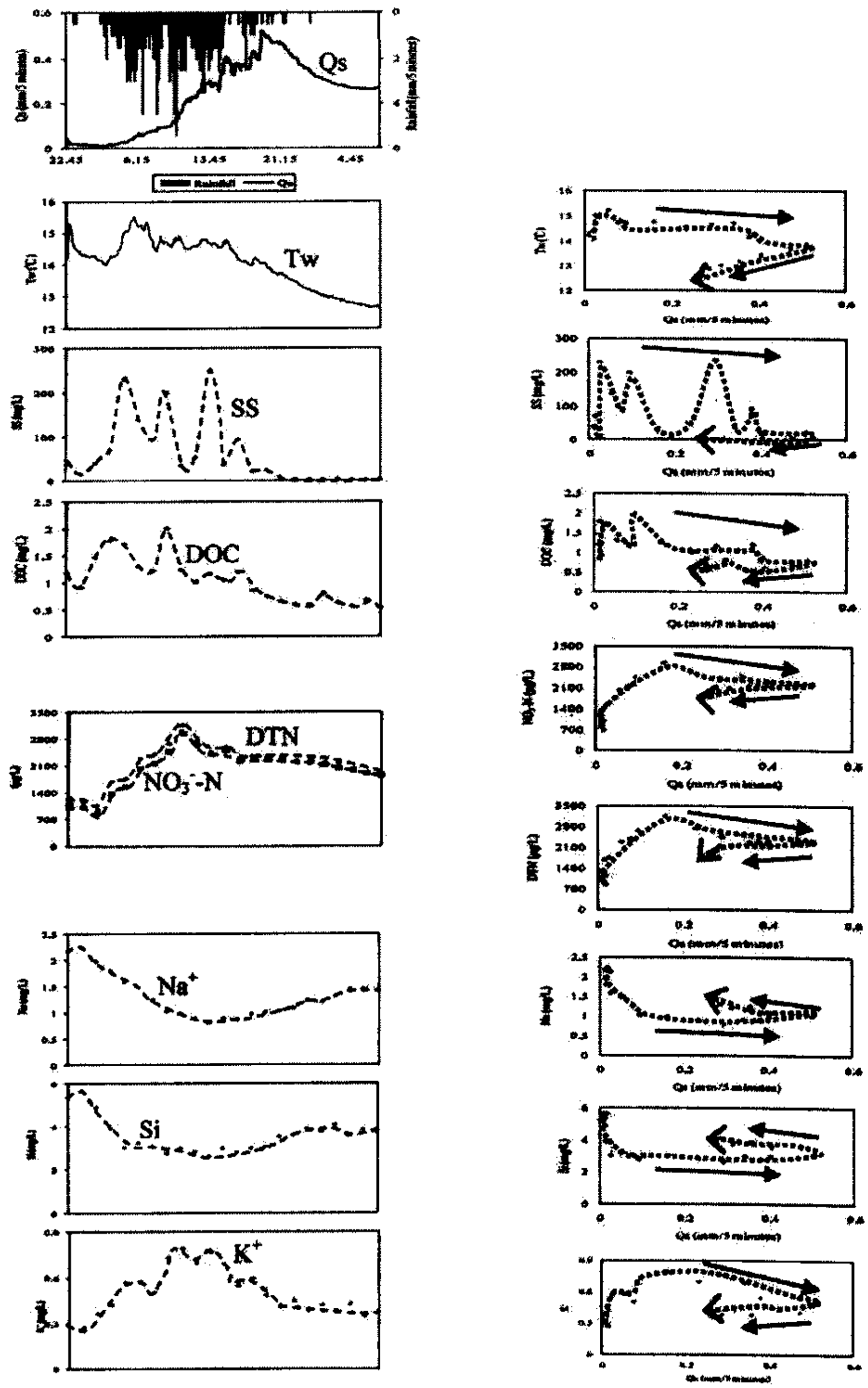

Figure 4. Stream hydrograph and time series of Tw, SS, DOC, NO_3^--N, DTN, Na^+, Si, K^+ and hysteretic loops at Tokyo 6 (July 25, 2005)

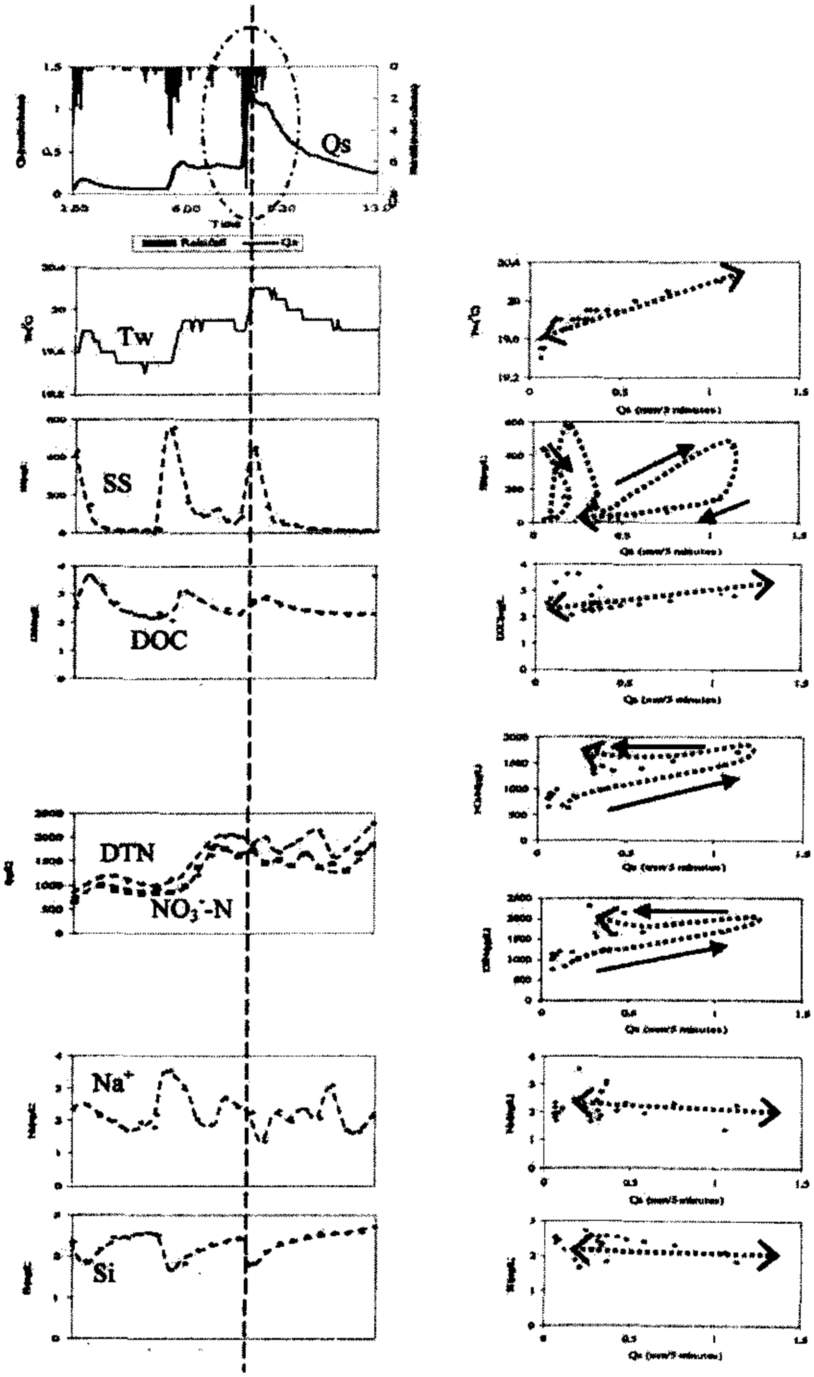

Figure 5. Stream hydrograph and time series of Tw, SS, DOC, NO3--N, DTN, Na+, Si and hysteretic loops at Aichi 3 (September 5, 2004)

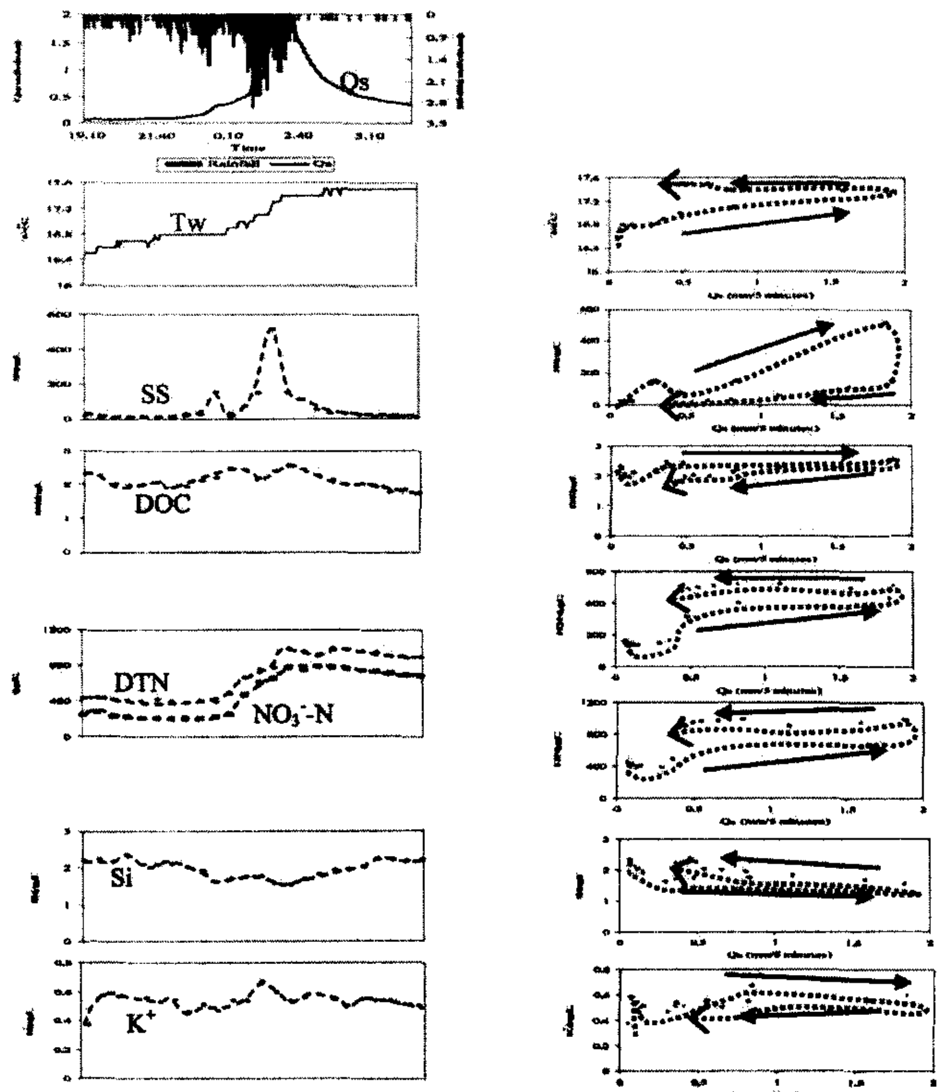

Figure 6. Stream hydrograph and time series of Tw, SS, DOC, NO_3^--N, DTN, Si, K^+ and hysteretic loops at Aichi 3 (October 8, 2004)

Analysis of the changes in stream water temperature and water quality during rainfall events at Aichi 3 site

From stream hydrograph and time series analysis at Aichi 3, the variations of *Qs*, *Tw* and those water quality parameters were also nearly proportional, except for Na^+ and Si concentrations with inverse relations in both periods. Different patterns of the hysteretic loops from other sites were observed at Aichi.The descriptions for the patterns which focused on Aichi 3 in Period I and Period II (Figs. 5 and 6, respectively) will be explained in more detail below.

At Aichi 3 in Period I, the three rainfall events occurred in this period. Then, at that moment we focused on the last rainfall of that event. Next, the clear hysteretic loops of *Qs* vs. *Tw*, *Qs* vs. DOC, *Qs* vs. Na^+ and *Qs* vs. Si could not be observed at Aichi 3 in Period I (Fig. 5). The higher concentrations of SS were observed during the rising limb period compared with the decreasing limb (clock-wise loop). On the other hand, the relations between *Qs* vs. NO_3^--N and *Qs* vs. DTN were counter-clockwise loops.

At Aichi 3 in Period II, the counter-clockwise loops were observed in the relations between *Qs* vs. those water quality parameters except for SS, DOC and K^+ which showed clockwise loops (Fig. 6). The counter-clockwise loop was also observed in the relation between *Qs* vs. *Tw*. In addition, the clear hysteretic loop of *Qs* vs. Na^+ could not be observed in this period.

According to the results, the relations between *Qs* and *Tw* at all sites were clockwise and counter-clockwise in Period I and Period II, respectively which agreed with [*Subehi et al.,* 2010]. These differences in hysteretic loops could be explained by the differences in *Tw* and in response times to rainfall among runoff components. Next, the hysteretic loop pattern of *Qs* vs. water quality parameter depends not only on the time course of runoff but also the vertical distribution of the sources in the watershed. For example, the sources of SS concentrations were on the surface which resulted in clockwise loops observation. The direction of the loop could be influenced by the slight changes in such conditions. Therefore, the distinct pattern should be discussed mainly below.

The changes in SS, DOC, Na^+, Si and K^+ concentrations during rainfall events

In the case of SS concentrations of which sources were on the soil surface, all events at all sites above showed clockwise loops (Figs. 2, 3, 4. 5 and 6), indicating that the surface flow occurred at the beginning of runoff and distributed those concentrations. In contrast, the reverse characteristics were observed for Si concentrations, which are higher in groundwater, suggesting that the latter parts of runoff are occupied mainly by deeper parts of watershed, e.g. groundwater (Figs. 2, 3, 4 and 6). Next, Na^+ on the small stream showed similar patterns as the changes in Si concentrations at the sites with higher slope gradients, suggesting the larger contributions of deeper layer to the concentration formations. However, these patterns were not so clearly at Aichi 3 in Period I (Fig. 5), probably because the event had many peaks of rainfall. It was suggested that the flow path was not only fed significantly by groundwater or subsurface runoff, but also probably resulted from rainfall on the expanding streamside areas as a surface runoff.

The loop pattern of DOC at all sites were clockwise loops but not so clear at Aichi 3 in Period I where the successive rainfalls occurred (Fig. 5). During rain-fall events with high intensity, DOC concentrations often exhibit a flushing response, peaking prior to the hydrograph peak [*Boyer et al.* 1997]. It was suggested that surface flow contains DOC concentrations as a clockwise loop observation. In addition, the DOC dynamics observed at the watershed were probably controlled by the hydrologic connectivity of different landscape units or source pools within the watershed [*Hood et al.* 2006].

Next, clockwise hysteretic loops were observed for the concentrations of K^+ at Aichi 3 and Tokyo 6 (Figs. 4 and 6). The similar patterns for K^+ changes at other sites, without Kochi (Table.4) could be explained by faster runoff through infiltration excess overland flow and biomat flow during rainfall events. In addition, [*Gomi et al.,* 2009] pointed out that the K^+ was a good tracer on infiltration excess overland flow and biomat flow because the overland flow from small plot was significantly higher than through fall and stream flow prior to storm.

The changes in NO_3^--N and DTN concentrations during rainfall events

Generally, NO_3^--N (main part of DTN) is a material deeply related not only to the metabolism of plants but also the mineralization of organic matters, and it is a highly osmotic material with little adsorption onto the soil particles [*Muraoka and Hirata*, 1988]. Usually, the sources on nitrogen are considered to be located just below the soil surface or relatively thin surface layer [*Ebise,* 1984; *Takeuchi and Sakamoto,* 1986; *Muraoka and Hirata,* 1988].

As for NO_3^--N and DTN, the patterns were opposite between Aichi and other sites. Probably at Kochi, Mie and Tokyo sites, the saturated surface runoff (outflow from thin surface or subsurface layer) comes in the former part of the runoff as higher concentrations of nitrogen. This mechanism could be described from Fig. 1. Other possibility should also be considered for that at steep slopes, overland flow or surface runoff and subsurface flow are more likely on converging sections in hollows, where elevation contours display strong curvature, thus forcing convergence of flow paths [*Brutsaert,* 2006]. Similarly as those sites, [*Shinomiya et al.,* 2006] showed clockwise loops in NO_3^--N concentration at one tributary of Shimanto River, Kochi (slope gradient: 0.44).

To the contrary, counter-clockwise loops in NO_3^--N and DTN concentrations were observed at Aichi 3 (Figs. 5 and 6). It could be expected that the subsurface flow comes mainly in the latter part in Aichi 3 where the slope gradient is rather lower than other sites. Moreover, the attenuation in NO_3^--N concentration owing to denitrification in the groundwater near the stream water could possibly result in its lower concentration at the rising limb of the hydrograph at Aichi 3 in Period I, where the fast response of groundwater was observed in stream water temperature change as explained in the previously published paper [*Subehi et al.* 2010].

The subsurface contribution in NO_3^--N concentrations were also observed at several small rivers in the Lake Biwa and Lake Kasumigaura basins [*Ebise,* 1984], at the Ai River, in small mountainous tributary basin of the Fuji River [*Takeuchi and Sakamoto,* 1986] and at three rivers in Tsukuba experimental forested land [*Hirata and Muraoka,* 1988]. The counter-clockwise loops were observed for NO_3^--N concentrations at those sites. In addition, the geological condition at Lake Biwa and Lake Kasumigaura basins mainly composed by granite rocks as mountain streams with lower slope gradients (the average slope gradient: 0.13). The concentration enrichment of subsurface during rainfall is probably due to the leaching of soil water containing rich those parameters. In cases of NO_3^--N concentrations, subsurface flows will have a much greater opportunity for reactions with the solid phase than flow over the ground surface. Consequently, subsurface flows may carry much higher concentrations of those solutes than overland flow [*Hubbard and Sheridan,* 1983]. In conclusion, the relative magnitudes of surface runoff, subsurface or groundwater flow into the stream depend largely on the nature of the catchment (e.g. slope gradient, geology) and the precipitation [*Brutsaert,* 2006].

The changes in stream water temperature and water quality parameters analysis in order to understand the hydrological dynamics

The interpretation of stream water temperature results was not so simple, because temperature influences many different properties of water and because many factors are involved [*Caissie,* 2006]. The weak point of using stream water temperature as a tracer of water runoff is that it is affected by heat transfer processes e.g. solar radiation, sensible and latent heat transfer in running and stagnant water surfaces. Moreover, analysis of the changes in stream water temperature and water quality parameters with used the simplified layer assumption could help to understand the hydrological dynamics phenomena. On the other hand, the strong point of using stream water temperature as a tracer is that its continuous measurement is fairly easy and cheap. Keeping these characteristics in mind, the continuous measurement of stream water temperature could give valuable hydrological implications on water runoff processes.

CONCLUSIONS

We analyzed and understood the contribution of surface, subsurface and groundwater flows into the stream during rainfall events using the changes in *Tw* and water quality parameters. Few studies have linked the changes in *Tw* and water quality under various forested watershed conditions. Then, a hypothesis of how forested watershed condition affects the flow path and water quality contribution was developed and tested.

The patterns of hysteretic loop, stream hydrograph and time series of water quality show that the surface and subsurface flows contain higher concentrations of SS, DOC, K^+, NO_3^--N and DTN. On the other hand, the deeper pathways or groundwater discharges contain higher concentrations of Na^+ and Si. Some exceptional patterns of NO_3^--N and DTN concentrations at Aichi 3 with lower slope gradient were observed, indicating the different flow paths. Finally, we expect that stream water temperature would be a good tracer of basin hydrology as easily observable indicator.

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