J. Soil Groundw. Environ. Vol. 20(5), p. 34~40, 2015
http://dx.doi.org/10.7857/JSGE.2015.20.5.034
ISSN 1598-6438 (Print), ISSN 2287-8831 (Online)
≪ Research Paper ≫

Old Water Contributions to a Granitic Watershed, Dorim-cheon, Seoul

Hyerin Kim[1] · Sung-Hyun Cho[2] · Dongguen Lee[2] · Youn-Young Jung[3]
Young-Hee Kim[1] ·Dong-Chan Koh[3]* · Jeonghoon Lee[1]*

[1]*Dept. of Science Education, Ewha Womans University*
[2]*National Instrumentation Center for Environmental Management (NICEM), Seoul National University*
[3]*Groundwater department, Korea Institute of Geoscience and Mineral Resources (KIGAM)*

ABSTRACT

It is reported that the intensity of rainfall will likely increase, on average, over the world on 2000. For water resources security, many studies for flow paths from rainfall or snowmelt to subsurface have been conducted. In Korea, few isotopic studies for characterizations of flow path have been undertaken. For a better understanding of how water derived from atmosphere moves to subsurface and from subsurface to stream, an analysis of precipitation and stream water using oxygen-18 and deuterium isotopes in a small watershed, Dorim-cheon, Seoul, was conducted with high resolution data. Variations of oxygen-18 in precipitation greater than 10‰ ($\delta^{18}O_{max}$ = –1.21‰, $\delta^{18}O_{min}$ = –11.23) were observed. Isotopic compositions of old water (groundwater) assumed as the stream water collected in advance were –8.98‰ and –61.85‰ for oxygen and hydrogen, respectively. Using a two-component mixing model, hydrograph separation of the stream water in Dorim-cheon was conducted based on weighted mean value of $\delta^{18}O$. As a result, except of instant dominance of rainfall, contribution of old water was dominant during the study period. On average, 71.3% of the old water and 28.7% of rainfall contributed to the stream water. The results show that even in the small watershed, which is covered with thin soil layer in granite mountain region, the stream water is considerably influenced by old water inflow rather than rainfall.

Keywords : Hydrograph separation, Stable water isotopes, Granite region, Old water contribution

1. Introduction

Water from alpine region with predominance of granitic bedrocks and thin acidic soils is vulnerable to acidic deposition (McColl, 1981; Melack et al., 1985). Understanding how the water from storm event moves to stream and groundwater in granitic terrain is essential for securing water reserve efficiently. Because the increased intensity of precipitation can affect groundwater recharge, the importance of securing water as resource should be emphasized (Intergovernmental Panel on Climate Change, IPCC, 2007). In Korea, divided into a water-shortage country on 2000 by Population Action International, more than 50% of annual precipitation is concentrated on summer season (Hong et al., 2006). To manage water supply from the intensified precipitation, knowing the path of precipitation to the stream and groundwater plays an essential role (Clark and Fritz, 1997). Hydrograph separation can be one of a tool for knowing the movement of each water component (Eshleman et al., 1993).

For the past 40 years, many studies using a hydrograph separation technique with environmental isotopes as tracers to characterize the movement of water components such as groundwater, rainfall, snowmelt, and soil water in stream component have been conducted (Hoeg et al., 2000; Ladouche et al., 2001; Ogunkoya and Jenkins, 1993; Pu et al., 2013; Sklash and Farvolden, 1979; Xing et al., 2015). For hydrograph separation, water isotopes are proper tracers because of their conservativeness (Clark and Fritz, 1997). In Korea, a few isotopic studies for separating hydrograph have been undertaken (Cho et al., 2008; Cho et al., 2007; Lee et al., 2006). But most of these studies used single isotopic value of precipitation for each hydrograph. It is reported that even single storm event, comparing to isoto-

*Corresponding authors : chankoh@kigam.re.kr, jeonghoon.d.lee@gmail.com
Received : 2015. 10. 6 Reviewed : 2015. 10. 8 Accepted : 2015. 10. 13
Discussion until : 2015. 12. 31

pic value of groundwater component which has constant value because of its long residence time, isotopic value of precipitation has big variation (Lee et al., 2010; Taylor et al., 2001). From the study of Lee et al.(2014), variation of isotopic composition can create a systematic error for hydrograph separation.

For a better understanding of how water derived from atmosphere moves to subsurface and from subsurface to stream, an field experiment of precipitation and stream water with oxygen-18 and deuterium isotopes in a small watershed, Dorim-cheon, Seoul, was conducted with high-temporal resolution data.

2. A study site and methods

2.1. Study Area

This study was conducted at an upstream of Dorim-cheon, originated from Mt. Gwanak located in Seoul, Korea and flowing into Anyang-stream (Fig. 1). Dorim-cheon is a low-altitude watershed, ranging from 130 to 630 m.a.s.l., located between Mt. Gwanak with its highest peak of 632 m.a.s.l. and Mt. Samseong of 481 m.a.s.l. It is a granitic terrain of Mesozoic age intruding the Kyonggi massif, covered with thin and well-drainable soil layer (Jang et al., 2013; Kwon et al., 1995).

Rain sample site is located at 100 m upstream of the point where stream water was sampled (37°27'07"N, 126°56'58"E). We can exclude shadow effect from vegetation in this reason. Amount of rainfall was obtained from an Automatic Weather Station (AWS) at an Atmosphere Observatory in Seoul National University, located at east side of Dorim-cheon near from the stream sample site.

2.2. Sampling and analytical method

To conduct a study of hydrograph separation, it is necessary to obtain continuous stage data. To measure stage data during the study period, an automatic stage logger was used. We used MiniDiver® from Eijkelkamp, which has 0.05% of precision. A 30 mm diameter piezometer was produced and attached at the stream sample site on October 2, 2014, to install the stage logger. Stage was measured from October 2 to November 5 with an interval of 15 minutes continuously. Stage measurements can be converted to discharge using stage-discharge curve. To compute discharge, velocity-area method was used. Velocity-area method is based on a continuity equation,

$$Q = VA \quad (1)$$

where Q is discharge, the flow rate of the stream cross section (m^3/s), V means flow velocity (m/s), and A is the area (m^2) of stream cross section. Discharge of an entire cross section can be expressed with the summation of discharge of each small sections:

$$Q = \Sigma V_i A_i \quad (2)$$

where Q is discharge, V_i is mean flow velocity of a small

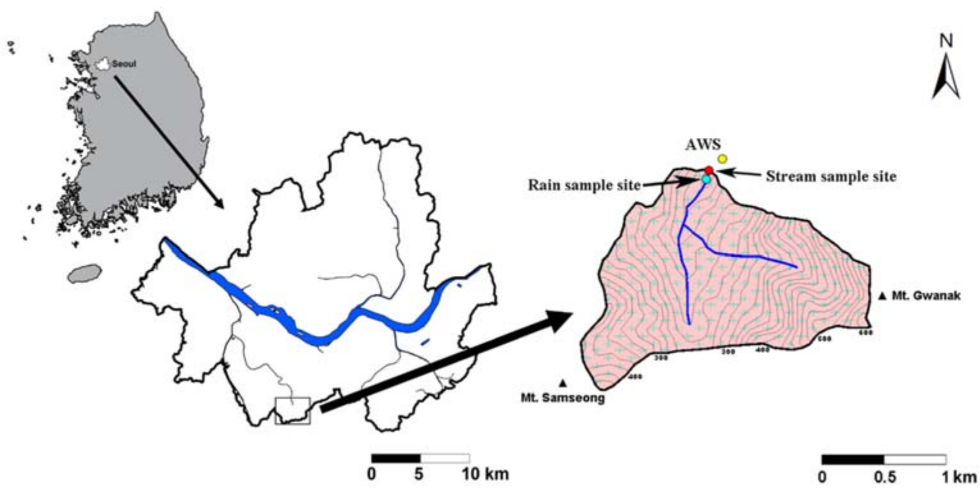

Fig. 1. Maps of Korea, Seoul, and Dorim-cheon watershed. AWS (Automatic Weather Station), stream sample site, and rain sample site are depicted with yellow, red and cyan colored circle.

cross section, and A_i is area of small cross section. Measurement of flow velocity and cross section area was performed from July 23 to October 28 with a current meter.

Stream samples were divided into two groups; one sample was collected in dry period on October 16, 2014 assumed as old water component (groundwater), and the other samples were collected from October 20 to October 28, 2014, including rain event period. Stream and rain samples were collected using LDPE Wide-Mouth 60 ml bottles from Nalgene™. Seventy four stream samples were collected in high-resolution interval ranging from 15 to 30 minutes during the two days of rainfall event, and 14 stream samples were collected sporadically after termination of rain event for 7 days at stream sample site. Forty four of rain samples were collected on October 20 and 21, 2014 at rain sample site every 30 minutes with adjustments of increasing sampling frequency as rainfall intensity went higher. Rain samples which had insufficient amounts for analyzing were excluded. Amount of rainfall at the sample site was obtained every hours from the AWS.

Isotopic compositions of hydrogen and oxygen from stream and rain water samples collected from each sites were analyzed. Analyses of each sample were conducted at the Korea Institute of Geoscience and Mineral Resources (KIGAM), using a Cavity Ring-Down Spectroscopy from Picarro (L2120-*i*) which has uncertainty within ±0.10‰ and ±0.50‰ for $\delta^{18}O$ and δD, respectively (Jung et al., 2013). The δ convention is used to represent isotopic values as follows:

$$\delta(‰) = \left[\frac{R_{SAMPLE} - R_{SMOW}}{R_{SMOW}}\right] \times 1000 \quad (3)$$

where R is $^{18}O/^{16}O$ or D/H, and SMOW is Standard Mean Ocean Water, used as standard water. Although the total number of water samples was 133, including 89 of stream samples and 44 of rain samples, 50 of representative samples were analyzed in advance.

2.3. Isotopic hydrograph separation

To separate stream component into new (rain) and old water component, mass balance equations initiated from Sklash and Farvolen(1979) is used as following:

$$Q_s = Q_o + Q_r \quad (4)$$

$$C_s Q_s = C_o Q_o + C_r Q_r \quad (5)$$

where Q is discharge, C is isotopic concentration, and the subscripts s, o, and r are stream water, old water, and rain water, respectively. There are several assumptions to utilize these equations initiated by Sklash and Farvolden (1979): (1) the isotopic values of old water and rain component are significantly different; (2) the isotopic value of rain water is constant; (3) old water and vadose water have isotopically equivalent concentration or contribution of vadose water is negligible; and (4) surface storage contributes minimum during runoff event. Table 1. Summary of studies using isotopic hydrograph separation technique shows previous studies using isotopic hydrograph separation technique. In this

Table 1. Summary of studies using isotopic hydrograph separation technique

Source	Topography	Scale	Rain water fraction
Sklash and Farvolden (1979)	Forested land (760-880 m.a.s.l.)	1.2 km^2	12%
	Forested land (720-780 m.a.s.l.)	3.9 km^2	20%
	Agriculture (202-212 m.a.s.l.)	~1 km^2	~20%
Ogunkoya and Jenkins (1993)	Peatland (325-1111 m.a.s.l.)	9.98 km^2	19%
Ladouche et al. (2001)	Hillslope (883-1146 m.a.s.l.)	0.8 km^2	2-13%
Onda et al. (2006)	Mountain (shale, < 1620 m.a.s.l.)	0.055 km^2	0-2%
	Mountain (granite, < 1470 m.a.s.l.)	0.063 km^2	36-53%
Pu et al. (2013)	Alpine (< 5596 m.a.s.l.)	29.4 km^2	38-59%
Xing et al. (2015)	Alpine (1235-7654 m.a.s.l.)	94.75 km^2	19-39%
Lee et al. (2006)	Hillslope (110-180 m.a.s.l.)	0.033 km^2	47-54%
Cho et al. (2007)	Forested land	4.09 km^2	6-18%
Cho et al. (2008)	Mountain and Agriculture	109.83 km^2	93%
		407.97 km^2	79%
		46.99 km^2	89%

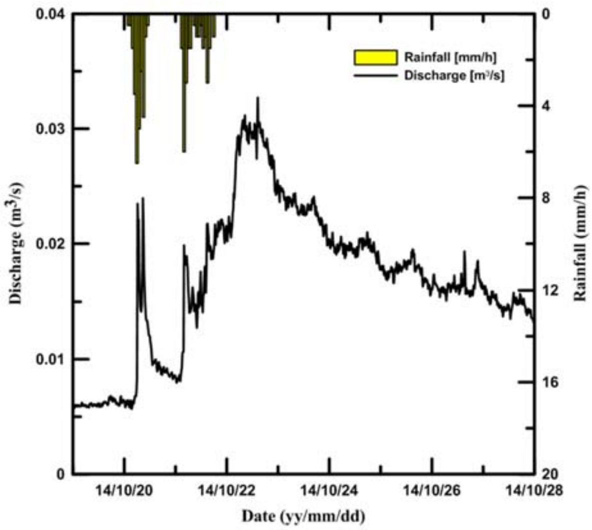

Fig. 2. Time series of rainfall amount (yellow bar) and discharge (black line) during the study period. Rainfall amount was measured at Gwanak AWS in every hour. Discharge was calculated with water level measured at the stream gauge every 15 minutes compensated with barometric pressure.

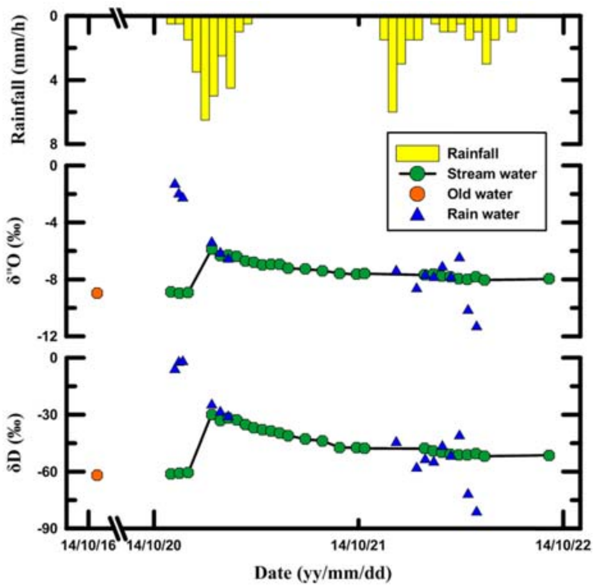

Fig. 3. Rainfall amount and isotopic compositions of each component during the study period. An old water sample was taken at the stream sampling site in advance.

Table 2. Characteristics of Dorim-cheon samples

Component	Tracer	Minimum	Median	Maximum	Mean	Standard deviation
Old water						
	$\delta^{18}O$				–8.98	0*
	δD				–61.85	0*
Rain water						
	$\delta^{18}O$	–11.23	–7.05	–1.21	–6.46	2.76
	δD	–80.44	–43.97	–1.28	–39.21	23.26
Stream water						
	$\delta^{18}O$	–8.98	–7.68	–5.88	–7.63	0.79
	δD	–61.10	–49.09	–29.94	–47.13	8.80

*There is only one sample for old water component.

study, a weighted mean of isotopic values of rain samples was used. It was assumed that there was no contribution of vadose water because the soil layer covering study site is very thin.

3. Results and Discussion

From the AWS at the study site, rainfall event was observed for 41 hours from 2 a.m. on October 20 to 7 p.m. on October 21, 2014 with its pauses of 17 hours (Fig. 2). Total amount of rainfall was 50.5 mm for the study period and mean discharge of base flow was 0.0061 m^3/s. There were two big peaks for discharge at 8:45 a.m. on October 20 and 2:30 p.m. on October 22 which were 0.0240 m^3/s, and 0.0327 m^3/s, respectively.

Fig. 3 shows $\delta^{18}O$ and δD compositions of old water, rain water and stream water. Characteristics of each component can be found from Table 2. Because old water was sampled from the same place with the stream sampling site before the rain event, isotopic compositions of old water and the three initial samples of stream water shows similar values.

Isotopic values of stream water were increased from 4:00 a.m. to 6:45 a.m. on October 20 with a value of –3.0‰ and –30.7‰ for $\delta^{18}O$ and δD, respectively. The increase of

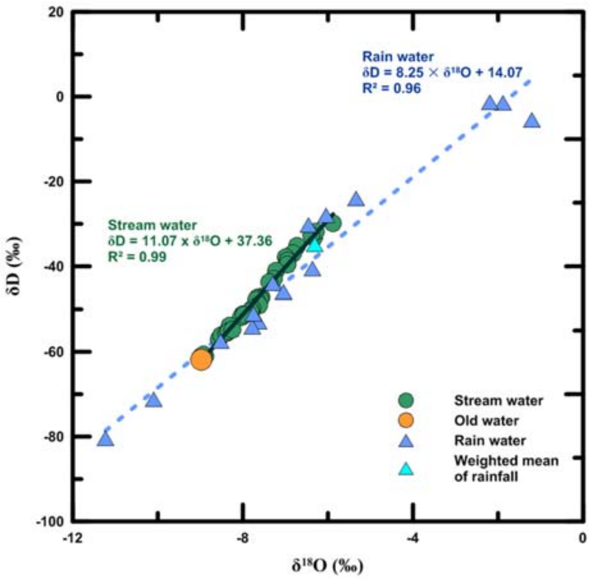

Fig. 4. MWL (Meteoric Water Line) of each component. The slope of 8.25 from rain water samples can be interpreted that rain water have not undergone excessive evaporation. It is shown that most of stream samples are plotted between old water sample and weighted mean of rainfall samples.

stream water value shows that stream water was affected by the rain water, which has relatively enriched isotopic value. After the peak of –5.9‰ for $\delta^{18}O$ and –29.9‰ for δD, respectively, the values of stream water have been continuously depleted during the study period. During the rain event, isotopic values of rain water had been continuously depleted. Variations of $\delta^{18}O$ and δD in rain water were 10.0‰ and 76.2‰, respectively.

Fig. 4 shows Meteoric Water Line (MWL) of rain water and stream water from the study period. Old water sample was also depicted in Fig. 4. The slope of rain water samples is 8.3, which is close to the value of 8 from Global Meteoric Water Line (GMWL) of Craig(1961), which can be explained that the rain water samples have not undergone excessive evaporation. The mean value of deuterium excess proposed by Dansgaard(1964) for rain water in Fig. 4 is 12.43‰, which is a close value with 10‰ from Craig's GMWL. Knowing that deuterium excess for precipitation is related to humidity during evaporation from the ocean surface, it can be inferred that the humidity for our study is similar with the humidity for Craig's line, 80% (Merlivat and Jouzel, 1979). Most of the stream water samples are plotted between old water sample and the weighted mean

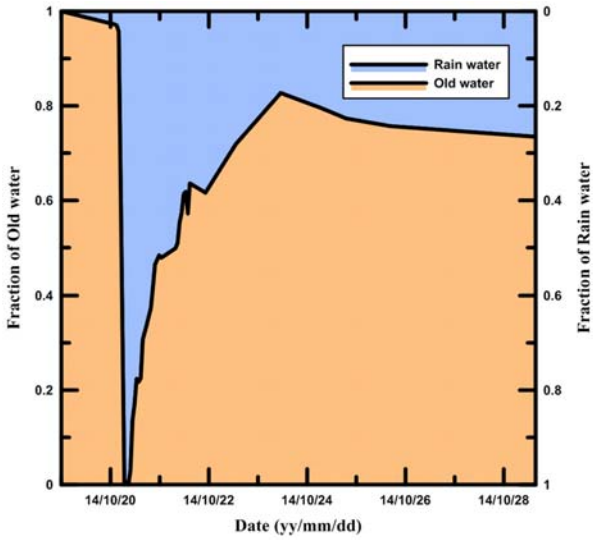

Fig. 5. Fraction of old water and rain water component using $\delta^{18}O$ during the study period.

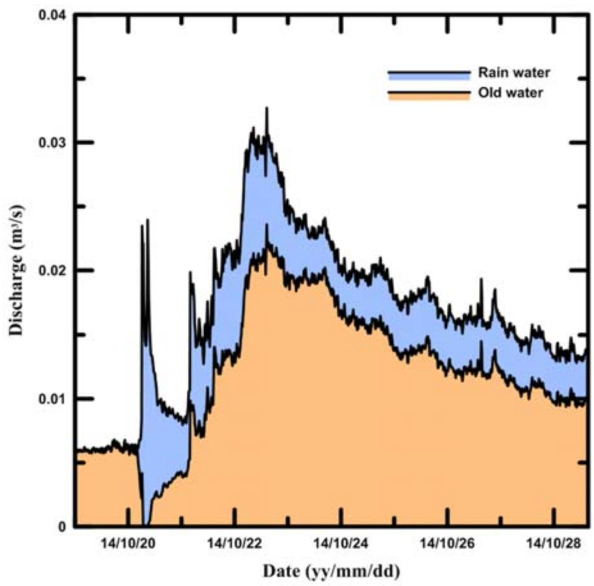

Fig. 6. Result of hydrograph separation using ä^{18}O during the study period.

value of rain water samples. The weighted mean value of rain water isotopes was calculated considering the amount of rainfall observed from the AWS.

Using mass balance equation of (4) and (5), a hydrograph separation of the stream water was carried out using $\delta^{18}O$ values of old water and weighted mean value of rain water (Fig. 5 and Fig. 6). Fig. 5 shows fractions of old water and rain water using $\delta^{18}O$. At the peak of isotopic values from the stream water in Fig. 3, little of old water contributed to the stream water. Except of instant dominance of rain water, contribution of old water was dominant during the entire study period. With discharge data from Fig. 2, discharge of old water and rain water can be depicted. On October 20, 2014 at 8:45 a.m., rain water had the largest amount of discharge (0.02340 m^3/s) and on October 22, 2014 at 2:30 p.m., old water had the largest amount of discharge (0.0236 m^3/s). From the beginning of rainfall event to the end of the study period, it can be inferred from the hydrograph separation using $\delta^{18}O$ value, among 13311 m^3 of water from stream water, 9491 m^3 of water (71.3%) came from old water. Using deuterium as a tracer, the amount of old water was 9316 m^3 and it took 70.0% of stream water during the study period. The dominance of old water component in this study area covered with thin soil layer can be comparable with other studies where hydrograph separation was conducted in mountainous area with little of soil and granitic area (Huth et al., 2004; Marc et al., 2001). Huth et al. (2004) showed that the fraction of event water (melt water) consists 80-90% in a glacial cirque with poorly developed soil. Marc et al.(2001) conducted hydrograph separation in a granitic mountain, which has 0.6 m of soil layer and showed that 22%, 33%, and, 100% of rainfall contributions according to each events. The difference of the fraction of event water component can account for the difference of seasons, altitudes and other characteristics of catchments.

4. Conclusion and future works

In this study, we conducted hydrograph separation of stream water into two different component, old water and rain water, in granitic watershed using a two-component mixing model to understand the impact of old water component to granitic watershed with thin soil layer. An analysis of rain water and stream water using oxygen-18 and deuterium isotopes was carried out.

Isotopic compositions of old water assumed as the stream water collected in advance were –8.98‰ and –61.85‰ for oxygen and hydrogen, respectively. The old water contribution to the Dorim-cheon in study area was dominant with a value of 71.3% for 8 days of study period. This represents that even in the small watershed, which is covered with thin soil layer in granite mountain region, the stream water is considerably influenced by old water inflow rather than rainfall. Temporal variations of oxygen-18 in precipitation greater than 10‰ ($\delta^{18}O_{max} = -1.21‰$, $\delta^{18}O_{min} = -11.23‰$) were observed. Lee et al.(2014) showed variation of isotopic value from new water (such as rainfall or snowmelt) generates a systematic error. For the next step of this study, fractionations of oxygen isotope as new water in isotopic hydrograph separation should be considered. On the other hand, using chloride as a tracer to separate hydrograph would be comparable to the result from this study. From the study of Kichner et al.(2010), they compared water isotopes and chloride as hydrological tracers and showed that both of tracers behave similarly as tracers of transport, storage and mixing but estimates of mean travel time is longer with $\delta^{18}O$ than Cl^-. For the future work, chloride from the same study site and period will be analyzed for comparison of hydrograph separations using each tracer.

Findings from this study can be utilized as a basic information for securing water resources. It is necessary to study applications of stable water isotopes to a small watershed and to better understand how water derived from atmosphere moves to subsurface and from subsurface to stream. This approach can be applied to a small watershed at Jeju Island, Ulleungdo and the mountain areas in Kangwon for water resources managements. Studies of stable water isotopes can be used to trace a source of water vapor and for prediction of flow paths from atmosphere to subsurface and stream water.

Acknowledgements

This work was supported by the Basic Research Project (15-3420) of the Korea Institute of Geoscience and Mineral Resources (KIGAM) funded by the Ministry of Science, ICT and Future Planning and partially supported by a research grant (PM15020) of the Korea Polar Research Institute.

References

Cho, S.-H., Cho, M.J., Moon, S.H., Kim, Y., and Lee, K.-S., 2008, Estimation of groundwater recharge in a district-scale area using ^{18}O tracer, *J. Korean Earth Sci. Soc.*, **44**(3), 331-340.

Cho, S.-H., Ha, K., Kim, T., Cheon, S.H., and Song, M.Y., 2007, Hydrograph separation for two consecutive rainfall events using tracers (δ^{18}O & Cl), *J. Korean Earth Sci. Soc.*, **43**(2), 253-263.

Clark, I.D. and Fritz, P., 1997, Environmental isotopes in hydrogeology, CRC press LLC, Boca Raton, FL, 328 p.

Craig, H., 1961, Isotopic variations in meteoric waters, *Science*, **133**(3465), 1702-1703.

Dansgaard, W., 1964, Stable isotopes in precipitation, *Tellus A*, **16**(4), 436-468.

Eshleman, K.N., Pollard, J.S., and O'Brien, A.K., 1993, Determination of contributing areas for saturation overland flow from chemical hydrograph separations, *Water Resour. Res.*, **29**(10), 3577-3587.

Hoeg, S., Uhlenbrook, S., and Leibundgut, C., 2000, Hydrograph separation in a mountainous catchment-combining hydrochemical and isotopic tracers, *Hydrol. Process.*, **14**(7), 1199-1216.

Hong, K.-O., Suh, M.-S., and Rha, D.-K., 2006, Temporal and spatial variations of precipitation in South Korea for recent 30 years (1976-2005) and geographic environments, *J. Korean Earth Sci. Soc.*, **27**(4), 433-449.

Huth, A., Leydecker, A., Sickman, J., and Bales, R., 2004, A two-component hydrograph separation for three high-elevation catchments in the Sierra Nevada, California, *Hydrol. Process.*, **18**(9), 1721-1733.

IPCC, 2007, Climate change 2007-the physical science basis: Working group I contribution to the fourth assessment report of the Intergovernmental Panel on Climate Change, 4, Cambridge University Press, Cambridge and New York, NY, 996 p.

Jang, J.-H., Han, B.-H., Lee, K.-J., Choi, J.-W., and Noh, T.-H., 2013, A study on the characteristics and changes of vegetation structure of the plant community in Mt. Kwanak, *Korean J. Environ. Ecol.*, **27**(3), 344-356.

Jung, Y.-Y., Koh, D.-C., Lee, J., and Ko, K.-S., 2013, Applications of isotope ratio infrared spectroscopy (IRIS) to analysis of stable isotopic compositions of liquid water, *Econ. Environ. Geol.*, **46**(6), 495-508.

Kirchner, J.W., Tetzlaff, D., and Soulsby, C., 2010, Comparing chloride and water isotopes as hydrological tracers in two Scottish catchments, *Hydrol. Process.*, **24**(12), 1631-1645.

Kwon, S.-T., Shin, K.B., Park, H.K., and Mertzman, S.A., 1995, Geochemistry of the Kwanaksan alkali feldspar granite: A-type granite, *Jour. Petrol. Soc. Korea.*, **4**, 31-48.

Ladouche, B., Probst, A., Viville, D., Idir, S., Baqué, D., Loubet, M., Probst, J.-L., and Bariac, T., 2001, Hydrograph separation using isotopic, chemical and hydrological approaches (Strengbach catchment, France), *J. Hydrol.*, **242**(3), 255-274.

Lee, J., Feng, X., Faiia, A., Posmentier, E., Osterhuber, R., and Kirchner, J., 2010, Isotopic evolution of snowmelt: A new model incorporating mobile and immobile water, *Water Resour. Res.*, **46**(11).

Lee, J., Koh, D.-C., and Choo, M.K., 2014, Influences of fractionation of stable isotopic composition of rain and snowmelt on isotopic hydrograph separation, *J. Korean Earth Sci. Soc.*, **35**(2), 97-103.

Lee, K.-S., Park, Y., Kim, Y., Jeong, J.-H., Park, S.-K., Shin, H.-S., Bong, Y.-S., and Shin, W.-J., 2006, A preliminary hydrograph separation study in a small forested watershed using natural tracers, *J. Geol. Soc. Korea.*, **42**(3), 427-437.

Marc, V., Didon-Lescot, J.-F., and Michael, C., 2001, Investigation of the hydrological processes using chemical and isotopic tracers in a small Mediterranean forested catchment during autumn recharge, *J. Hydrol.*, **247**(3), 215-229.

McColl, J.G., 1981, Effects of acid rain on plants and soils in California, Final Rep. Contract A8-136-31, California Air Resources Board, 111 p.

Melack, J.M., Stoddard, J.L., and Ochs, C.A., 1985, Major ion chemistry and sensitivity to acid precipitation of Sierra Nevada lakes, *Water Resour. Res.*, **21**(1), 27-32.

Merlivat, L. and Jouzel, J., 1979, Global climatic interpretation of the deuterium-oxygen 18 relationship for precipitation, *J. Geophys. Res.*, **84**(C8), 5029-5033.

Ogunkoya, O. and Jenkins, A., 1993, Analysis of storm hydrograph and flow pathways using a three-component hydrograph separation model, *J. Hydrol.*, **142**(1), 71-88.

Onda, Y., Tsujimura, M., Fujihara, J.-i., and Ito, J., 2006, Runoff generation mechanisms in high-relief mountainous watersheds with different underlying geology, *J. Hydrol.*, **331**(3), 659-673.

Pu, T., He, Y., Zhu, G., Zhang, N., Du, J., and Wang, C., 2013, Characteristics of water stable isotopes and hydrograph separation in Baishui catchment during the wet season in Mt. Yulong region, south western China, *Hydrol. Process.*, **27**(25), 3641-3648.

Sklash, M.G. and Farvolden, R.N., 1979, The role of groundwater in storm runoff, *J. Hydrol.*, **43**, 45-65.

Taylor, S., Feng, X., Kirchner, J.W., Osterhuber, R., Klaue, B., and Renshaw, C.E., 2001, Isotopic evolution of a seasonal snowpack and its melt, *Water Resour. Res.*, **37**(3), 759-769.

Xing, B., Liu, Z., Liu, G., and Zhang, J., 2015, Determination of runoff components using path analysis and isotopic measurements in a glacier-covered alpine catchment (upper Hailuogou Valley) in southwest China, *Hydrol. Process.*, **29**(14), 3065-3073.