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A weighted, multi-method approach for accurate basin-wide streamflow estimation in an ungauged watershed

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S U M M A R Y

River discharge is a commonly measured hydrologic variable; however, estimate uncertainty is often higher than acceptable limits. To quantify method limitations and spatiotemporal variability, a multi-year hydrologic flow partitioning investigation was completed under monsoonal conditions in the ungauged complex terrain of the Haean Catchment, South Korea. Our results indicate that sediment transport from a single annual monsoonal event can significantly modify the channel cross-sectional area resulting in inaccurate stage-discharge rating curves. We compare six discharge measurement methods at 13 locations that vary in slope from 1% to 80%, with discharge ranging up to four orders in magnitude, which enabled us to weight the accuracy of each method over a specific range in discharge. The most accurate discharge estimation methods are the weir, the acoustic Doppler current profiler, and the in-stream velocity area method; however, under certain conditions each of these methods is less desirable than other methods. The uncertainty in the three methods is on average 0.4%, 4.7%, and 6.1% of the total discharge, respectively. The accuracy of the discharge estimates has a direct influence on the characterization of basin-wide hydrologic partitioning, which can lead to significant variability in sediment erosion rates and nutrient fate and transport.

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1. Introduction

To quantify the spatial water balance and flow patterns within a watershed, it is necessary to first characterize the flow partitioning within hydrologic compartments. Watershed-scale flow partitioning can be separated into surface water, the variably saturated zone, shallow groundwater, deep groundwater, and evapotranspiration (ET). Of these, surface water discharge is an important variable governing stream function with respect to habitat diversity, nutrient export, and water yield. However, many river discharge studies overlook these changes with temporally limited and ineffective spatial discretization of monitoring locations; providing limited process understanding of watershed hydrologic connectivity. In fact, as Bjerklie et al. (2003) describe, river discharge is inadequately monitored due to a variety of technological and economic obstacles and the overall availability of discharge data has been declining for decades (Shiklomanov et al., 2002; Vorosmarty et al., 1999).

River discharge is typically estimated by measuring the water velocity, cross-sectional channel area, and stage height, which is repeated at multiple locations throughout a watershed. The relationship between the calculated discharge and stage height is developed into a continuous rating curve from an array of instantaneous measurements. The use of acoustic Doppler current profilers (ADCP) has increased over recent decades as a tool to more accurately approximate discharge (Dinehart and Burau, 2005; Muste et al., 2004). More recently, remotely sensed earth observation techniques have been utilized with varying success to quantify discharge in ungauged basins and overcome difficulties in obtaining reliable, trans-boundary, long-term measurements (Negrel et al., 2011; Sun et al., 2010). Many studies calibrate rainfall-runoff models to gauged streamflow data and use empirical and stochastic regionalization methods to parameterize ungauged catchments

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(Vaze et al., 2011; Viviroli et al., 2009). Although, river discharge in monsoonal mountainous regions is highly variable in space and time and the concept of parameter regionalization may provide an insufficient estimation of hydrograph responses (Wagener and Wheater, 2006). Local storms, which cause sediment aggradation and degradation can significantly alter annual discharge and influence the accuracy and uncertainty of surface water discharge measurements.

In the relatively rare locations where discretized river discharge monitoring networks exist, limited effort has been instituted to quantify the uncertainty in discharge measurements and long-term trends. There is limited access to spatially distributed, long-term monitoring locations in large complex watersheds such as those found throughout Asia and these monitoring sites are typically constrained to areas adjacent to roads, bridges, and engineered structures (Lam et al., 2005). In fact, much of Korea, particular near the demilitarized zone (DMZ) along the border with North Korea, is relatively ungauged. Accurate, extreme discharge conditions are not often measured since reliable data are typically restricted to a smaller range of discharge conditions; however, these estimates are particularly warranted during peak or drought conditions. The combination of the lack of data and the decrease in measurement accuracy during extreme conditions increases the method uncertainties. Typically, a single annual monsoonal event alters the channel cross-sectional area by aggrading or degrading the sediment, which invalidates the stage versus discharge rating curve and has been shown to be an important control on altering groundwater and surface water interactions (Bartsch et al., submitted for publication). Arnhold et al. (2013) calculated average annual terrestrial erosion rates within Haean between 30.6 and 54.8 t ha^{-1}. Therefore, accurately quantifying spatiotemporal river discharge rates throughout a catchment can have significant implications on a better understanding of the groundwater and surface water interactions and soil erosion and sediment transport processes, which contribute to the diminished water quality that is affecting major metropolitan areas.

The primary focus of this study is to determine accurate basin-wide streamflow measurements in an ungauged basin using several different methods, over periods of extreme discharge variability. We use a multi-year, multi-method discharge estimation approach throughout the Haean catchment to quantify spatial variations in river discharge, identify temporal patterns, and characterize the appropriate range of discharge measurements for each method under baseflow and monsoonal conditions. We have focused our study in a topographically complex landscape under monsoonal precipitation conditions to better quantify the weighted uncertainty in each of these estimations and elaborate on the difficulties of individual measurement techniques.

2. Study location

2.1. General location and physiography

The study was conducted in the Haean catchment of Gangwon province, South Korea. The 62.7 km^2 catchment is located adjacent to the demilitarized zone (DMZ) between South and North Korea (38.2388–38.3293°N; 128.0825–128.1728°E). The unique bowl-shaped topographical characteristics of the Haean catchment range

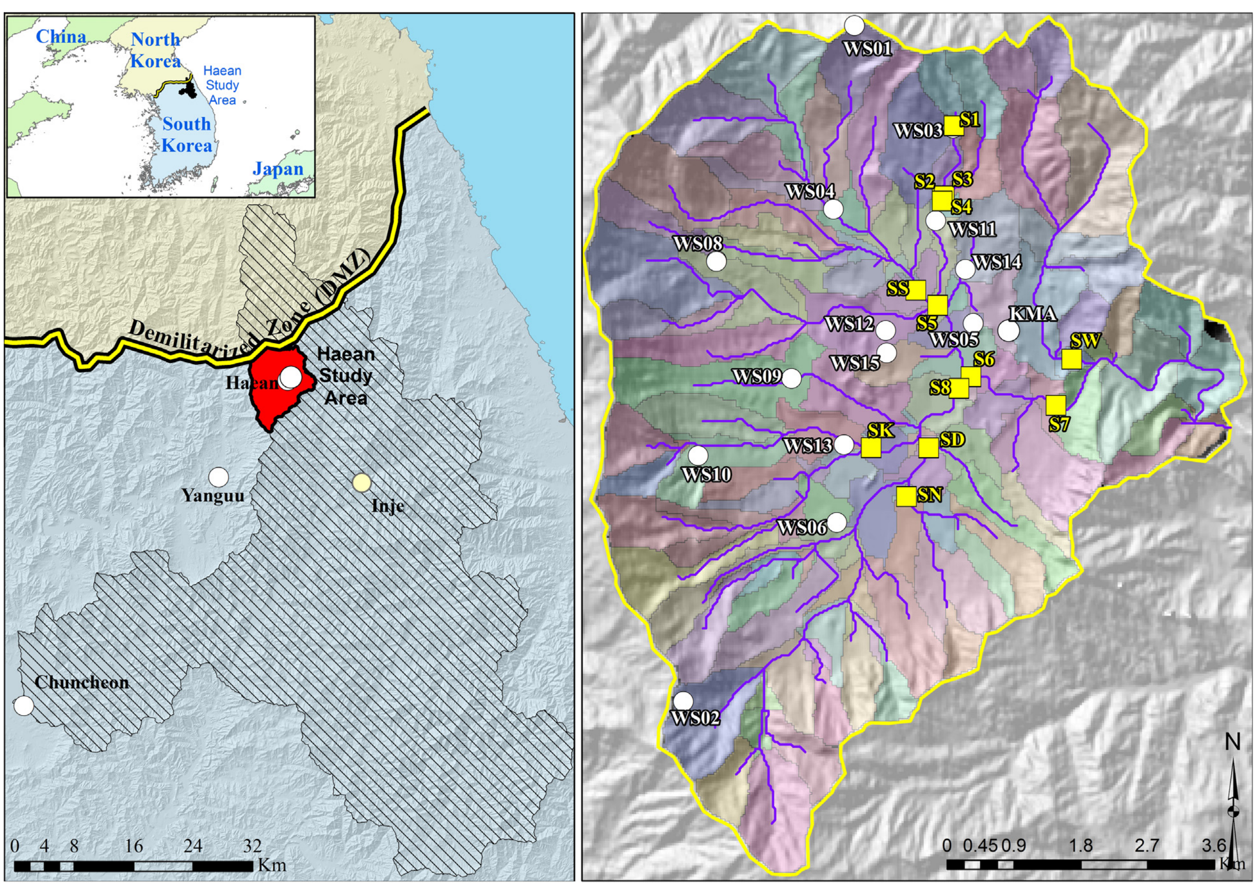

Fig. 1. Haean study area within the Lake Soyang watershed is located in northeastern South Korea along the demilitarized zone (DMZ) border with North Korea. Local and regional meteorological stations are denoted with white circles and the prefix (WS). River discharge monitoring locations are denoted by the yellow squares and the prefix (S). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)