Agricultural Water Management 212 (2019) 378–387

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Response of surface water quantity and quality to agricultural water use intensity in upstream Hutuo River Basin, China

Shumin Han, Qiuli Hu, Yonghui Yang*, Yanmin Yang, Xinyao Zhou, Huilong Li

Key Laboratory of Agricultural Water Resources, Hebei Laboratory of Agricultural Water-saving, Center for Agricultural Resources Research, Institute of Genetics and Developmental Biology, Chinese Academy of Sciences, 286 Huaizhong Road, Shijiazhuang 050021, China

A R T I C L E I N F O

Keywords:
Hydrochemistry
Runoff
Agricultural water use
Hutuo River Basin
China

A B S T R A C T

A field hydrology survey was conducted to determine spatial variations in regional water yield and use intensity and clarify the main causes of the variation in upstream Hutuo River Basin (UHTB). The study showed that: 1) the spatial distribution of flow, salt and stable isotopes reflected variations in regional water yield and use intensity. Total Dissolved Solids (TDS) in river water were lower in Qingshui tributary and the headwater region of Hutuo River (HTR). The distributions of δD and δ^{18}O of river water were nearly parallel to the Local Meteoric Water Line (LMWL), except for the middle reach. Intensive agricultural activities were responsible for the deviation of spatially stable isotopes from LMWL, the highest TDS and 0.85 evaporation fraction in the middle reach. 2) The spatial flow indicated that almost all the river water was used in agriculture (especially in the middle reach of UHTB) before inflow from Qingshui tributary. Based on the balance in monitored flow rate and isotopes, about 67.9% of the water flow (11.66 m^3/s) was from upstream Shanxi province and discharged into the downstream of Hebei Province; 91.9% of which was from Qingshui tributary. 3) Irrigation function of upstream reservoirs was not fully reflected due to less storage of water along with low recharge and discharge events. Given the declining water yield and high water requirement, there was the need to overhaul agricultural water use strategies to ensure cross-border water availability. The research could lay the basis for designing cross-border agricultural water use strategies in UHTB and other basins with similar hydro-climatic conditions.

1. Introduction

River runoff is a vital hydrological process especially in headwater catchments. The volume of runoff influences the degree of water availability, vegetation distribution and land cover change in the runoff producing area. Runoff is also directly related with lateral flow (surface and subsurface) from mountains to downstream regions.

There is an increasing trend of runoff decline in terrestrial ecosystems around the world. With increasing scarcity of water, hydrologists and policy-makers have increasingly focused on the factors that influence runoff decline in river catchments. Generally, climate variability and human activities have emerged as the two important factors influencing runoff decline (Buendia et al., 2016; Gao et al., 2016). While the effect of the variation in climate is mainly in form of decreasing precipitation, human activities through land use/cover change, reservoir operation and direct surface water extraction affect spatio-temporal distribution of streamflow (Wang and Hejazi, 2011; Xu et al., 2014). The above conditions are generally studied through analysis of long-term data, which are turn strongly dependent on the time period.

Hutuo River Basin (HRB) is a typical headwater basin in North China Plain (NCP) that is the main source of groundwater for the entire central region of the plain. Hutuo River (HTR) flow has been declining in the last half-century and runoff during non-flood season since the early 2000s has decreased to one third of that in the 1950s (Cheng et al., 2014). The decline in inflow from upstream catchment during non-flood season is the main cause of significant environmental deterioration in downstream regions. Human activity has the highest impact on runoff decline and agricultural water use is the dominant factor (Tian et al., 2009; Yang and Tian, 2009). Furthermore, there are no disturbances in evapotranspiration and precipitation in HRB headwater region. Also evapotranspiration in the region is strongly influenced by precipitation, which has been decreasing in the past half-century (Zhang et al., 2012).

Long-term monitoring points of runoff are generally scarce in mountain catchments. There are only three such national monitoring points in the 15 915 km^2 upstream of HRB, which does not provide sufficient data on river water quality and quantity in this region. This is not enough for hydrological and meteorological analysis in space, but

* Corresponding author.
E-mail address: yonghui.yang@sjziam.ac.cn (Y. Yang).

https://doi.org/10.1016/j.agwat.2018.09.013
Received 30 May 2018; Received in revised form 4 September 2018; Accepted 6 September 2018
Available online 20 September 2018
0378-3774/

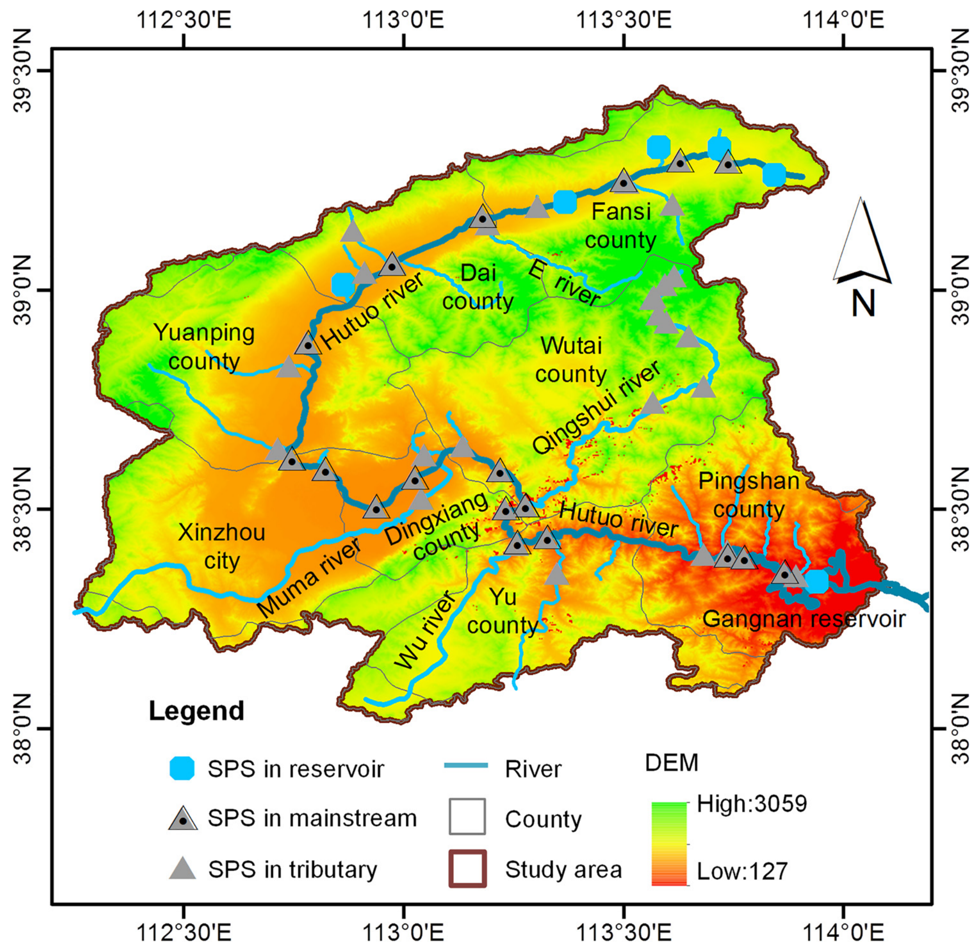

Fig. 1. A map of the study area depicting the spatial distribution of sample sites (SPS), rivers, counties and topography of Upstream Hutuo River Basin.

also for analysis of runoff processes and regional water use in complex mountain catchments. Environmental isotopes and chemical studies of the hydrogeology along with dense field survey is an excellent way of depicting spatial correlations of hydrological processes, water chemistry and water use.

The evaluation of the main factors of specific hydrological processes has been the center of hydrological research. As environmental isotopes are not significantly affected by transpiration, stable isotopes of oxygen and hydrogen can be used to differentiate between evaporation (which fractionates isotopes) and non-fractionating process of transpiration (Cartwright et al., 2012). The combined assessment of oxygen, hydrogen and major ion chemistry can be used to determine the primary processes by which evaporation and transpiration control solute concentration (Moya et al., 2016). This can in turn be used to evaluate the relative importance of evaporation and transpiration in the build-up of salinity (Sun et al., 2016). In basins with dominant native vegetation and efficient use of available precipitation, Cartwright et al. (2012) noted that ^{18}O is not correlated with groundwater TDS and that transpiration is a more important process in solute concentration. In Sambhar Lake in Rajasthan (India), Yadav (1997) observed that ^{18}O in the lake water varied linearly with salt content, which phenomenon was dominantly driven by evaporation. Stable isotope fractionation during evaporation from open water bodies is described by Rayleigh evaporation model. As isotope ratio increases with increasing evaporation rate, evaporation of open water bodies can be estimated using isotope count (Dreybrodt and Deininger, 2014; Wang et al., 2014b). By estimating the remaining fraction and salt content of water bodies, it is possible to isolate the contributions of evapo-driven concentration and mineral dissolution and/or transpiration to total salinity of a given water sample (Huang and Pang, 2012; Wang and Guo, 2015).

Isotope mass balance is widely used to evaluate water balance and transformation in hydrological processes, especially in estimating inflow, outflow and interaction of surface water and groundwater. Zhang et al. (2013) estimated inflow, outflow and evaporation of Bosten Lake in China. Gibson et al. (2017) evaluated the trends in regional evaporation loss and water yield based on stable isotope mass balance in lakes of Precambrian shield drainages in Ontario, Canada. Fan et al. (2016) quantified the ratio of ice-snowmelt, rain and groundwater flow into Tarim River, the largest inland river in China. Yang et al. (2012) estimated groundwater composition at 60–70% river water after the wet season period. Shaw et al. (2017) estimated groundwater inflow and outflow for Georgetown Lake, a lake with structurally complex geology in Montana, USA.

Against the declining runoff and degrading environment in Hutuo River Basin (HTB), there is the need for spatial hydrology data and improved hydrological characterization of surface water systems in HTB. The use of environmental isotopes and hydro-chemical methods can deepen our understanding of spatial water consumption in various land use conditions. This can in turn lead to more accurate determination of the root cause of runoff decline and to develop guidelines for scientific water use and management. Also the isotope and salinity of stream water sampled before the rainy season (that is not mixed with the present-day rainwater characterized by relative low ion and isotope concentration) can reasonably reflect true spatial water use and yield of native vegetation and crops.

In this study, several surface water systems (including rivers and reservoirs) were sampled before the rainy season and river flow rates estimated along mainstream and tributaries of HTR in upstream Hutuo