Spatial Variation and Long-Term Change of Hydrological Regime of Kherlen River Basin, Mongolia

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1 Background

In the northeastern Asia including Mongolia and the northeastern China, a climatic shift from northern humid area to southern arid area exists in a relatively narrow band. A steep, meridional gradient in climatic conditions, a distinct "ecotone" (i.e., forest-grassland-desert) is formed in the northeastern Asia. Such an ecotone is thought to be very sensitive to changes in external environment (e.g., global warming and human activities). It has been reported that air temperature in winter and spring gradually increased and precipitation amount decreased in the last four decade. It is highly possible that the warming and drying of the atmosphere induce drastic changes in plant growth and vegetation distribution through changes in hydrological cycle.

2 Purpose, study basin and data

This study is part of CREST/RAISE (Core Research for Evalutional Science and Technology/Rangelands Atmosphere-Hydrosphere-Biosphere Interaction Study Experiment in Northeastern Asia) project. The main purpose of this study is to understand the hydrological regime and its variability of the study basin, the Kherlen River basin located in east part of Mongolia shown in **Figure 1**. There are four hydrological gauging stations, Mongenmoryt (MGM), Baganuur (BGN), Underkhaan (UDK) and Choibalsan (CBS). Because Mongenmoryt is newly set up, only Baganuur, Underkhaan and Choibalsan are used in this study. Their drainage areas are 7,329, 40,095 and 72,528 square kilometers. There are several tens of meteorological stations covering the basin and its environs. They are distinguished two types, "Meteo-post" and "Meteo-station" (higher rank station).

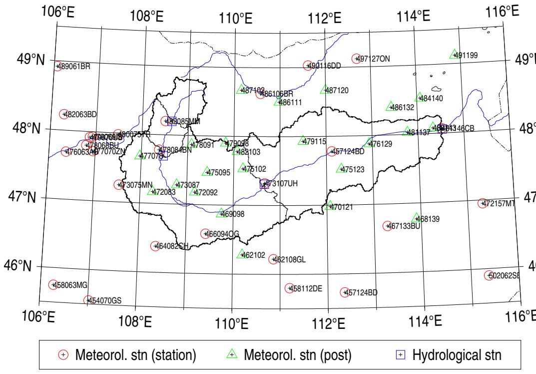

Figure 1: Study basin and stations.

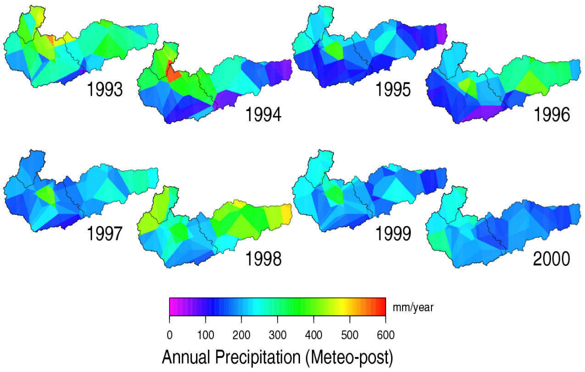

Figure 2: Distribution of annual precipitation.

3 Rainfall distribution

In this study, the target basin is divided into one by one kilometer square grid cells. The daily precipitation at all grid cells are interpolated from precipitation data at 23 Meteo-posts and one Meteo-station by using Thiessen polygon based on nearest neighbor method. **Figure 2** shows the annual precipitation over the basin from 1993 to 2000. It is shown that

- The annual precipitation changes from 100 mm/year to 500 mm/year;

- The upstream mountainous area, the sub-basin above Baganuur has the largest precipitation;

- There is a significant north-south gradient of precipitation. More precipitation falls at the northern part of this basin than the southern part; and

- There is a large temporal variation of annual areal precipitation.

These may be major causes of the so-called "ecotone".

4 Water balance of three sub-basins

The water balance of three sub-basins, the sub-basin above Baganuur (above BGN), the tributary area between Baganuur and Underkhaan (BGN to UDK) and the tributary area between Underkhaan and Choibalsan (UDK to CBS) are considered. The drainage areas are 7,329, 32,766 and 32,433 square kilometers respectively. For dividing into sub-basins and estimating of drainage areas, we use HYDRO1k produced by USGS (U. S. Geological Survey, 1999). HYDRO1k is a geographic database developed to provide comprehensive and consistent global coverage of topographically derived data sets, including streams, drainage basins and ancillary layers derived from the USGS' 30 arc-second digital elevation model of the world (GTOPO30). **Figure 3** shows the location of these sub-basins. **Figure 4** shows the water balance of these sub-basins. For each sub-basin, we have water balance equation as following:

$$E = P - \delta Q, \quad (1)$$

$$\delta Q = Q_{in} - Q_{out}, \quad (2)$$

where P is precipitation; E is evapotranspiration; Q_{in} is the inflow from upstream area; and Q_{out} the outflow. Runoff generated within the sub-basin is included in δQ. For sub-basin above Baganuur, $Q_{in} = 0$. Because the river get completely frozen during cold season, the water balance is taken for the period from May to September. Also almost all precipitation is concentrated in this period. And we assume that storage tendency is zero.

From **Figure 4**, it is shown that

- For two downstream sub-basins, δQ are almost zero. This means locally generated runoff do not contribute to the increase of river discharge;

- The upstream sub-basin, above Baganuur is the

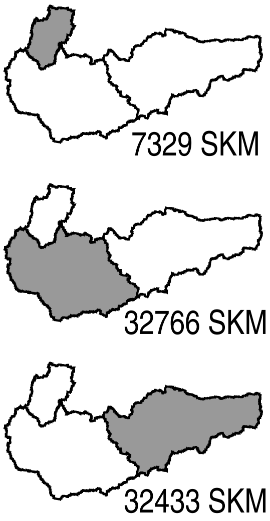

Figure 3: Location of three sub-basins. Upper, middle and lower sub-basins are above Baganuur, Baganuur to Underkhaan, and Underkhaan to Choibalsan respectively.

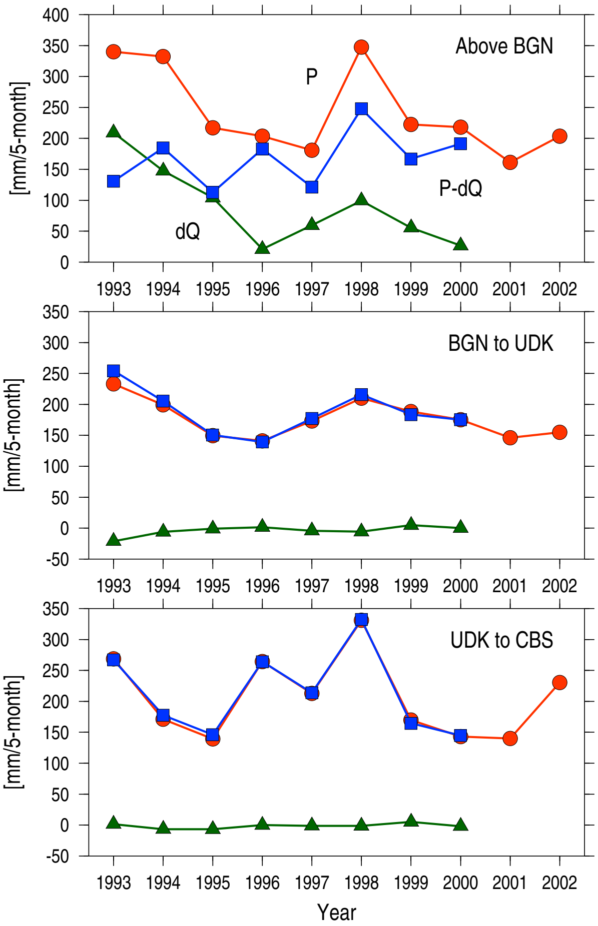

Figure 4: Interannual change of water balance of three sub-basins.

main source area of the Kherlen River basin.

5 Interaction between the river system and the hillslopes

As described above, two downstream sub-basins do not contribute to the increase of the river discharge. In order to know the amount of locally generated runoff and where does the runoff disappear, we consider the water balance of the river system and the hillslopes separately. The river system with open water surface is identified by using Landsat TM (Thematic Mapper) data (Tucker *et al.*, 2004). We have two water balance equations:

for the hillslopes,

$$P - E_H - R_H + R_R\frac{A_R}{A_H} = 0, \tag{3}$$

for the river system,

$$P - E_R - R_R + R_H\frac{A_H}{A_R} - \delta Q\frac{A_R + A_H}{A_R} = 0, \tag{4}$$

where subscripts H and R indicate the hillslopes and the river system; A denotes the areas; E_H is evapotranspiration from terrestrial surface; E_R is evaporation from river water surface; R_H is runoff generated on the hillslopes and flows to the river system; and R_R is seepage from river system to surrounding area. For the same reason, the water balance is taken for the period from May to September. And we assume that storage tendency is zero.

5.1 Identification of river surface

In this study, the Landsat TM data, called "GeoCover" and produced by the EarthSat (Earth Satellite Corporation) for NASA (National Aeronautics and Space Administration), is used to identify the land surface condition. At first, a mask is made to mask out the mountainous area. Then the masked area is classified into ten classes by using K-means clustering algorithm (non-hierarchical method). Finally, these classes are merged into two classes, river surface and land surface. The water surface areas on each sub-basin, above Baganuur, Baganuur to Underkhaan and Underkhaan to Choibalsan, are 82 (1.12%), 315 (0.96%) and 318 (0.98%) square kilometers respectively.

5.2 Calculation of potential evaporation

The evaporation from river surface is considered to be the potential evaporation which is estimated by following bulk formula:

$$E_R = E_p = \rho C_E V[q_s(T_s) - q_a], \tag{5}$$

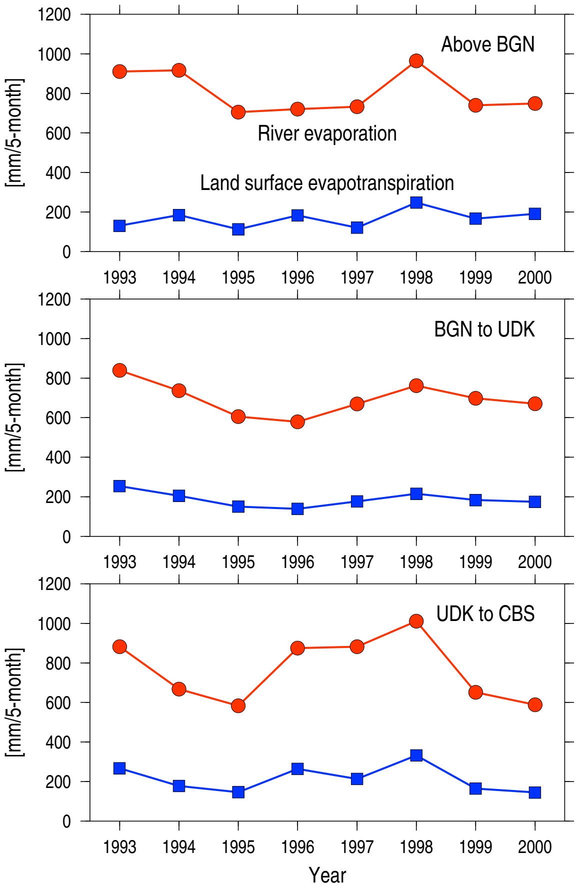

Figure 5: Interannual change of river evaporation and land surface evapotranspiration.

where T_s is surface temperature; $q_s(T_s)$ is saturated specific humidity at T_s; q_a is specific humidity of the air; V is wind velocity; ρ is density of the air; and C_E is the bulk transfer coefficient.

5.3 Calculation of land surface evapotranspiration

From the water balance equations for the river system and the hillslopes, we can derive

$$E_H = (P - \delta Q)\frac{A_H + A_R}{A_H} - E_R\frac{A_R}{A_H}, \tag{6}$$

and calculate the evapotranspiration from land surface. **Figure 5** shows the evapotranspiration from land surface, and evaporation from river water surface from all three sub-basins.

5.4 How large is the river seepage?

For the hillslopes, $R_H - R_R(A_R/A_H)$ means the net amount of water flowing to the river system, and can be calculated from $P - E_H$. As shown in **Figure 6**, it is always plus for sub-basin above Baganuur. However, it becomes minus in some years for other two sub-basins. This means the river seepage may be

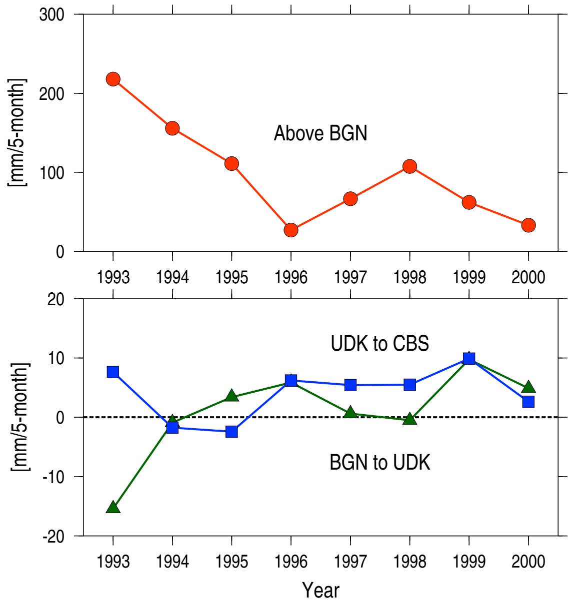

Figure 6: Interannual change of net amount of water flowing into the river system.

larger than runoff. Considering the area of the hillslopes is much larger than that of the river system, this is a very big loss.

6 Long-term variation of river flow

Figure 7 shows the hydrographs of mean discharge from May to September at three hydrological gauging stations, Baganuur, Underkhaan and Choibalsan. The mean discharge at Baganuur has largest natural variance. And the downstream station has smaller variance. Decreasing trends seem to exist at all three stations. Considering their large natural variance, the significance of these trends should be checked carefully by using other data such as long-term temperure and precipitation data.

For other years not used in above analysis, the area from Underkhaan to Choibalsan also does not contribute to the increase of the river discharge. In the 1950s, Baganuur always had larger discharge than Choibalsan. In the 1960s, discharge at Underkhaan was always larger than that at Choibalsan.

7 Conclusions

In Kherlen River basin, the area above Baganuur is the main source area. Most of the river flow comes from this area and the area from Baganuur to Choibalsan does not contribute to the increase of the river discharge. It is shown that the runoff generated in this area is consumed by the river surface evaporation and river seepage. In some years, the river seepage can be larger than locally generated runoff.

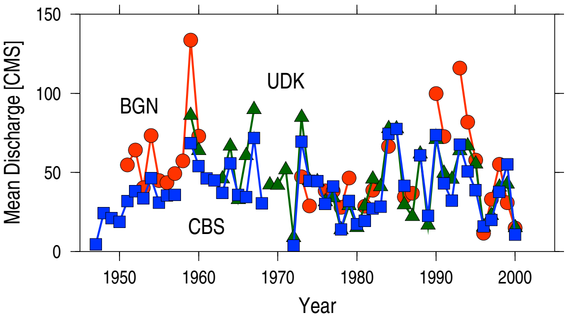

Figure 7: Hydrographs of mean discharge from May to September at three gauging stations.

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