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# Changes in The High-Latitude Headwater Basin of The Nenjiang River Basin, Northeast China, 1970s-2000s

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**Abstract.** The Nenjiang River Basin (NRB), an important wetland area in China, has experienced large-scale degradation of the wetland area and the evolution of land-use patterns over the last 50 years due to global warming, changes in precipitation patterns and anthropogenic activities, especially in the headwater basin of the NRB. In order to investigate these changes, temperature, precipitation, runoff, land-use/vegetation and wetland changes from 1970s-2000s were analyzed using the Mann-Kendall non-parametric test and Arcgis10.2 software. Our results show that a temperature increase was recorded in the headwater basin of the NRB, and precipitation showed an overall increasing trend which became more evident in the headwater basin. Runoff presented an increasing trend on the right side of the basin and a decreasing trend on the right side. The occupation of agricultural land on the wetland area and a decrease of forest and grassland areas did not result in a significant reduction in floodplain wetland area. These land-use changes, however, did have an impact on water supply shortages in the agricultural zone to the left side of the NRB.

## 1. Introduction

Over the last century, global climate has presented a prominent change, mainly characterized by global warming. With current predictions indicating that warming trends will continue, an impact of rising temperatures will result in vulnerable high-latitude ecosystem environments being severely affected [1], the acceleration of permafrost melting [2], and declines of large-scale wetlands [3].

Wetland ecosystems are complex systems that have developed in the transitional zone between aquatic and terrestrial systems. Hydrological processes play an important and direct role in their formation, development and evolution, as well as the subduction of wetlands [4]. During the development and evolution of wetlands, the interaction and mutual effects between hydrological processes and ecological processes is an important foundation and dependence condition [5]. However, the characteristics and dynamic change of wetlands is dependent on the interaction between climate, soil and vegetation [6]. Any effects which impact on the hydrological conditions of wetlands can result in their degradation [7]. In addition, human activities have also significantly affected these habitats, especially with changes to wetland land-use and vegetation cover [8].

High-latitude highland headwater basin develop under the unique natural conditions of high elevation and cold temperatures. These conditions determine the vulnerability of these ecosystems; micro-disturbance of this environment will induce a strong response in the ecosystem and result in the

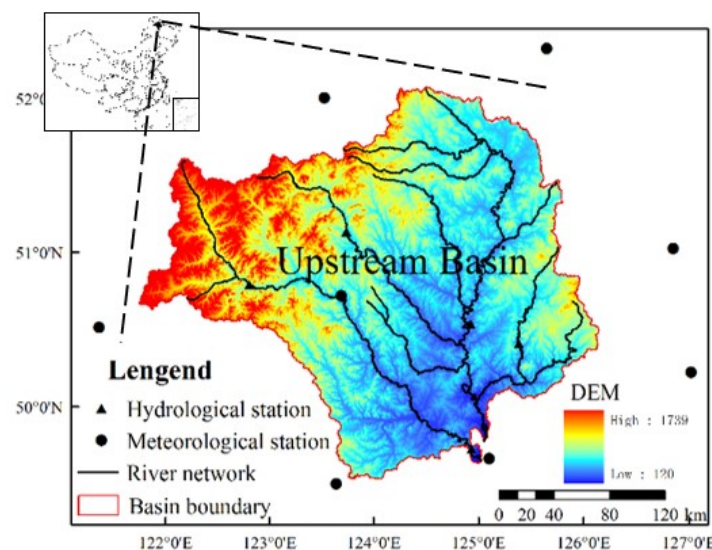


change of the highland ecosystem pattern and processes [9]. For this investigation, the headwater basin of the NRB was selected as the study area [10]. By investigating temperature, precipitation, runoff, land-use/vegetation and wetland changes, the relationship between geographical environmental change and wetland evolution since the 1970s in this area will be discussed. Results from this study will not only provide fundamental data for studying highland cold basins, they will also provide important theoretical information for wetland conservation.

## 2. Methodology

### 2.1. Study Area

Since 1978, around 28% of the wetland area has been drained and utilized as agricultural fields, or used for urban development; cultivation of the wetlands and urbanization has created considerable stress on the ecological health of the Nenjiang River region. For this study the headwater basin was selected because of its important water conservation and wetland conservation functions. The climate in the headwater of NRB is semi-humid continental, characterized by short, warm, humid summers with frequent thunderstorms, and cold winters with frequent snowfall and persistent snow cover. Mean annual temperature ranges from  $-0.1\sim 3.9^{\circ}\text{C}$  and average precipitation ranges from 309~661 mm/yr. Figure 1 shows the location of the headwater basin of the NRB, and the distribution of hydrological and meteorological stations.



**Figure 1.** Location of the study area

### 2.2. Data source and processing

Meteorological data collected at 8 meteorological stations from the National Meteorological Data Center ; monthly runoff data spanning 1960-2010 from six headwater hydrological stations selected to analyze runoff change; the remote sensing map of wetland distribution for four time periods (1970s, 1980s, 1990s and 2000s), provided by the Institute of Remote Sensing Application of the Chinese Academy of Sciences; land-use/land cover data (based on TM images) for the four periods were selected as the land-use dataset.

### 2.3. Methods

Analysis of historical temperature, precipitation and streamflow trends were undertaken using a non-parametric Mann-Kendall test. The test statistic  $S$  for this test was defined as:

$$S = \sum_{j=1}^{n-1} \sum_{i=j+1}^n \text{sgn}(X_i - X_j) \quad (1)$$

$$\text{sgn}(X_i - X_j) = \begin{cases} 1 & \text{if } X_i > X_j \\ 0 & \text{if } X_i = X_j \\ -1 & \text{if } X_i < X_j \end{cases} \quad (2)$$

and the magnitude of the slopes were defined as:

$$\text{slope} = \text{median} \frac{X_i - X_j}{i - j} \quad (j < i) \quad (3)$$

The time variable was 1 year for trend analysis and the null hypothesis stated that there was no trend in temperature or precipitation at a given station  $\delta = 0.05; \delta = 0.1$ . To determine if trends varied across the seasons, early spring (March to April) and high summer (July to August) seasonal trends were compared with annual temperature trends. Furthermore, seasonal trends were used to evaluate the effect of climate change and land cover change on streamflow, respectively. Pearson Product Moment Correlation was also used to determine if a relationship existed between temperature, precipitation and streamflow trends identified in this study.

The Markov chain equation was constructed using the land-use distributions at the beginning ( $M_t$ ) and at the end ( $M_{t+1}$ ) of a discrete time period as well as a transition matrix ( $M_{LC}$ ) representing the land-use changes that occurred during that period. The three matrices created above were then assembled to form a link in the Markov chain using the following equation:

$$M_{LC} * M = M_{t+1} \quad (4)$$

$$\begin{bmatrix} LC_{uu} & LC_{ua} & LC_{uw} \\ LC_{au} & LC_{aa} & LC_{aw} \\ LC_{wu} & LC_{wa} & LC_{ww} \end{bmatrix} \begin{bmatrix} U_t \\ A_t \\ W_t \end{bmatrix} = \begin{bmatrix} U_{t+1} \\ A_{t+1} \\ W_{t+1} \end{bmatrix} \quad (5)$$

Where  $U_t$  represents the probability of any given point being classified as urban at time  $t$ , and  $LC_{ua}$  represents the probability that an agricultural point at  $t$  will change into urban land by  $t+1$  and so on.

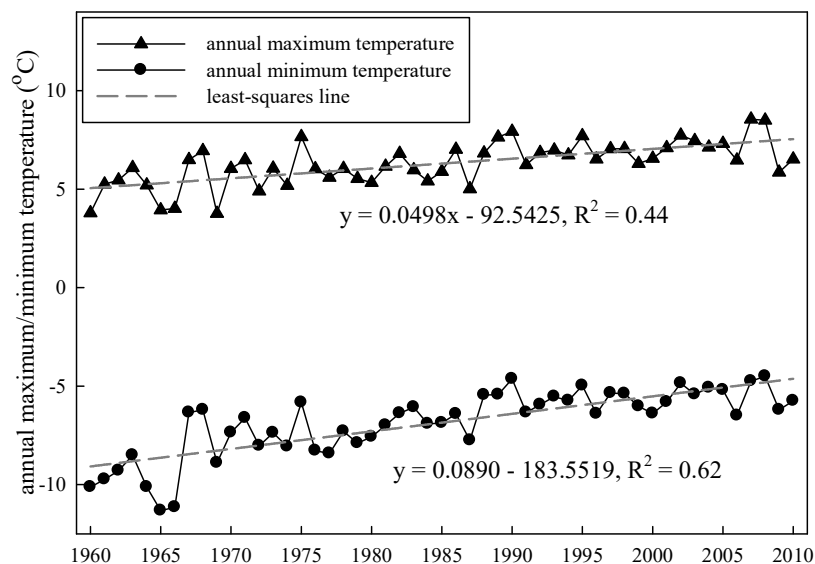
### 3. Results and discussion

#### 3.1. Temperature and Precipitation Trends

Temperature trends in the headwater of the NRB are in accordance with historical global temperature trends which have recorded a temperature increase of approximately  $0.74^\circ\text{C}$  since the early nineteenth century, and annual mean maximum and minimum temperatures across the headwater basin since 1960 recorded a significant ( $p < 0.05$ ) increase (Figure 2). Average maximum and minimum temperatures in the study region recorded an increase across the area, shows that minimum temperature had a greater change, resulting in a narrowing of the diurnal temperature range (DTR: the difference between maximum and minimum temperatures) in this area.

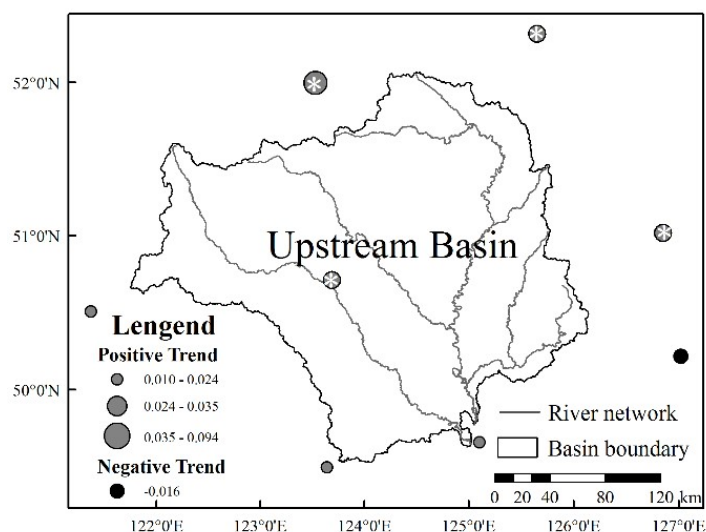
Mean annual precipitation trends recorded variations across the headwater basin from 1960 to 2010. Decreasing trends were detected at five of the eight stations, however they were not statistically

significant ( $P < 0.05$ ); increasing trends were recorded at three of the stations with one being statistically significant ( $P < 0.05$ ).



**Figure 2.** Mean annual maximum and minimum temperature trends for the headwater basin

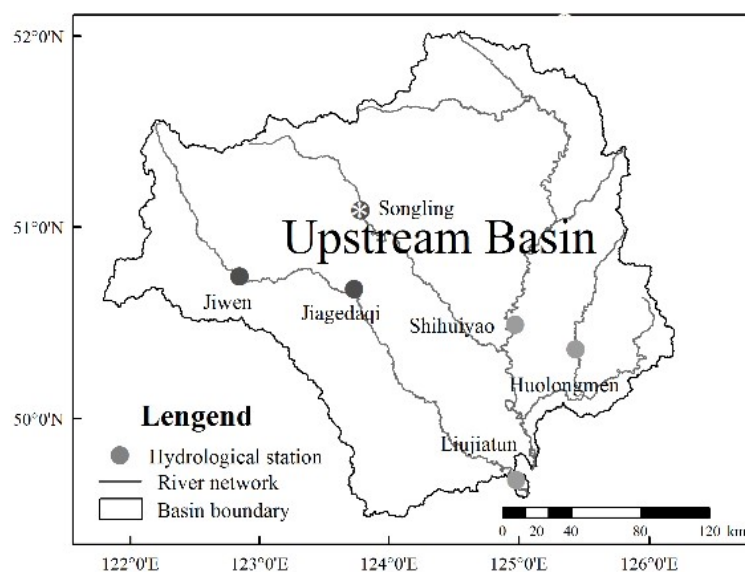
Results for maximum daily precipitation, however, recorded a relatively significant trend compared with mean annual precipitation across the entire headwater basin. An increasing trend in high intensity precipitation events (greater than the 95th percentile) was also recorded across the headwater basin; increasing trends of high intensity precipitation were recorded at seven of the meteorological stations, with an annual average increase of 0.03 mm/yr for the high intensity events. Four of the seven decreasing trends were statistically significant ( $P < 0.05$ ), and only one station recorded a decreasing trend (-0.016), but it did not reach a significant level (Figure 3).



**Figure 3.** Trends in the magnitude of high intensity precipitation in mm/yr for the headwater of the NRB, 1960-2010 (\* denotes significant trend)

### 3.2. Changes in seasonal streamflow

Monthly mean streamflow hydrological data recorded at six stations situated in the study area (Figure 4) were used to determine spatial distribution trends during the study period. Hydrological stations situated on the left bank (light grey) displayed positive trends, suggesting an increase in monthly mean streamflow. In contrast, stations on the right bank (dark grey), generally showed negative trends. Results for early spring (March and April) recorded similar positive/negative trends, however these trends were more significant than those recorded for monthly mean streamflow. Late summer (July and August) trends at the hydrological stations differed from the monthly mean streamflow trends, and from those recorded in early spring, especially in the downstream area of the left bank where streamflow recorded an increasing trend. All trends detected for this analysis were significant at the 0.05 level.

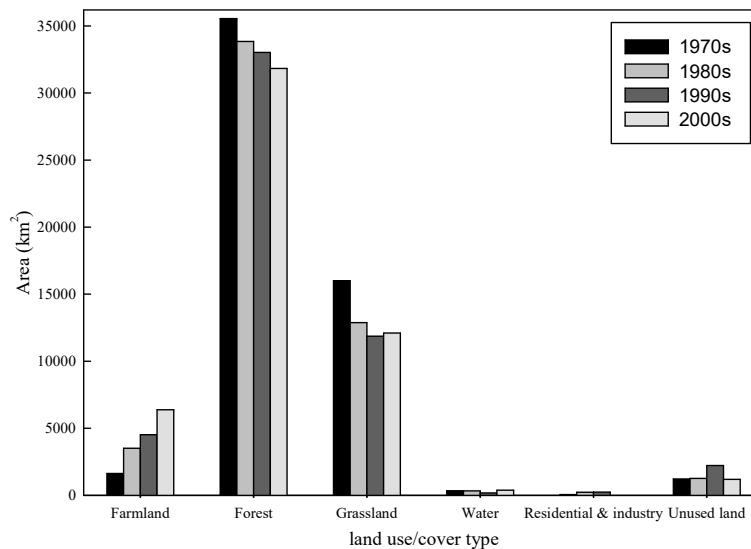


**Figure 4.** Trends in the monthly mean streamflow for the headwater of NRB from 1960-2010 (\* denotes significant trend)

### 3.3. Changes in land cover and wetlands

Temporal changes in land use/cover across the headwater basin since the 1970s are shown in Figures 5. Results in Figure 5 show that area covered by forest has recorded a sharp decline (4000 km<sup>2</sup>) since the 1970s, while the area of farmland has recorded nearly a 4-fold increase, from 1600 km<sup>2</sup> in the 1970s to 6300 km<sup>2</sup> in the 2000s. The area of grassland cover in the study area, however, recorded a decline from the 1970s to the 1990s; since the 1990s a slight increase has been recorded. Slight increases in the area of residential and industrial land were recorded over the study period whilst water and unused land cover remained relatively stable.

Between 1970s-2000s, the area of land which has been converted to farmland has been: 1340 km<sup>2</sup> (44.6%) of grassland, 3249 km<sup>2</sup> (8.4%) of forest, 367 km<sup>2</sup> (4.4%) of unused land, 3 km<sup>2</sup> (3.3%) of water, and 1 km<sup>2</sup> (3.2%) of residential and industry; changes to forest, grassland and other land-use types has been significantly less (Table 2). The significant area converted to farmland and other land-use types will significantly affect water storage capacity in the basin and aggravate soil erosion



**Figure 5.** Historical changes in land use/cover on the headwater basin from 1970

**Table 1.** Land-use transition matrix in the NRB from the 1970s to the 2000s (%)

| Land use type |                        | 2000s    |        |           |       |                        |             |
|---------------|------------------------|----------|--------|-----------|-------|------------------------|-------------|
|               |                        | Farmland | Forest | Grassland | Water | Residential & industry | Unused land |
| 1970s         | Farmland               | 95.04    | 0.80   | 0.86      | 0.00  | 2.01                   | 1.29        |
|               | Forest                 | 8.37     | 87.69  | 1.69      | 0.01  | 0.04                   | 2.19        |
|               | Grassland              | 44.58    | 4.54   | 47.92     | 0.31  | 1.02                   | 1.61        |
|               | Water                  | 3.25     | 2.70   | 0.60      | 92.41 | 0.00                   | 1.04        |
|               | Residential & industry | 3.21     | 0.00   | 0.00      | 0.00  | 96.79                  | 0.00        |
|               | Unused land            | 4.36     | 6.13   | 1.87      | 0.05  | 0.08                   | 87.50       |

Wetlands in the NRB can be divided into two categories: natural wetlands (fluvial wetlands, floodplain wetlands, lake wetlands and marsh) and constructed wetlands (reservoirs/ponds and artificial wetlands) (Table 3). Table 3 shows that the total area of wetland in the study region has declined (1970s - 2000s), especially during the period from the 1990s to the 2000s. The area of marsh, accounting for 89%~95% of the total wetland area, increased during the 1970s to the 1990s, before decreasing. Both the fluvial and floodplain wetlands recorded a decrease from the 1970s to the 1980s, with no clear trend after that date. Moreover, the lake wetland, reservoirs/ponds and artificial canals showed no obvious trends during the study period.

**Table 2.** Variation trends of wetland area in the headwater basin of the NRB from the 1970s to the 2000s (km<sup>2</sup>)

| Type<br>Year | Fluvial<br>wetland | Floodplain<br>wetland | Lake wetland | Marsh  | Reservoirs /<br>ponds | Artificial<br>canals | Total  |
|--------------|--------------------|-----------------------|--------------|--------|-----------------------|----------------------|--------|
| 1970s        | 144.7              | 410.4                 | 2.7          | 4619.6 | 4.2                   | 0                    | 5181.6 |
| 1980s        | 94.6               | 177.8                 | 2.4          | 4758.8 | 3.8                   | 0                    | 5037.4 |
| 1990s        | 82.7               | 178.9                 | 3.0          | 4855.6 | 3.9                   | 0                    | 5124.2 |
| 2000s        | 90.5               | 168.5                 | 1.7          | 4440.8 | 3.6                   | 0                    | 4705.0 |

#### 4. Conclusions and Discussion

Temperature trends in the headwater of the NRB are in accordance with historical global temperature trends which have recorded a temperature increase of approximately 0.74°C since the early nineteenth century. Average maximum and minimum temperatures in the study region recorded an increase across the area, having an increasing diurnal temperature range (DTR; the difference between maximum and minimum temperatures). Precipitation records indicated an overall increasing trend which was more evident headwater. Runoff results showed changing patterns across the study area, with an increasing trend in the area with higher DEM at the right side of the basin, and a decreasing trend in area with lower DEM at the left side of the basin. This finding was a result of increased precipitation in the forest area on the right side of the basin. However, agricultural areas situated on the left side of the basin are threatened with water shortage and drought. In combination with these findings, a trend of increase of agricultural land in the study area and the dramatic decrease of forest and grassland will further aggravate drought episodes. These changes are believed to have resulted in a 58.9% reduction of floodplain wetland from the 1970s to the 2000s.

Due to the important effect of headwater forests on runoff recharge and the hydrological effect of headwater forests, maintaining forest in this area is an important role in wetland restoration. Changing global temperatures has also resulted in downstream agricultural areas facing severe water shortages; agricultural production efficiency can be promoted via measures such as efficient irrigation practices and water supplement, thereby guaranteeing water resources and water security in the headwater areas.

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