# Hydrological changes in the upper Tuul River basin

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## I Background

The catchment is bounded by the watershed, and since water drains from catchment, downstream, integrates all natural and human influences within the catchment, therefore, the watershed was considered as the natural ecosystem boundary.

Stream functions are processes influenced by the interaction of soil, water and vegetation in the basin. They include physical filtering of sediment in overland and channel flows, bank stability, and water storage and recharge aquifers in the basin. Improving vegetation cover in the basin through proper livestock, forest and other land use management can increase infiltration rates, reduce overland flows, and add to the water stored by stream systems. The historic evidence in general indicates that vegetation cover have changed drastically in last decades that chief cause has been improper livestock grazing (Chognii, 2001) and forest management (Enkhsaikhan, 2000). Main focus of the study was to reveal changes occurring in the hydrological system of the Tuul River.

The Tuul River raises at western slope of the Khentei range, in particular at southern slope of the Chisaalai peak and Shoroot pass, elevated up to 2,000 m a.m.s.l. It is formed by the confluence of Namiya and Nergui streams. Catchment area till Ulaanbaatar is 6,300 sq.km covering forest and steppe area. Hydrological station was operating on Tuul River at Ulaanbaatar since 1945. There are 4 other stations operating in relatively short period of time in upper basin of the river.

It was estimated that the annual composition of runoff of Tuul River has a portion of about 69% of rainfall water, 6% of snow melting water and 25% of groundwater. So, there are three components such as contribution of precipitation, snowmelt and groundwater. Annual mean river flow in Ulaanbaatar site is estimated to be 26.6 cub.m/sec. Ulaanbaatar is fully dependent on it's groundwater resources hydraulically connected with surface runoff.


**Fig. 1 Location and geographical features of the Tuul River, Mongolia.**

During the last 60 years were increasing annual mean air temperature by 1.56 °C, air temperature in winter by 3.61 °C and in spring-autumn period by 1.4-1.5 °C and while, summer temperature was decreasing by 0.3 °C (Natsagdorj *et. al*., 2003).

## II Methods and data

To reveal hydrological changes caused by changes in ecosystems in the upper Tuul River basin have been analyzed integral factors such as storage ratio, runoff coefficient, drainage factor and water balance elements. Hydrological data of the Tuul River and precipitation observed in Ulaanbaatar, since 1945 to 2003 years and normalized difference vegetation index (NDVI) data, as 10 days composite NOAA/NDVI 8 km resolution from 1982 to 2001, provided from NOAA/NASA Pathfinder data set have been used in the study.

Annual storage ratio ($\varphi$) series of the basin, expressed as ratio of area of hydrograph below annual average discharge to the total area of annual hydrograph indicates water regime regulating capability of the basin and it's overall changes with time and space.

$$\varphi = \int_{k=0}^{k=1} T dk \qquad (1)$$

where: $T$ is days, $k$ is the ratio of daily average discharge to yearly average discharge.

Analyses of autumn recession curves allow an opportunity to investigate river flow and regimes and to evaluate the development groundwater potential. Investigation of recession curves together with base flow or storage fluctuations of an aquifer or river basin in the wet and dry seasons gives useful information. Recession curves yield after the last peak in autumn is expressed by the following exponential function (Maillet, 1905).

$$Q_t = Q_o \exp(-at) \qquad (2)$$

where: $Q_t$ – autumn recession flow at time $t$, $m^3/s$, $Q_o$ – autumn flow at the beginning of the recession period (t = 0), $m^3/s$, $a$ – storage variation or drainage factor, 1/day, $t$ – duration recession flow, day.

Runoff coefficient ($C$) expressed as ratio of runoff depth to the basin average precipitation, indicates changes in elements of water balance in the basin (6). Observation data on runoff depth and basin average precipitation series are divided into two periods namely period with natural flow regime and period with influences of anthropogenic pressures in the basin. Then average runoff coefficient in the period of natural flow regime of river is determined by following:

$$C_{natural} = \frac{h_{natural}}{P_{basin}} \quad (3)$$

where, $C_{natural}$ is runoff coefficient in the period of natural flow regime, $h_{natural}$ is annual runoff depth, mm, $P_{basin}$ is annual and basin average precipitation, mm in the same period.

Natural flow rate in the period of increased anthropogenic pressures is determined using the runoff coefficient in the period of natural flow regime and precipitation occurred in the period of increased anthropogenic pressures, as follows.

$$h_{natural\ in\ anthropogenic\ period} = C_{natural}\ P_{anthropogenic\ period} \quad (4)$$

Then, change in runoff will be the difference runoff in the period of natural flow regime ($h_{natural\ in\ anthropogenic\ period}$) and runoff, observed in the period of increased anthropogenic pressures $h_{anthropogenic\ period}$.

$$\Delta h = h_{natural\ in\ anthropogenic\ period} - h_{anthropogenic\ period} \quad (5)$$

## III Results and discussions

The value of discharge recession coefficient decreases then the underground retardation increases. In that case recession curve is less steep but longer. The curve indicates large dynamic (above the river level) reserves of the aquifer. The rivers of this type of aquifer are mostly permanent. Oppositely, when "a" is large, the recession curve is steep and the underground has poor retardation capability. Dynamic reserves in this case are very quickly depleted making the reserves only temporary so the river of such aquifers is intermittent. Drainage factor of the Tuul River at Ulaanbaatar has clearly increasing trend in last 56 years. Therefore, underground retardation decreases due to change in natural characteristics of the river basin (Davaa and Sharkhuu, 2001). Drainage factor values range from 0.04 to 0.01. Increase in drainage factor or storage ratio "a" indicate that size of active drainage decreases in the basin (fig.2).

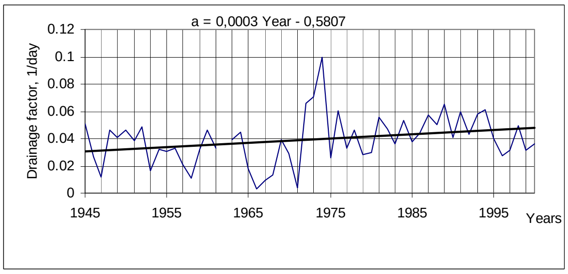


**Fig. 2 Drainage factor trend of the Tuul River basin (Tuul-Ulaanbaatar).**

Cyclic fluctuation of annual flows of the Tuul River is clearly indicated by the curve sum(k-1)/Cv verses with time. Where k=$Q_i$/ $Q_{average}$. There are 2 cycles. First cycle is observed in the period of 1945-1976 and second one is in the period of 1977-2003. These 2 periods are highly distinguished by anthropogenic pressures. First period is considered to be the period of natural flow regime and second period is period with increased anthropogenic pressures in the basin (fig. 3).

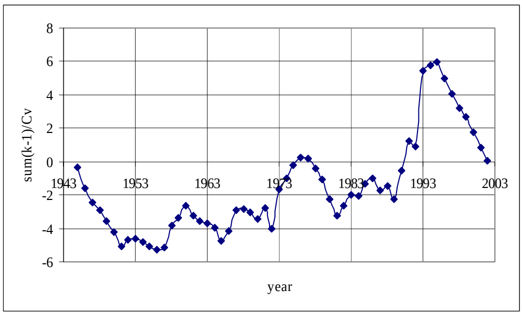


**Fig. 3 Cyclic pattern of annual flows of the Tuul River at Ulaanbaatar.**

Relating annual precipitation observed in Ulaanbaatar (Buyant-Ukhaa meteo. station) with effective rainfall or runoff depth of the Tuul River at Ulaanbaatar, annual basin average precipitation in last cycle has been approximated by the following regression equation (fig. 4).

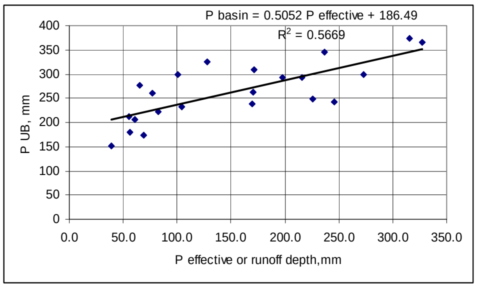


**Fig. 4 Relationship of precipitation observed in Ulaanbaatar and effective rainfall or runoff depth of the Tuul River.**

Basin average evapotranspiration has been estimated by simple water balance equation, assuming that change in water storage in year is near zero. Annual flow series are remarkably and basin average precipitation are slightly increasing, while evapotranspiration or evapotranspiration and change in water storage are drastically decreasing in last 60 years (fig. 5).

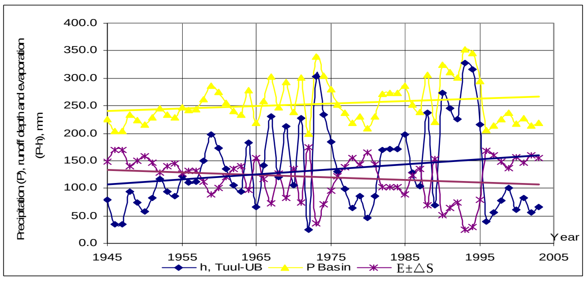


**Fig. 5 Annual runoff (hmm), basin average precipitation ($P_{basin}$) and evapotranspiration or evapotranspiration and change in water storage (E±ΔS).**

Analyses of annual runoff coefficients, expressed as ratio of annual runoff depth to the basin average precipitation show its increasing trend, indicating increase in overland flow or direct runoff and decrease in groundwater recharge (fig. 6).

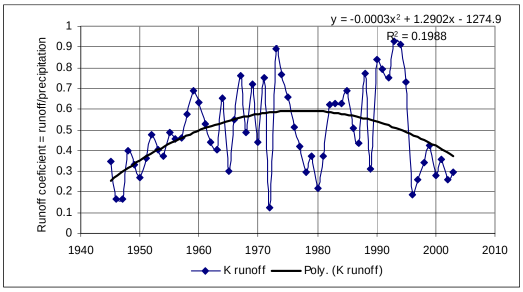


**Fig. 6 Runoff coefficient time series and its tendency of change, Tuul River at Ulaanbaatar.**

Basin average precipitation was 251 mm in the period of 1945-1976 and its slight increase (257 mm) is observed in the next period of 1977-2003. However, annual and long term mean flow of the Tuul River was 128 mm in the first and increased till 139 mm in the second periods. Following these changes annual evapotranspiration and water storage in the basin have been decreasing from 123 mm in the first and till 118 mm in the second periods. This evidences that annual runoff coefficient has increased by 0.03 value, indicating degrease in roughness in the basin. Decrease of roughness indicates degradation of vegetation cover in the basin. With increasing runoff coefficient decreases annual storage ratio ($\varphi$) series and it indicates flow regime regulating capability of the basin has been decreasing. Change of runoff coefficient of 0.03 corresponds to the change of storage ratio by 0.005. It means that runoff coefficient is sensitive indicator than storage ratio, which is function of flow regime regulators as forest, wetland and lakes in the basin (fig. 7).

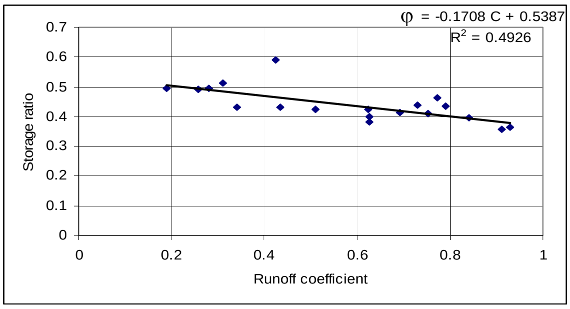


**Fig. 7 Relationship between runoff coefficient and storage ratio of the Tuul River at Ulaanbaatar in the second period.**

Therefore, storage ratio is somewhat function of vegetation cover dynamics. However, between NDVI and storage ratio wasn't revealed good relationship in the particular basin. However, with increasing NDVI the water regime regulating capability in the basin increases (fig.8).

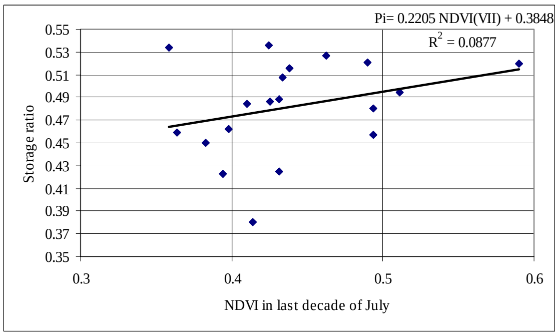


**Fig. 8 Relationship between storage ratio and normalized difference vegetation indexes (NDVI) in the basin.**

Decrease in active drainage area, degradation of vegetation cover, leading to the deterioration of flow regime, regulating capability lead to increase in vulnerability to flooding. Annual maximum discharge series show that it tends to increase and duration of occurrence of rainfall floods decreases from 15 days to 12 days in the basin (fig. 9).

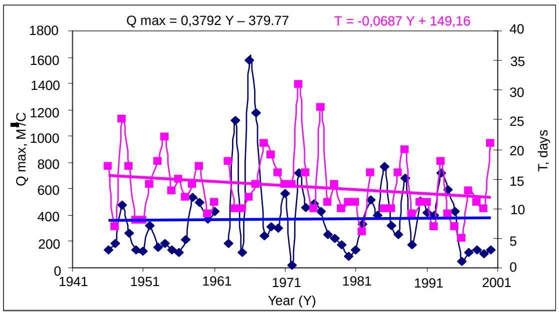


**Fig. 9 Annual maximum discharge ($Q_{max}$) and summer flood duration (T, days) series and their tendency of change in last years (Y).**

Trend of annual maximum flow series, observed during rainfall floods shows that they it is increased by 20 cub.m/s per a year. However, maximum discharge values of spring floods tend to decrease by 3.1 cub.m/s and its duration of occurrence prolonged by 14 days per a year due to early occurrence of discontinuous snow melting resulted from air temperature variation in spring. It was revealed that magnitude of annual maximum flows depends not only on amount and intensity of rainfall but also flow regime regulating capability of the basin. Good relationship exist between annual maximum flows and annual storage ratio in the second period (fig. 10 a)). Therefore, for the estimation of annual maximum flows, it is important to include flow regime regulating capability of a basin. This is getting one of the basis for regional streamflow estimation in this changing environment (fig. 10 b)).

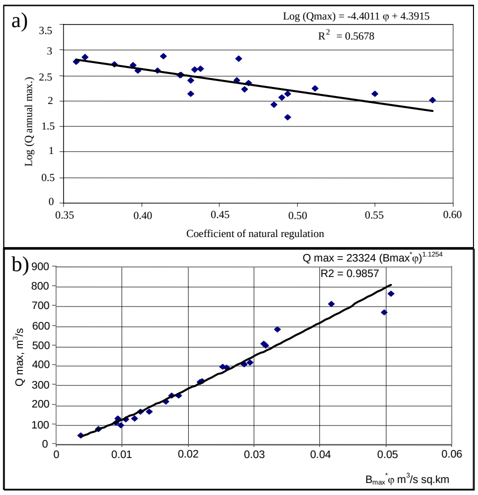


**Fig. 10 Relationships between annual maximum discharge and storage ratio (a), and specific discharge (b).**

For the Tuul River, $Q_{max}$ can be estimated by following empirical equation:

$$Q_{max} = 23324(B_{max}\varphi)^{1.1254} \quad (6)$$

where, $Q_{max}$ is annual maximum discharge, cub.m/s, $B_{max}$ is specific discharge, which is function of climate variables, cub.m/s sq.km, $\varphi$ is storage ratio of the Tuul River.

Impacts of climate change and anthropogenic pressures as fire, overgrazing and wood cut are causing primarily changes in other hydrological characteristics of the river basin. Standard deviation of daily flows is drastically increased by 15.6 cub.m/s per year and evidences the increase of flood peaks and decrease of low flows. Water temperature of the river has been increased by 1.9 °C and number of days with ice cover and ice phenomena decreased by 12 and 8 days, respectively due climate warming.

## IV Concluding remarks

Analysis of storage ratio, drainage factor and runoff coefficient series show that water regime changes occurring in the Tuul River basin. Changes in natural components such as forest, vegetation and soil cover leading to predominantly changes in hydrological regime. For the estimation of annual maximum flows, it is important to include flow regime regulating capability of a basin. This is getting one of the basis for regional streamflow estimation in this changing environment.

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