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A Spatio-Temporal Assessment of the Water Quality in Tuul River, Mongolia

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Abstract

The study was carried out in the surrounding area of Ulaanbaatar, the capital city of Mongolia. The research indicates that the Tuul River is not polluted until the Ulaanbaatar city and the pollution starts when the river runs through the city. All high values of Water Quality Index are measured at a sampling point Tuul-lower Songino. The quality of the river strongly depends on how well water has been treated when discharged from Central Wastewater Treatment Plant. The distance between pollution point sources at downstream section of study area is not enough for the river self-purification process to take place. The water quality was decreased during the period of this study and the value of WQI increased. The WQI are calculated with greater values in cold period and with lower values in warm period of the year. The time series of water quality maps are produced.

Key words: water quality assessment, spatial and temporal changes, point source of pollution

Introduction

Over the last decade, rapid urbanization and increment of industries have been negatively influencing the water quality and chemical composition of rivers in surrounding areas of Ulaanbaatar city (Javzan *et al*., 2004). Surface water quality in surrounding areas of Ulaanbaatar has been monitored at 14 points since 1980s. For this purpose, 10 sampling points along the Tuul River and 4 points at tributaries of the Tuul River (1 at Terelj river, 1 at Uliastai river, 2 at Selbe river), were chosen by the Central Laboratory of Environmental Monitoring (CLEM) (Ministry of Nature and Environment, 2006). Stationary hydro-biological monitoring of invertebrate species along the river has started since 1997.

In 1995, the self-purification coefficient of the river estimated by Mongolian scientists and concluded that the coefficient was 6.57 until it reaches first pollution point source, but it reduced to 0.98 after the Central Wastewater Treatment Plant (CWTP) discharge poured into the river. The treatment efficiency of the CWTP as well as other Wastewater Treatment Stations (WTSs) in the region is often inadequate due to technical and financial problems. Efficiency of the CWTP was 71% in 2002. This value dropped to 66% in 2003. Therefore, the plant was not operated in May 2003 and April 2004 (Orchlon, 1995).

Air, soil pollution and accumulated wastes in catchment area, which are transferred by surface runoff and flood channel, also have significant impact on the river water quality. Major causes of water pollutant are mining industries in lower basin of the Tuul River. Approximately, 179 licensed mining companies are operating in 145 km^2 areas of the basin (Ministry of Nature and Environment, 2006). Water demand of the city had increased by 20% from 1998 to 2005. Population growth, urbanization and intensity of industries have created water exploitation, deterioration of natural water regime and ecological degradation of the river basin (Roza-Butler, 2004).

The aim of this research is to assess spatio-temporal variability of Tuul River's water quality in surrounding area of Ulaanbaatar city using Surface Water Quality Index (SWQI) and to produce time series of the river water quality maps.

Materials and Methods

Study area. The study was carried out in surrounding area of Ulaanbaatar, the capital city of Mongolia. The Tuul River, flowing through the heart of the Ulaanbaatar city, is an environmentally, economically and socially significant natural resource. The study area covered Tuul River and its three tributaries, namely Terelj, Uliastai and

Table 1. Spatial and temporal information of water quality sampling points

ID	Name of sites	Latitude	Longitude	Altitude, m	Sampling frequency	Selection
1	Terelj - Terelj	47°59'30.67"N	107°27'35.55"E	1522	monthly	Tributary of main river
2	Tuul - Uubulan	47°48'26.40"N	107°22'50.30"E	1383	monthly	Base load
3	Tuul - Nalaih	47°49'14.00"N	107°15'56.40"E	1364	monthly	Discharge from local WTS
4	Tuul - Bayanzurh	47°53'28.10"N	107°03'04.70"E	1309	monthly	Inflow to city
5	Tuul - Zaisan	47°53'19.40"N	106°55'05.70"E	1293	monthly	Center of city
6	Uliastai - UB	47°54'07.80"N	107°01'51.77"E	1310	monthly	Tributary of main river
7	Selbe - UB	47°54'30.77"N	106°55'55.77"E	1290	monthly	Tributary of main river
8	Dund - UB	47°54'11.96"N	106°51'23.25"E	1276	monthly	Tributary of main river
9	Tuul - Sonsgolon	47°52'28.70"N	106°46'50.10"E	1272	monthly	Outflow from city
10	Tuul - upper Songino	47°51'17.80"N	106°41'23.20"E	1256	monthly	Upper reach of CWTP
11	Tuul - lower Songino	47°50'51.70"N	106°40'29.70"E	1254	monthly	Lower reach of CWTP
12	Tuul - Chicken farm	47°46'21.00"N	106°35'59.20"E	1233	monthly	Discharge from Bio-factory
13	Tuul - Khadanhyasaa	47°45'08.90"N	106°30'02.60"E	1217	monthly	Indicator of self-purification
14	Tuul - Altanbulag	47°41'53.40"N	106°17'40.60"E	1182	monthly	Indicator of self-purification

Selbe Rivers. Table 1 shows the characteristics of sampling points, and their geographical locations are illustrated in Figure 1.

As shown in Figure 1, there are five point sources of pollution (some may overlap) marked by triangles and 14 diamonds indicate the water quality monitoring sites.

According to the Mongolian river classification, developed by Davaa.G (2006), which is based on long-term annual mean flow, the Tuul River is a moderately big river. In the territory of Ulaanbaatar city, there are about 50 streams and rivers (most of them are dried up). Three of them, named Selbe, Uliastai and Tuul, flow through the central part of the capital city. In Shuttle Radar Topography Mission data, territory of Ulaanbaatar is located at 106^{0}43'E - 107^{0}02'E and 47^{0}53'N - 47^{0}57'N and stretches from northwest to southeast, at elevation between 1214 m and 2079 m above sea level (Altansukh, 2008b).

Annual runoff of the Tuul River consists of three contributors (i) 69% from the rainfall, (ii) 26% from groundwater and (iii) 5% from snow melt. The spatial distribution of groundwater contribution decreases along the river, because 80% of the Ulaanbaatar city's water supply is provided by groundwater. Meanwhile, contribution of precipitation increases in downstream with

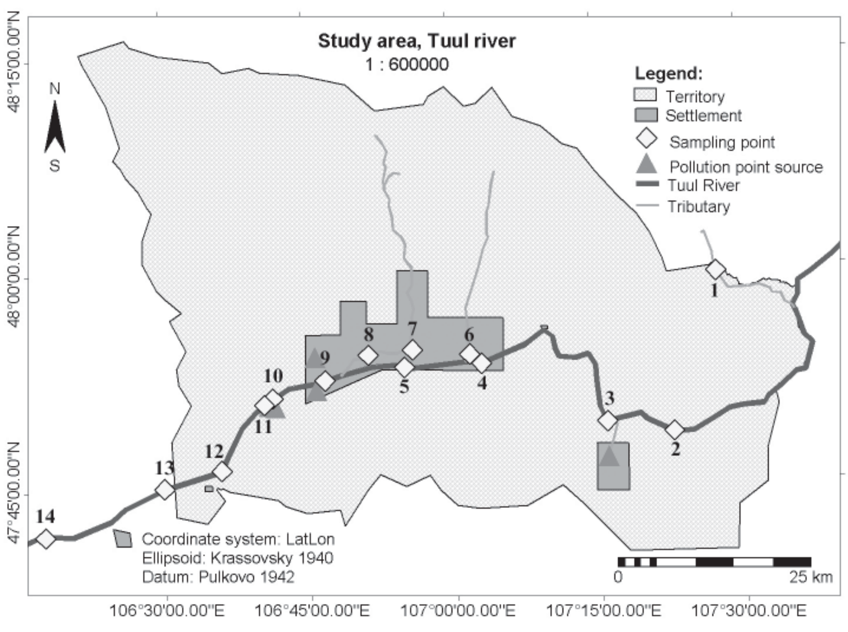


Figure 1. Locations of sampling points (Source: Altansukh, 2008a)

increment of catchment's area (Basandorj & Davaa, 2006). The average channel width of the river is 35 to 75 meters during non-flooding time, depth is 0.8-3.5 m and the velocity is 0.5-1.5 m s^{-1}. The long-term annual mean flow of the river is approximately 26.6 $m^3 s^{-1}$. The observed maximum discharge has reached 1580 m^3s^{-1} and 564 m^3s^{-1} at Ulaanbaatar and Terelj stations, respectively. During the low flow period of warm season, it dropped until 1.86 $m^3 s^{-1}$ at Ulaanbaatar station and 0.44 $m^3 s^{-1}$ at Terelj station (National Agency for Meteorology, Hydrology and Environment Monitoring, 1999).

The Tuul River basin has continental climatic feature that is characterized by wide variation of annual, monthly and daily temperatures; low range of air humidity; non-uniform distribution of precipitation; cold and long-lasting winter and warm summer. The rainy period continues from June to August in the upper Tuul River basin, of which rainfall shares about 74% of the annual precipitation (Ministry of Nature and Environment, 1997a). The annual average air temperature is -1.2^{0}C in the study area. Annual minimum temperature reaches -39.6^{0}C in January, while maximum temperature reaches +34.5^{0}C during summer period (Basandorj & Davaa, 2006).

The Tuul River quality is naturally clean and rich of calcium bicarbonate. Total dissolved solid of the river water ranges from 100-210 mg l^{-1}, pH = 6.1-7.5 along its reaches. The river contains ≈ 28.1 mg l^{-1} mineral and it belongs to the hydro-carbonate class, calcium group. The main cation is calcium and dominant anion is hydro-carbonate. Moreover, cation proportion is $Ca^{+2} > Mg^{+2} > (Na^+ + K^+)$ and anion ratio is $HCO_3^- > SO_4^{-2} > Cl^-$. Naturally, anion and cation proportions and chemical content of water match with the pure water river (National Agency for Meteorology, Hydrology and Environment Monitoring, 1999). However, chemical contents of the river suddenly changes from the western part of the city. The main factor of the chemical changes is the incompletely treated wastewater from the CWTP that is pouring into the Tuul River. According to the results of a hydrological survey conducted in 2003, the hydrological regime and its runoff formation zones of the Tuul River are gradually being changed and polluted by the settlements, intensive overgrazing, timbering, wild fires and improper wastewater treatment in the river banks (Basandorj & Davaa, 2006).

Methods. In Mongolia, surface water quality is being estimated by three different methods. Permissible level of surface water variables specified in Mongolian National Standard 4586-98 (1998)

1. Water quality grade developed by Water sector of Ministry of Nature and Environment (MNE) in 1997.

2. Water quality index (WQI) developed by Erdenebayar and Bulgan (2006).

In this research, the third method was used to calculate water quality. Reasons of the third method selection are (i) the first method includes in the index calculation (ii) dissolved oxygen takes high weight in the index. The WQI is estimated by a set of equations. A main formula is:

$$W_{qi} = \frac{\sum_i \left(\frac{C_i}{Pl_i} \right)}{n} \quad \text{(eq.1)}$$

where,

W_{qi} water quality index

C_i concentration of i-th variable

Pl_i maximum permissible level of i-th variable

n number of variables (Erdenebayar & Bulgan, 2006)

Mongolian National Standard (MNS 4586-98), which was developed by National Standard Agency in 1998, specifies maximum permissible level of i-th variable. Dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammonium (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-) and other variables should be included in the calculation of quality index (Davaa *et al*., 2006). After calculation, water sample can be classified as shown Table 2.

According to the classification of Surface Water Quality (SWQ) in Mongolia, the first critical value of SWQ in river water is 0.3. The values between 0.31 and 0.89 indicate the second level of water quality, namely clean. The values between 0.9 and 2.49 belong to the third level and from 2.5 to 3.99 is the fourth level. The values greater than or equal to 6.0 concern the sixth level that is strictly forbidden to be used for any purpose. Surface water usage depends on quality of the water. The MNE of Mongolia determined the water usage of specific water (Ministry of

Table 2. Classification of surface water quality (Source: Ministry of Nature and Environment, 2006)

WQI	Water quality degree	Water quality class
≤ 0.30	1	Very clean
0.31 – 0.89	2	Clean
0.90 – 2.49	3	Slightly polluted
2.50 – 3.99	4	Moderately polluted
4.00 – 5.99	5	Heavily polluted
6.00 ≤	6	Dirty

Nature and Environment, 1997b).

For the quality assessment, hydro-chemical datasets of the Tuul River, measured by CLEM between 1996 and 2006, for a total of 11 years, are used and chemical variables, DO, BOD_5, COD, NH_4^+, NO_2^- and NO_3^-, were used to calculate the WQI. In total, 1192 observations were conducted at 14 sampling points along the Tuul River and its tributaries. ILWIS software was used for the quality mapping (Koolhoven *et al*., 2005). Geo-statistical analysis has been conducted using software R version 2.5.1 (Gentlemen & Ihaka, 2007).

Results

Descriptive statistics. The minimum and maximum values of WQI are 0.15 and 34.2, respectively, and the difference between minimum and maximum value is 34.05. The highest value was measured in December 2004 for a sample from Tuul-lower Songino. In addition, all high values were measured at this sampling point in downstream, after the CWTP discharge enters the river.

Exploratory graphics. The R geo-statistical software package provides rich environment for statistical visualization. There are two graphics systems: the base system (in the graphics package, loaded by default when R starts) and the Trellis system (implemented in R by the lattice package) (Rossiter, 2007). In the study, the base system has been used, because this system is free and included in the software package.

The histogram showed in Figure 2 visualizes the frequency distribution of WQI. As seen from figure 2, the distribution is strongly right-skewed and there are very rare high values. The most of values are in the range of 0 to 2. Figure 3 shows WQI variability at sampling points along the river. Most dynamic one is a sampling point 11, namely "Tuul-lower Songino", the index depends on how well water has been treated when discharged from CWTP. Then it is naturally purified along the river flow. First 10 sampling points have less variability of WQI due to less human impact (except some tourist camps and towns) on the river.

Spatial water quality assessment. Spatially, the water quality decreases along the river. Several point and non-point pollution sources exist in the study area. The point sources of polluters in the Tuul River are improperly treated wastewater from such WTSs as Nalaih (1400 m^3 day^{-1}), Niseh (400 m^3 day^{-1}), CWTP (190000 m^3 day^{-1}), Bio-industry (490 m^3 day^{-1}) and Bio-Songino (600 m^3 day^{-1}). The biggest point source is CWTP, which is located in western edge of Ulaanbaatar city (Orchlon, 1995).

Water pollution of the river continuously increases from upper to its lower reach in surrounding areas of the city. Naturally, upstream of the river is running through mountainous area and it has high velocity and turbulence. Hence, the upper part of the river has more capability of oxidization, re-aeration and self-purification. When it reaches Ulaanbaatar city, natural condition changes from mountainous area to valley. In the valley, velocity and turbulence of the river decrease, then ability of oxidization, re-aeration and self-purification also decreases as well. This is the natural factor of possibility to store pollutant elements in the river waters for a longer time and distance (Altansukh, 2000). A scatter plot is produced by WQI fluctuation and spatial distribution of sampling sites.

Table 3. The proportion of samples with critical values

Threshold values	Number of observations	Percentage in total observations
≤ 0.30	244	20.5
≥ 0.31	948	79.5
≥ 0.90	453	38.0
≥ 2.50	167	14.0
≥ 4.00	97	8.1
≥ 6.00	74	6.2

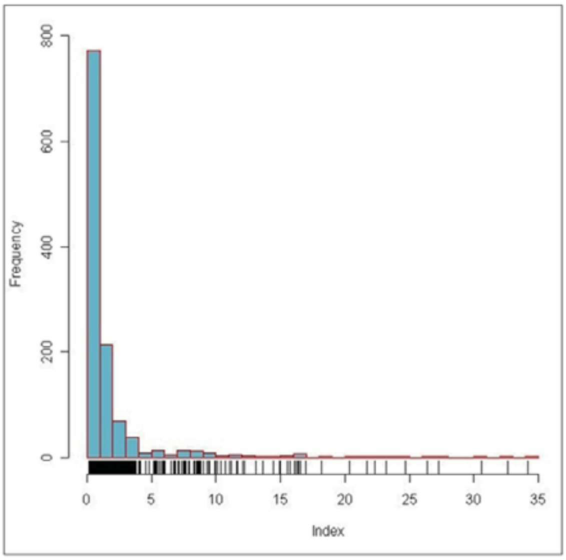


Figure 2. Histogram of WQI.

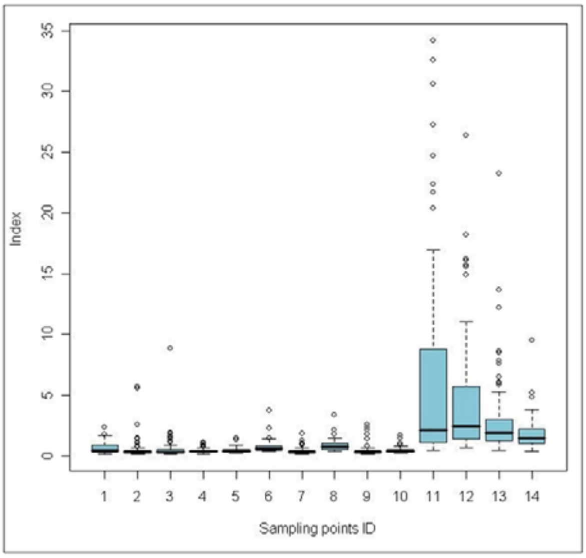


Figure 3. Box plot for spatial variability of WQI.

Until around 60 km from the first sampling point, the water quality is almost stable (comparing with high peak values). However, high peaks are starting from 11th sampling point that is located in 62 km away from the first sampling point. Based on the above analysis, entire hydro-chemical dataset has been separated into two datasets, namely upstream (natural waters) and downstream (waters affected by human activity) of the Tuul River. The upstream dataset contains data from the sampling point number 1, namely Terelj-Terelj, until the 10th sampling point, Tuul-upper Songino, located just upper reach of joint part of Tuul River and CWTP discharge. The downstream dataset includes data from sampling point number 11 (Tuul-lower Songino) until last sampling point

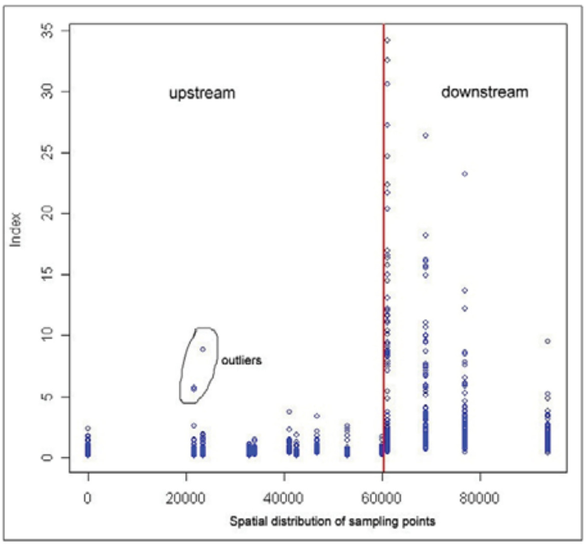


Figure 4. WQI fluctuation in different sampling sites.

number 14 (Tuul-Altanbulag) of this study.

In the upstream portion, fluctuation of water quality was slightly changed along the river. Moreover, quality index did not reach to maximum critical value 6, ignoring some outliers. Reason of outliers, there is no such a big pollution source that exists yet. Two point pollution sources out of five operate in upstream study area, namely Nalaih and Niseh WTSs. Total amount of discharge released from those two sources, is approximately 1800 m^3 day^{-1}. This amount of discharge does not have strong effect on the river water quality. In addition, distance between two points is around 54 km along the river. This is enough distance for the river self-purification after first waste matter pours into the water.

In the downstream portion, from the main pollutant source, quality index is gradually decreased along the distance. The values of figure 4 show the index already exceeds the maximum critical value 6, because of the biggest point source of pollution. Three point sources are located in downstream portion. Total volume of discharge from CWTP, Bio-industry and Bio-Songino WTSs is approximately 191090 m^3 day^{-1} and distance between points is around 2.5 km. The distance is not enough for the river self-purification process to take place, especially after huge volume of effluent was poured into the river. Pollution of the river is reduced along the downstream, but not completely purified even 35 km downstream of the city.

Temporal water quality assessment. Rapid urbanization, increasing number of tourist camps as well as different agricultural and mining activities have significant negative impacts on Tuul River's water quality and its related ecosystems. Consequently, water becomes seriously polluted and loses its clarity and transparency, and its self-purification distance increases year by year (Basandorj & Davaa, 2006).

The general trend of WQI and variability gradually increases in the study's time steps. In the year 1999, the water quality was most stable, but in 2005, it was most variable. The reason of stabilization is a new filtering system that was installed in the treatment plant in 1999 by the support of Japanese International Cooperation Agency. However, the system has not been renewed. Besides that, the amount of wastewater is significantly increased due to population growth of the capital city and raise of industrialization.

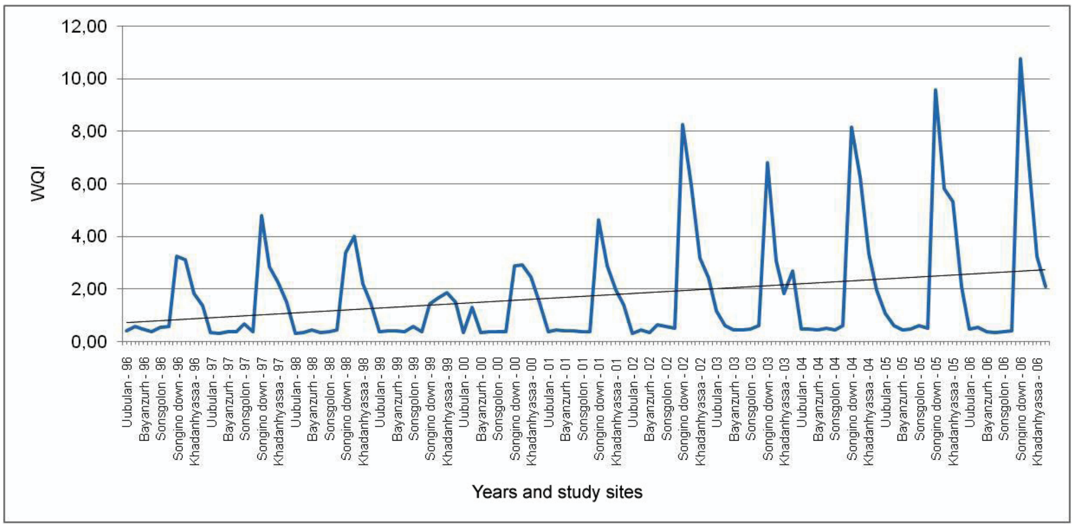


Figure 5. Time series of WQI.

Generally, water quality was not changed at a selected point (a) of the upstream portion, because of the absence of influential pollution source. However, there is a slight increment of general trend in WQI. In downstream portion (b), the water quality was decreased during the period of this study and the value of WQI increased.

The following time series of maps have shown temporal changes of water quality along the Tuul River in three selected years, namely 1996, 2002 and 2006.

In 1996, the Tuul River was not seriously polluted. Classes of heavily polluted and dirty waters are not visualized in map.

In 2002, the river started to be seriously polluted. Classes of heavily polluted and dirty water are visualized in map.

In 2006, the river was strongly polluted due to the efficiency of CWTP operation fail, lack of spare parts, outdated equipment and frequent power shortages and above-mentioned reasons.

Seasonal water quality assessment. Mongolia has four seasons. In this study, all months of the year were divided into two broad periods such as warm

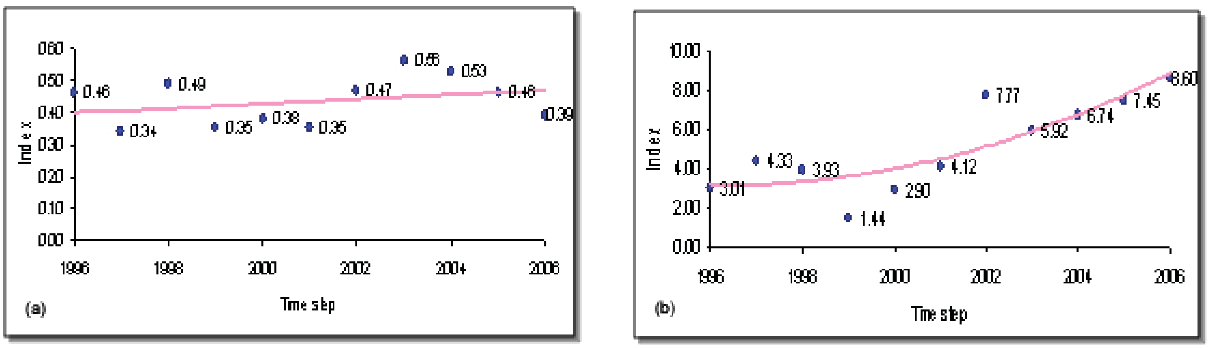
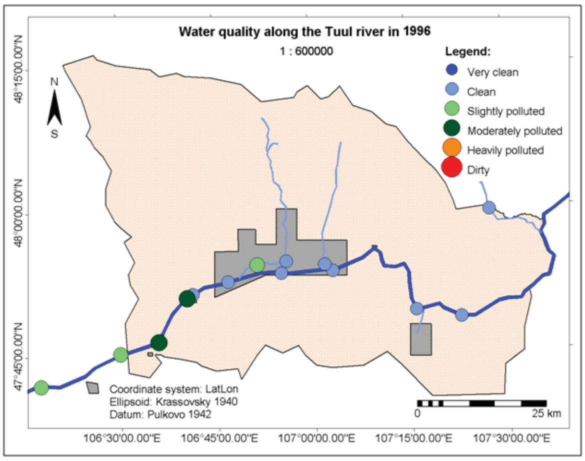
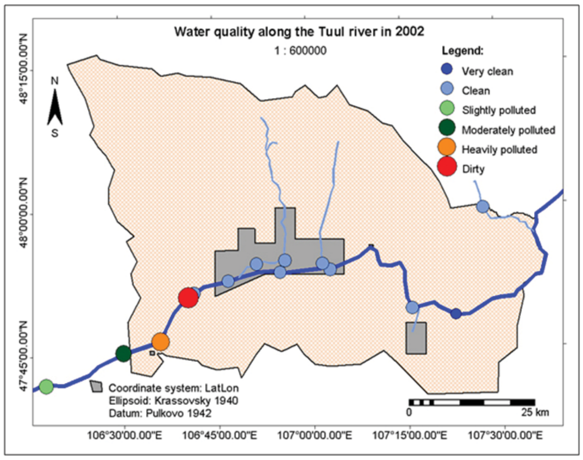


Figure 6. Water quality fluctuation (a) at "Tuul-upper Songino" and (b) "Tuul-lower Songino"during time step.





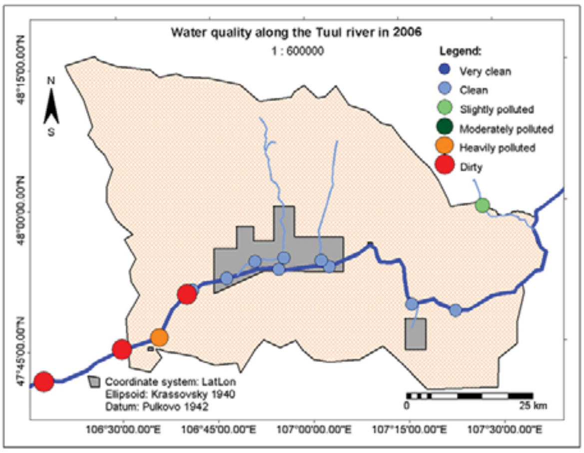


Figure 7. Water quality maps of Tuul River in 1996, 2002 and 2006.

and cold. Cold period continues from November until the end of March. In this period, average air temperature is below zero, deposits snow, and freezes the rivers. This natural phenomenon negatively affects river internal processes and interaction between river and other natural components. That means dispersion, dilution and advection processes cannot intensively take place in this period. The river discharge reaches between 0 - 4 $m^3 s^{-1}$ and CWTP discharge is 2.2 $m^3 s^{-1}$, normally. Warm period begins in April and lasts until end of October. During this period, air mean temperature is above zero and precipitation is in the form of rain.

In upstream portion, there is no such a big pollutant source (effluent from Nalaih WTS is approximately 0.02 m^3s^{-1}) and WQI calculated with less values, difference between indexes in warm and cold periods is small. In downstream portion, several pollutant point sources exist and total discharge is 2.2 m^3s^{-1}, approximately. WQI calculated with greater values in cold period and difference between both periods is high. Because of self-purification process intensively takes place in warm period and this process is almost interrupted during the cold period. Overall index of water quality calculated maximum value with 2.94 in warm period and 11.05 in cold period (Table 4).

Conclusions

The study on surface water quality assessment was carried out in surrounding area of Ulaanbaatar city using hydro-chemical datasets between 1996 and 2006, SWQI method and the following results were found.

The CWTP is one of the biggest and strongest point source of pollution in Tuul River, nowadays. This research is indicated that the Tuul River is not polluted until the Ulaanbaatar city and the

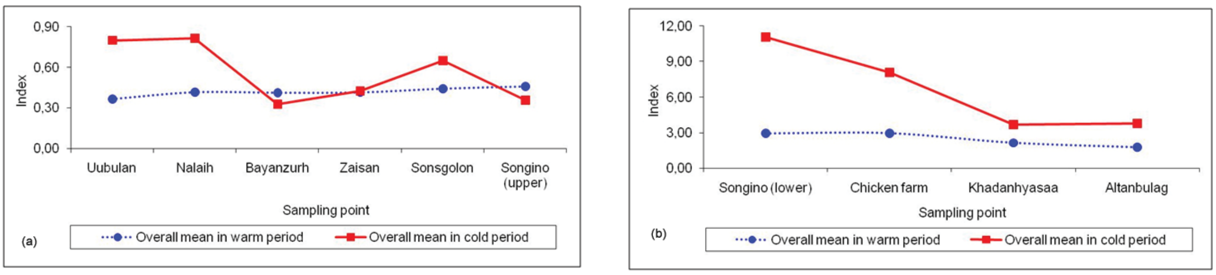


Figure 8. Seasonal water quality in (a) upstream and (b) downstream portions.

Table 4. Annual mean of WQI

Years	Tuul-Uubulan	Tuul-Nalaih	Tuul-Bayanzurh	Tuul-Zaisan	Tuul-Sonsgolon	Tuul-upper Songino	Tuul-lower Songino	Tuul-Chicken farm	Tuul-Khadanhyasaa	Tuul-Altanbulag
Warm period										
1996	0.40	0.42	0.46	0.39	0.56	0.56	1.13	1.84	1.75	1.42
1997	0.35	0.32	0.41	0.35	0.40	0.37	1.56	1.87	1.65	1.44
1998	0.36	0.36	0.48	0.35	0.38	0.48	3.26	2.73	2.56	2.01
1999	0.36	0.40	0.40	0.36	0.59	0.36	0.91	1.36	1.50	1.36
2000	0.36	0.36	0.34	0.37	0.34	0.38	2.27	2.48	3.11	1.55
2001	0.34	0.38	0.41	0.38	0.37	0.36	2.36	2.11	1.98	1.37
2002	0.32	0.38	0.33	0.63	0.55	0.54	4.26	3.31	2.65	2.18
2003	0.41	0.47	0.45	0.44	0.46	0.60	4.55	6.52	1.33	2.69
2004	0.39	0.51	0.48	0.54	0.48	0.58	1.27	1.68	1.96	1.58
2005	0.37	0.50	0.39	0.39	0.34	0.39	3.69	3.62	2.43	1.70
2006	0.36	0.47	0.38	0.34	0.41	0.41	6.87	4.85	2.54	2.00
Overall mean	0.37	0.42	0.41	0.41	0.44	0.46	2.92	2.94	2.13	1.75
Cold period										
1996	0.40	1.06	0.40	0.30	0.35	n.a	7.47	7.59	2.00	1.26
1997	0.27	0.25	0.24	0.51	2.53	0.30	11.19	8.69	3.40	1.58
1998	0.24	0.29	0.27	0.30	0.30	0.26	3.65	6.09	1.82	0.77
1999	0.27	0.32	0.28	n.a	0.26	0.28	3.16	3.65	3.02	1.89
2000	0.28	3.44	n.a	n.a	0.52	n.a	7.08	3.53	1.51	0.68
2001	0.37	0.50	0.32	0.43	0.34	0.26	8.56	4.19	1.92	1.42
2002	0.28	0.50	0.35	n.a	n.a	0.29	15.20	10.52	4.11	3.17
2003	3.42	0.85	0.32	0.39	n.a	n.a	12.10	5.52	2.57	n.a
2004	0.55	0.39	0.25	0.17	0.17	n.a	17.78	12.62	5.21	3.25
2005	2.05	0.73	0.48	1.05	1.15	0.87	17.76	13.40	9.36	3.01
2006	0.65	0.62	0.35	0.23	0.21	0.23	17.57	13.07	5.59	20.80
Overall mean	0.80	0.81	0.33	0.42	0.65	0.36	11.05	8.08	3.68	3.78

pollution appears when the river runs through the city. Based on water quality and its contamination, the river can be separated into two different parts, (i) natural waters and (ii) technological waters. The water quality of Tuul River gradually decreased during the study period due to population growth and the CWTP operation fail. According to the time series of water quality maps, the river is started to strongly pollute since 2006. Pollution of water reduces along the river, but not completely purified at last sampling point. Highest values of WQI were indicated mostly in cold period of the year due to shortage of river natural flow. Therefore, the CWTP must renew its equipments and improve efficiency of the system operation. Perhaps a new wastewater treatment plant is needed for Ulaanbaatar city.

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Хураангуй

Судалгаанд 1996-2006 онуудад Туул болон түүний цутгал голуудын (Тэрэлж, Сэлбэ, Улиастай) 14 мониторинг судалгааны цэгүүд дээр Байгаль Орчны Шинжилгээний Төв Лабораторийн хэмжсэн нийт 11 жилийн 1192 гидрохимийн мэдээг ашиглав. Судалгааны дүнд Туул гол Улаанбаатар хот хүртэл бараг бохирдоогүй байдаг бөгөөд усны бохирдол нь хот дундуур урсах явцад илэрч эхэлж байгааг тогтоолоо. Голын усны бохирдлын зэргийг илтгэгч усны чанарын индексийн өндөр утгууд Туул-Сонгино доод судалгааны цэгээс авсан дээжүүдэд илэрч байна. Энэ нь голын усанд цутгах Төв Цэвэрлэх Байгууламжийн ус хэр зэрэг цэвэрлэгдэж буйгаас шууд хамаарч байна. Судалгааны талбайн доод хэсгийн Туул голын усыг бохирдуулагч цэгэн бохирдуулагч эх үүсвэрүүдийн голд цутгах байршлийн хоорондох зайголын ус өөрийгөө цэвэршүүлэхэд хангалтгүй байгаа нь ажиглагдав. Судалгаа явуулсан хугацааны туршид голын усны чанар улам муудаж, чанарыг илтгэгч индексийн утга өссөөр байна. Үүний зэрэгцээ улирлын шинжтэй усны бохирдлын хэлбэлзлийг тодорхойлсон бөгөөд хүйтний улиралд чанарын индексийн утга өндөр, дулааны улиралд бага утгатай байсан нь голын байгалийн урсацын хэмжээтэй шууд холбон тайлбарлана. Судалгааны үр дүнд Туул голын судалгаанд хамрагдсан хэсгийн бохирдлыг усны чанарын индексээр үнэлж, орон зай-цаг хугацааны өөрчлөлтийг илтгэсэн газрын зургийг боловсруулан гаргалаа.

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