Application of index analysis to evaluate the water quality of the Tuul River in Mongolia

1. Introduction

It is widely accepted that discharges from sewage treatment plants provide major fluxes of nutrients to rivers, predominantly in populated urban areas [1]. The use of water quality index (WQI) simplifies the presentation of results of an investigation related to a water body as it summarises in one value or concept a series of parameters analysed. In this way, the indices are very useful to transmit information concerning water quality to the public in general, and give a good idea of the evolution tendency of water quality to evolve over a period of time [2].

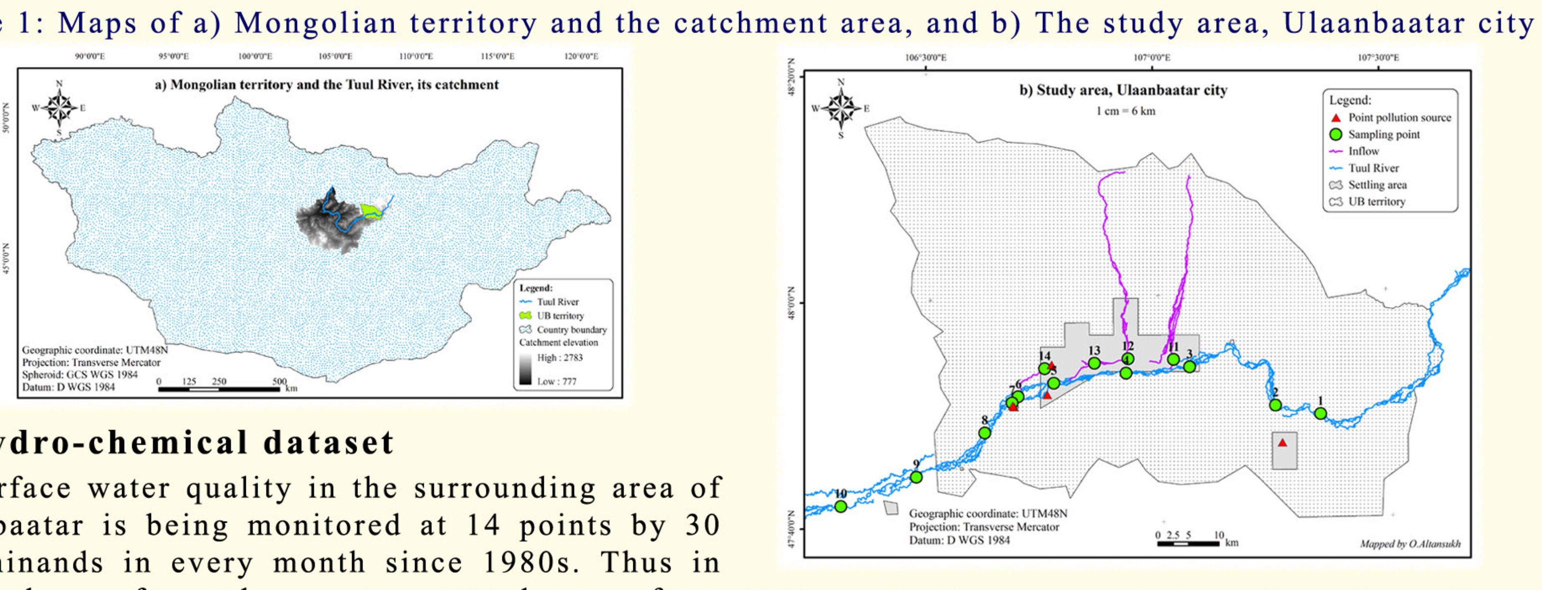
This study has carried out a water quality of the Tuul River in surrounding area of Ulaanbaatar city, Mongolia using WQI in order to assess the state of water quality and sources of pollution. This poster presents the comprehensive analysis of chemical data of water quality in the Tuul River and identifies spatio-temporal patterns in water quality from 1998 to 2008. The aims of this research are i) to assess spatio-temporal variability of water quality in the Tuul River and its tributaries; ii) to evaluate the overall state of water quality, and iii) to produce time series of water quality maps of the river using surface water quality index (SWQI) in surrounding area of the city.

2. Study area and data

Study area

The Tuul River, flowing through the heart of the city, is an environmentally, economically and socially significant natural resource. The study area covered the Tuul River and its two tributaries, Uliastai, Selbe Rivers and discharge from CWTP. The river pertains to 6th order of the Strahler river classification system.

Figure 1: Maps of a) Mongolian territory and the catchment area, and b) The study area, Ulaanbaatar city



Hydro-chemical dataset

Surface water quality in the surrounding area of Ulaanbaatar is being monitored at 14 points by 30 determinands in every month since 1980s. Thus in this study, we focused on more recent datasets from 1998-2008, total 11 years, at those 14 sites, including the chemical monitoring location of CWTP discharge for evaluation of the treatment plant effect (Figure 1b and Table 1). In total, 1196 samples were taken at 14 sampling points and analysed by the Central Laboratory of Environmental Monitoring. Water quality determinands presented in this poster are dissolved oxygen (DO), biological oxygen demand (BOD_5), chemical oxygen demand (COD), ammonium (NH_4^+-N), nitrite (NO_2^--N), nitrate (NO_3^--N) and phosphate (PO_4^{-3}), totally seven variables.

Table 1: Spatio-temporal information of sampling

ID	Name of sites	Latitude N	Longitude E	Altitude m	Distance km	Temporal sampling	Selection
	Monitoring sites along the Tuul River						
1	Tuul – Uubulan	47°49'11"	107°21'02"	1383	0	monthly	Base load
2	Tuul – Nalaikh	47°49'56"	107°15'07"	1364	11	monthly	Nalaikh WTS impact
3	Tuul – Bayanzurkh	47°53'34"	107°03'53"	1309	28	monthly	Inflow to the city
4	Tuul – Zaisan	47°53'13"	106°55'36"	1293	12	monthly	Centre of the city
5	Tuul – Sonsgolon	47°52'26"	106°46'21"	1272	13	monthly	Outflow from the city
6	Tuul – Songino (upper)	47°51'17"	106°41'22"	1256	9	monthly	Upper reach of CWTP
7	Tuul – Songino (down)	47°50'50"	106°40'28"	1254	2	monthly	Lower reach of CWTP
8	Tuul – Chicken farm	47°48'13"	106°36'46"	1233	10	monthly	Self-purification
9	Tuul – Khadankhyasaa	47°44'23"	106°27'35"	1217	21	monthly	Self-purification
10	Tuul – Altanbulag	47°41'54"	106°17'40"	1182	19	monthly	Self-purification
	Main inflows into the Tuul River						
11	Uliastai - UB	47°54'07"	107°01'51"	1310	…	monthly	Tributary of the river
12	Selbe - UB	47°54'30"	106°55'55"	1290	…	monthly	Tributary of the river
13	Selbe - Dund	47°54'11"	106°51'23"	1276	…	monthly	Tributary of the river
14	CWTP - outflow	47°53'49"	106°44'56"	…	…	daily	Strongest impact

Method

The annual means of water quality datasets have been calculated by WQI, so that water quality classes can be assessed (Figure 5). The following equations were used. In a main equation (1), WQI is calculated as the sum of the different sub-index scores. Sub-indices of DO and BOD_5 receive different weights (W) depend on concentration and calculate by slight different equations [3]. The results of index application present quantitatively, are corresponding to a grade of 1-6, and qualitatively in Table 2.

$$WQI = \frac{\sum_i \left(\frac{C_i}{Pl_i} \right)}{n} \quad (1) \qquad \frac{C_{BOD}}{W_{BOD}} \quad (2) \qquad \frac{W_{DO}}{C_{DO}} \quad (3)$$

WQI water quality index; *Ci* concentration of i variable

n number of variables; *Pli* permissible level of i variable

Table 2: A Mongolian classification of SWQ

WQI	Water quality degree	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

3. Results

Data analysis

Hydro-chemical primary datasets were used in the secondary data (WQI) calculation. The number of samples with critical values of the waters, excluding CWTP discharge, is shown in Table 4.

Table 4: The number of samples with critical values

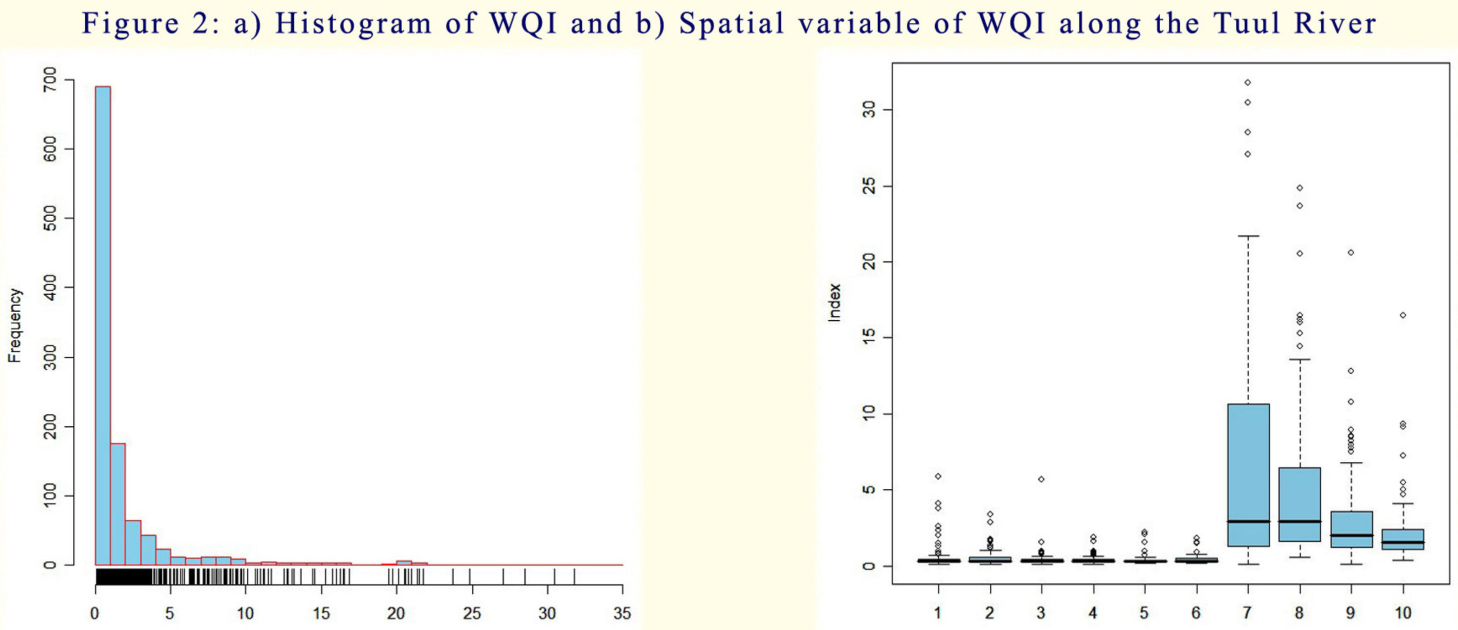
Threshold values	Number of observations	Percentage in total observations
≤0.30	291	26.6
0.31-0.89	370	33.7
0.90-2.49	242	22.1
2.50-3.99	70	6.4
4.00-5.99	35	3.2
6.00≤	88	8.0
Sum	1096	100

Table 3: Annual mean WQI at sampling sites

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1998	0.27	0.28	0.39	0.30	0.32	0.41	2.80	3.45	2.11	1.33	0.33	0.39	0.51	6.25
1999	0.36	0.34	0.34	0.29	0.55	0.31	1.26	2.21	1.71	1.42	0.44	0.66	0.68	8.20
2000	0.77	0.34	0.30	0.32	0.32	0.33	2.82	3.15	2.35	1.37	0.33	0.48	0.61	4.82
2001	0.45	0.38	0.35	0.34	0.32	0.31	4.53	2.71	1.84	1.32	0.42	0.60	0.66	7.70
2002	0.65	0.38	0.29	0.49	0.48	0.45	7.70	5.70	3.19	2.35	0.35	0.39	0.39	17.47
2003	0.75	0.50	0.38	0.38	0.39	0.58	7.99	5.59	7.54	2.59	0.40	0.53	0.65	27.21
2004	0.37	0.41	0.36	0.35	0.37	0.52	7.72	6.02	3.13	1.94	0.51	0.74	0.79	29.52
2005	0.39	0.67	0.38	0.42	0.51	0.47	8.53	5.86	5.36	3.49	0.52	1.07	1.09	16.56
2006	0.40	0.47	0.33	0.26	0.30	0.32	11.16	7.20	8.83	6.51	0.52	0.54	0.73	23.40
2007	0.30	0.46	0.47	0.34	0.35	0.35	11.91	10.15	3.07	2.43	n.a	0.69	n.a	n.a
2008	1.14	1.14	1.14	0.65	0.39	0.70	6.01	5.17	3.25	2.73	n.a	1.14	2.72	n.a
Summary:														
Mean	0.53	0.49	0.43	0.38	0.39	0.43	6.58	5.20	3.85	2.50	0.42	0.66	0.88	15.68
Std	0.27	0.24	0.24	0.11	0.09	0.13	3.45	2.29	2.38	1.50	0.08	0.25	0.67	9.45
Min	0.27	0.28	0.29	0.26	0.30	0.31	1.26	2.21	1.71	1.32	0.33	0.39	0.39	4.82
Max	1.14	1.14	1.14	0.65	0.55	0.70	11.91	10.15	8.83	6.51	0.52	1.14	2.72	29.52

The histogram shown in Figure 2a visualizes the distribution frequency of the WQI. Figure 2b shows WQI variability at the sampling points along the Tuul River. A most dynamic one is a sampling point 7, namely Tuul-Songino (down), the index strongly depends on how well water has been treated when discharged from the CWTP. Then it is naturally purified along the river flow.

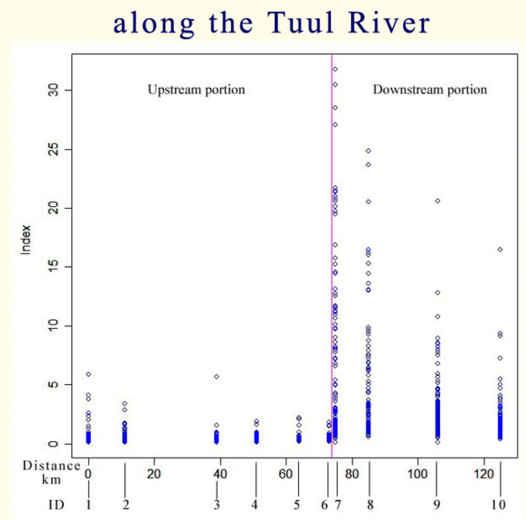
Figure 2: a) Histogram of WQI and b) Spatial variable of WQI along the Tuul River



Spatial water quality assessment

The spatial distribution of average values for the quality indices from 1998 to 2008 along the Tuul River is given in Figure 3. General spatial pattern in the study area with lower values in the upper section of the river, but then rapidly increase at point number 7, caused by CWTP discharge. From this point, there is a gradual decrease to the last point due to dilution.

Figure 3: Spatial WQI fluctuation along the Tuul River



Based on the above analysis, the entire hydro-chemical dataset has been separated into two datasets, namely upstream (natural waters) and downstream (waters affected by human activity) of the river. The upstream part contains data from the Tuul-Uubulan (1) until the Tuul-Songino upper (6), which is located in upper reach of junction of the Tuul River and the CWTP discharge. The downstream part covers from the Tuul-Songino down (7) until the last sampling point Tuul-Altanbulag (10) of this study.

Two point pollution sources out of five operate in the upstream, Nalaikh and Nisekh WTP. Total amounts of discharge release from those two sources are approximately 1800 m^3/day. This amount of discharge does not really have strong negative effect on the river water quality. In addition, distance between two points is around 54 km along the river.

In the downstream portion, from the main pollutant source, quality index gradually decreases along the distance. The index has exceeded the maximum critical value. Three point sources are located in the downstream portion. Total volumes of discharge from CWTP, Bio-industry and Bio-Songino WTP are approximately 191090 m^3/day and distance between points is around 2.5 km. This is not enough distance for the river self-purification process, especially after huge volume of effluent pours into the river. Pollution of the river reduces along the downstream, but not completely purified even 50 km downstream of the city.

Temporal water quality assessment

The general trend of WQI and variability gradually increase in the study time steps. In the year 1999, the water quality was good, but in 2007, the index was highest. Besides of that, increased values of the indices during the time could be due to rise of industrialization and increased the amount of wastewater related to population growth.

The following series of maps have shown spatio-temporal changes of water quality along the Tuul River and its inflows in the selected research years.

Figure 4: Annual average WQI 1998-2008

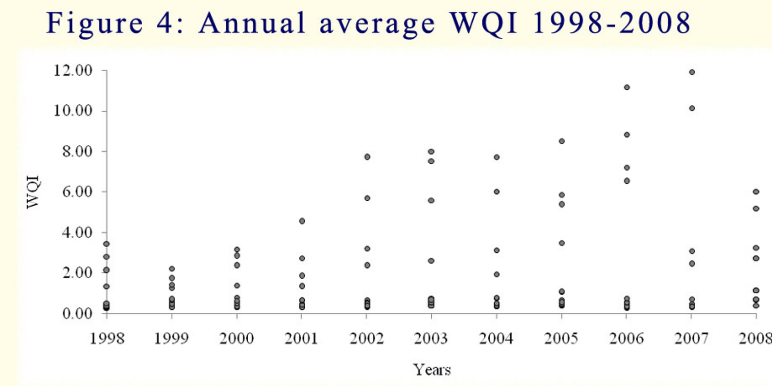
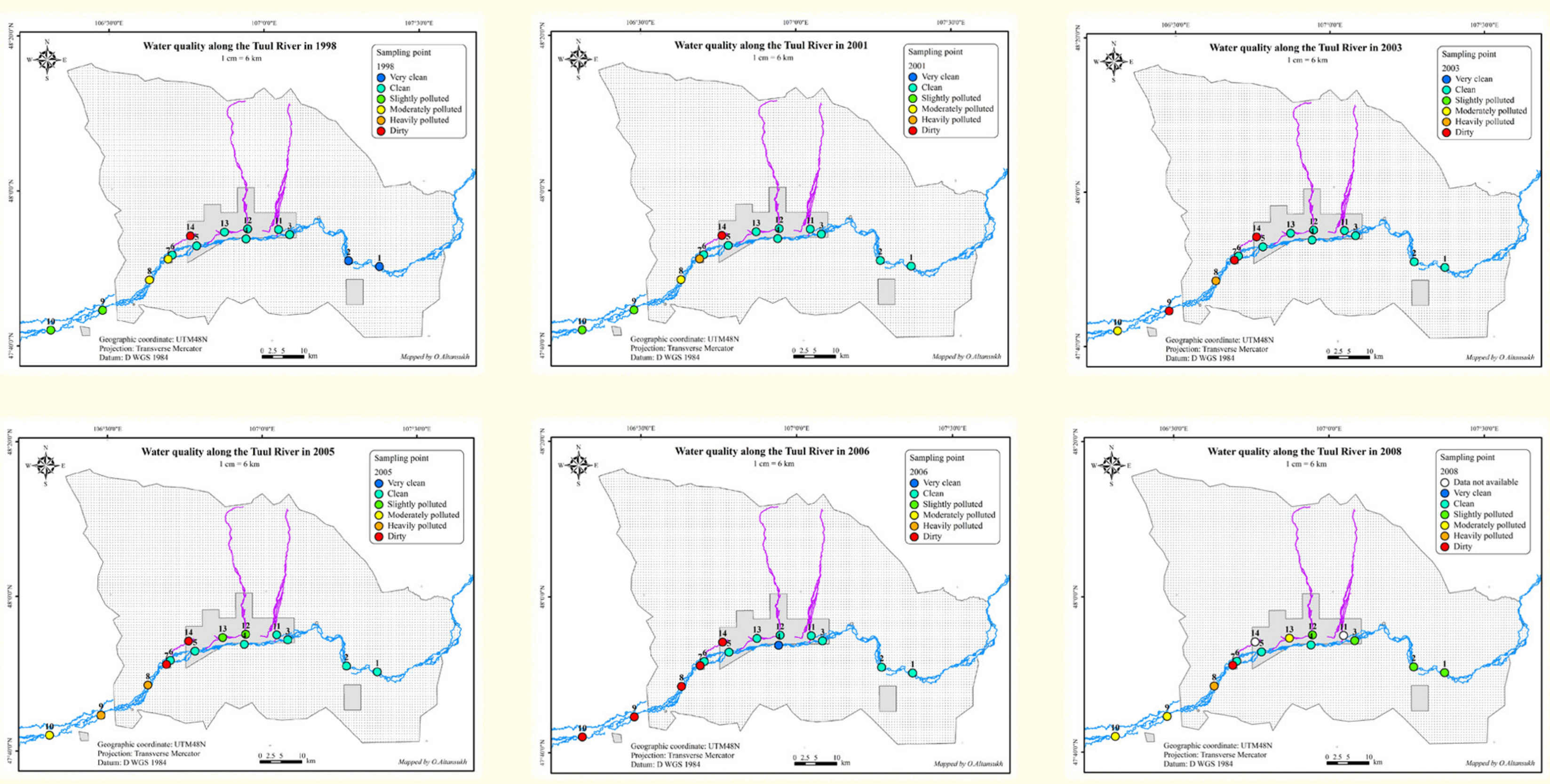


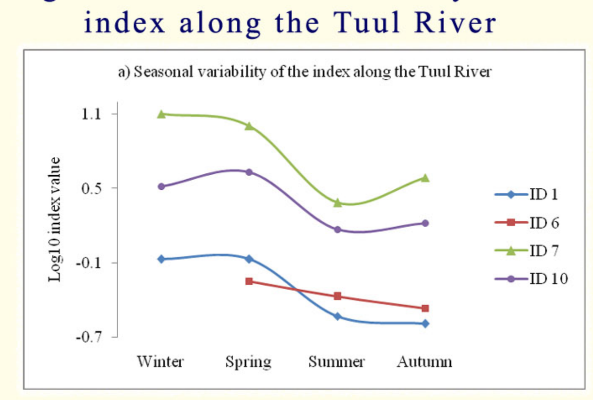
Figure 5: Spatio-temporal series of water quality index map of the Tuul River and its inflows



Seasonal water quality assessment

Average index values of each season were calculated and used to seasonal assessment. The higher values of indices tend to occur in winter and lower values likely to occur in summer. There is a steady descend trend in the index value, means increment of water quality from winter to autumn. The seasonal variability of index depends on both natural and human processes. The higher values in winter time are related to the river low flows and enormous amount of discharge from the CWTP. The river discharge reaches between 0-4 m^3/s and the CWTP discharge reaches 2.2 m^3/s, normally.

Figure 6: Seasonal variability of the index along the Tuul River



Almost same concentrations as winter in spring are derived from snow melt and surface runoff, plus the treatment plant discharge. The lower values in summer are associated with not only normal flow of the river, but also related to re-aeration and nitrification process. The increased concentrations in autumn are derived from the rainfall-runoff process that washes away pollution elements from the catchment area.

4. Conclusions

Human activity in the region has a significant impact on surface water quality. Increments of hydro-chemicals are strongly associated with CWTP operation. Clearly, there is a need to improve the water quality in the Tuul River system in surrounding area of the Ulaanbaatar in order to bring it up to the class, I or II of the index assessment. The quality assessment suggests that the waters in the downstream section of the river are unsuitable for drinking and recreational purposes. Among the pollution sources, the CWTP is a biggest and strongest point source of pollution in the Tuul River in the study area, nowadays.

5. Discussion

In order to change this situation, improvement of the operation efficiency of the CWTP becomes crucial to recover the water quality significantly. Accordingly, a modelling of water quality with different scenarios such as certain limits on chemical concentrations of the CWTP discharge and artificial increment of DO concentrations have important roles in the river system. DO concentrate can be artificially increased using bull stone wall (not weir) which has big enough holes that fish and sediment can easily pass through. The penetration theory by Higbie, 1935 and a surface renewal model that formalized Danckwerts in 1951 are theoretical part of the DO artificial increment method. This method can be more eco-friendly (economically and ecologically) and works more effectively over the long period. Also, there are several advantages of this method such as i) materials that can use to build the wall are natural, ii) no extra operation cost after the wall built, iii) no negative impact on river system, aquatic fauna and sediment can easily pass through by holes between bull stones, iv) works efficiently for a long time, v) easy to stop operation, just take out stones and vi) an artificial pond will not be created in upstream of the wall. However, there are also some disadvantages, which include i) not applicable to big rivers, ii) the wall may collapse in the fact of strong flows, and iii) heavy machinery such as a crane is required.

FURTHER INFORMATION

Ochir Altansukh[1]*, G.Davaa[2]

[1]School of Earth Sciences,
National University of Mongolia,
Ulaanbaatar 210646, Mongolia
[2]Water Research Sector,
Institute of Meteorology and Hydrology,
Mongolia

*Corresponding author address:
altansukh@num.edu.mn

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