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DETERMINATION OF DEOXYGENATION RATE OF SELBE RIVER AND ITS PURIFICATION STUDY

Bachelor Thesis

By

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Ulaanbaatar/Nalaikh, May 16th, 2022

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Statutory Declaration

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I hereby affirm in lieu of an oath that I provided the submitted bachelor thesis

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List Of Abbreviations

BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
MNS	Mongolian National Standard
DO	Dissolved Oxygen
IWRM	Integrated Water Resources Management
Km	Kilometer
°C	Degree Celsius
Km^3	Cubic kilometer
%	Percent
mm	Millimeter
BSk	Cool Semi-Arid
mg/L	Milligrams Per Liter
k	Deoxygenation Rate
R^2	Coefficient of Determination
d	Day
t	Time
BOD_t	Amount of Organic Waste Presence at T Time
UBOD	Carbonaceous Ultimate Biochemical Oxygen Demand
L_0	Ultimate Biochemical Oxygen Demand
N	Latitude
E	Longitude
$K_2Cr_2O_7$	Potassium Dichromate
Q	Discharge

A	Area
$\bar{v}$	Average Velocity
m/s	Meters Per Second
m^3/s	Cubic Meters Per Second
V	Velocity
D	Depth
Σ	Sum
M	Meter
mmHg	Millimeter of mercury
mL	Milliliter
NAMHEM	National Agency for Meteorology, Hydrology and Environmental Monitoring

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Executive Summary

The Selbe river is one of the major tributaries of Tuul river, which flows through Ulaanbaatar city. The total length of Selbe river is 36.6 km and it is located in Tuul river Basin, where around 46% of the Mongolian population is concentrated. However, in recent years Selbe River has lost its original state and appearance due to unplanned and unregulated urbanization near the river area.

The purification system of the Selbe river, the Streeter-Phelps model, is used to describe the self-purification distance, critical oxygen deficiency and critical time of the Selbe river. Therefore, the deoxygenation rate k_1 and the reaeration rate k_2 constant are determined during the thesis study.

The mean deoxygenation rate constant k_1 is calculated using two models, namely the Thomas slope and first-order function methods. The results showed that the first order function model is more suitable for describing the deoxygenation rate k_1, which is 0.1070 and 0.2465 correspondingly in 10 and natural logarithmic base, because of sampling standard deviation are 0.0236, 0.0543 respectively in natural and 10 logarithmic bases of statistical analysis.

The mean reaeration rate constant k_2 is estimated using 22 different models for the reaeration rate calculation. Jha (2001) model results are valid, because it had lowest sampling standard deviation of 1.009 compared with other models. Accordingly, the mean reaeration rate k_2 in Selbe river is 3.91.

As a result, using the hydrological measurements, deoxygenation rate k_1 and reaeration rate constant k_2, the critical oxygen deficiency distance in Selbe river is calculated 4.14 km with critical oxygen deficit 2.43 mg/L and 0.25 days of critical time applying Streeter Phelps oxygen sag model.

1 Introduction

Mongolian people have a proverb “Water is a wish granting jewel” or “Ус бол чандмань эрдэнэ”, which specifies that Mongolians have been living near to the water sources by cherishing, protecting and worshiping water for the generations.

The water resources in Mongolia are about 599 km^3/year, which is 0.00004 percentage of the world total water volume (1). Furthermore, rivers, lakes, and swamps are known as surface water, which makes up only 0.26 percent of all fresh water on our planet (2). On the other hand, the total water resources in rivers or streams in Mongolia are estimated at 34.6 km3/year, as of 49% form up in the Arctic Ocean basin; 11 percent to Pacific Ocean basin and 40% belongs to Central Asian closed basin (Figure 1).(3). Additionally, in Mongolia there are total of 29 river basins (Figure 1) including surface and groundwater basins (4).

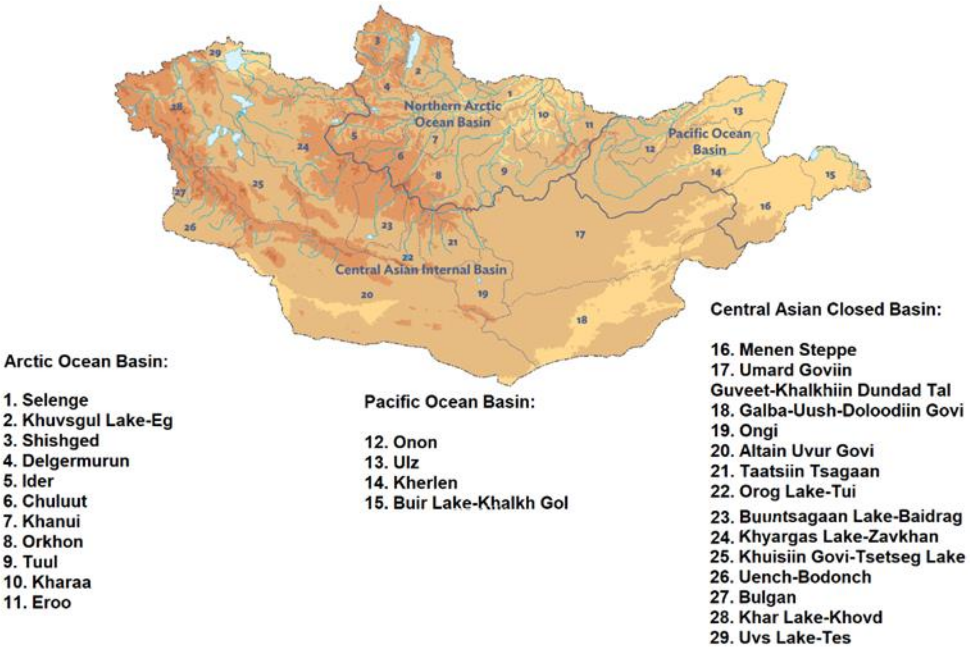

Figure 1 Mongolian Continental Basins (5)

Water consumption and distribution throughout Mongolia is uneven, with 45 to 55.2 million liters of water per capita in Khentii, Selenge, Bulgan and Khuvsgul aimags, and 100 to 123 thousand liters per person per year in the Gobi region (6).

According to the 2021 data of National Statistics Office of Mongolia, around 46% of the Mongolian population is concentrated in the capital city of Ulaanbaatar, which is the main factor of adverse impact on the surface water quality of Tuul River Basin.

Also, surface runoff is expected to increase through all river basins in the Arctic Ocean, Pacific Ocean and Central Asian continental basins by 13 mm, 8 mm and 3 mm, increasing accordingly in 2050. Meanwhile, most of the river basins in Mongolia are likely to be drier in the next decades due to global warming and climate change (3). According to the Food and Agriculture Organization, in 2014 (Figure 2), Mongolia ranks 92nd regarding total fresh water out of 179 countries and 45th regarding water per capita, which is rapidly decreasing annually (7).

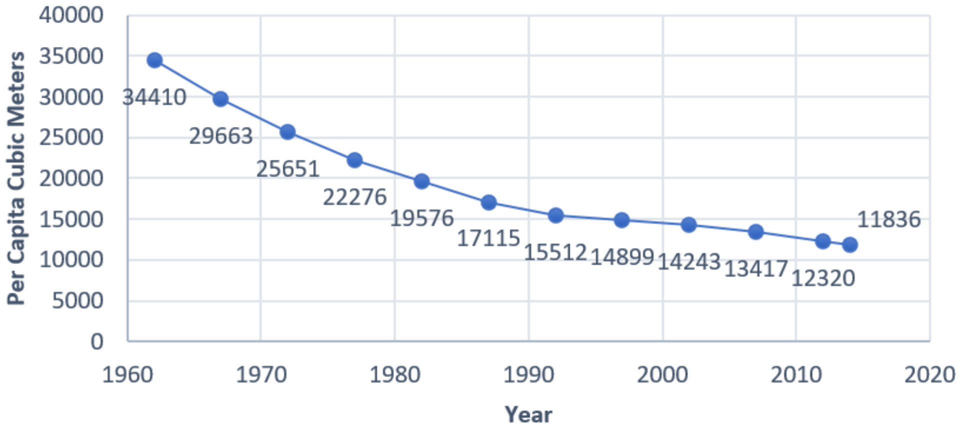

Figure 2 Mongolia Freshwater Decline from 1960 to 2014 (Author)

Drinking water resources are declining year by year due to global warming, improper human consumption, and anthropogenic-related degradation of sources (3).

1.1 Research Objective and Goals

The main objective of the thesis study is to:

- To describe the purification system of the Selbe river.

The following objectives to achieve the main:

- Determine the rate of deoxygenation k_1 using the ultimate and 5 days of Biochemical Oxygen Demand
- Determine the rate of reaeration k_2 using the studies of hydrological data of the river, which was investigated previously

1.2 Hypothesis and Expected Outcome

Assessment level of contamination in Selbe river and creating oxygen sag curve, time and distance of oxygen depletion.

2 State of the Art

The study area of the thesis study is based on Selbe and Dund rivers, which are one of the major tributaries of Tuul river, that flow through Ulaanbaatar city. The Selbe river flows 36.6 km from north to south and originates in the Khentii Range. When Selbe river enters Ulaanbaatar city, after passing the Narnii road, it turns sharply to the west direction, which makes the Selbe river flow parallel with Tuul River, and this part is called Dund River, which confluences with Tuul River.

In accordance with Köppen-Geiger climate classification system (Figure 3), which is the most used climate system by researchers all around the world, that was first invented by Wladimir Köppen in the 1900s and developed by Geiger in 1930. Ulaanbaatar is classified as “BSk” or Cool Semi-Arid Climate.

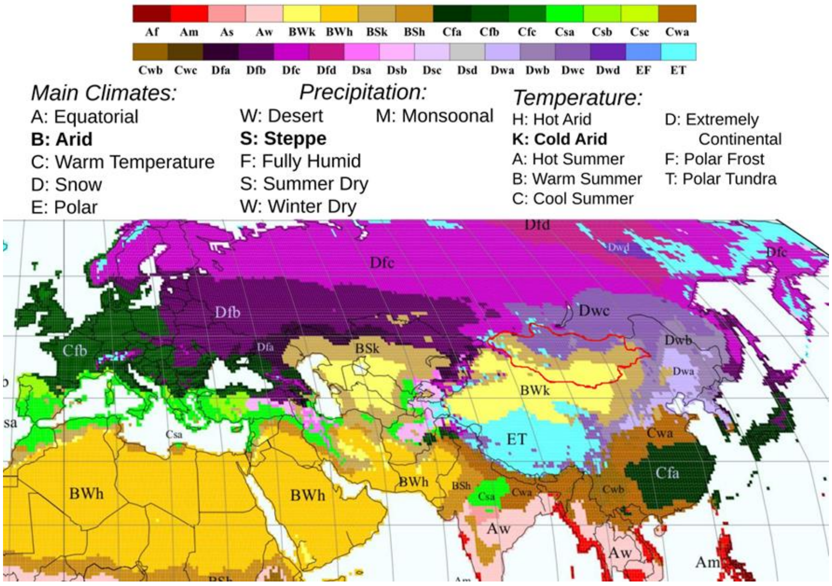

Figure 3 World Map of Koppen-Geiger Classification (28)

Therefore, the average temperature for the year in Ulaanbaatar is around -0.6 °C, and annual rainfall is 264 mm near Selbe river area (8). Besides, in recent years Selbe River lost its original state and appearance due to the unplanned and unregulated urbanization near the river area. Also, justify the accelerated temperature increase and climate change over the western and central regions of Mongolia, which led to continuous warming and reduced rain on a yearly basis (9).

Indonesia was done to determine the deoxygenation rate in 2018, which had used the slope method to determine the rate of deoxygenation on Cimanuk river. Additionally, the results of the Cimanuk river were estimated 0.06-0.12 per day, and the ultimate BOD measurements ranged between 23.33 mg/L to 34.83 mg/L. Moreover, this study used empirical equation method to estimate the deoxygenation rate, which obtained the result of 0.422 and 0.462 of k coefficient per day (10).

A study which was done on municipal waste water samples in Tarapith, India has determined the BOD deoxygenation rate constant using Fujimoto graphical method. As a result, the first sample had a high rate of reaction k (0.2428 d^{-1}) at low ultimate BOD (468.506 mg/L). On the other hand, in the second sample the reaction rate k (0.1525 d^{-1}) was low at high ultimate BOD (776.74 mg/L) (11). In theory, k is 0.23 d^{-1} (base e); 0.10 d^{-1} (base 10) for untreated wastewater at 20 °C (12) is used to solve the problems.

The Selbe River belongs to the Tuul River Basin, which has lost its natural appearance, its composition and characteristics due to anthropogenic and technogenic activities near Ulaanbaatar city. In relation with the MNS 4586:1998 “Water Quality. General Requirements” Standard, in 2012, an assessment of surface water quality has been done on Selbe and Dund rivers. As a result, these two rivers were assessed as moderately polluted with the water quality index between 0.9 to 2.49 (13).

There are various BOD deoxygenation rate estimation methods such as non-linear regression, the logarithmic method of Thomas, two-points method, ratio method, and Fujimoto methods. Oke et. all had studied comparison of the accuracy and efficacy between these methods. This study found the best model using total error for the coefficient determination. As the result has been shown that the non-linear regression and Thomas methods were the best methods for calculating the deoxygenation rate of BOD, based on the error analysis with the values of 100% and 98% accuracy compared with other methods. However, Fujimoto and ratio methods had the highest error, which had precisions of 45% and 33% (14).

The study on Brantas river, Indonesia was done to determine the rate of deoxygenation using Thomas method. Thus, the results in the upper and downstream of the Brantas river demonstrated that through 30 days the BOD values had increased in values. Furthermore, the deoxygenation rate *k* was estimated to have 0.019 d^{-1} in upstream and 0.046 d^{-1} in downstream of the river, while the ultimate BOD was measured to have between 9.614 to 17.291 mg/L. Last but least, the study suggests to use other methods of deoxygenation rate estimation such as least square and non-linear regression, because the coefficient of determination R^2 value was low as 0.31 to 0.84 with using Thomas method (15).

With population increases in settled areas or cities, urbanization accelerates, which has led to serious environmental impacts to the air, soil and water. As an example, the water quality of Rangkui river in Pangkalpinang city, Indonesia is degraded and polluted. Therefore, there was done a scientific study to identify the actual deoxygenation rate coefficient *k* in Rangkui river using slope, Winkler, and empirical formula methods. Consequently, the deoxygenation rate *k* was between 0.14 d^{-1} to 0.41 d^{-1} using the slope method, and the ultimate BOD was between 8.53 mg/L to 70.64 mg/L. However, for the empirical formula method, the deoxygenation rate ranged between 0.49 d^{-1} to 0.55 d^{-1} (16).

2.1 Biochemical Oxygen Demand

Biochemical Oxygen Demand is an indicator for assessing the quality of water, expressed by the amount of oxygen (mg / l) required for biochemical oxidation of organic substances in water. Usually, BOD is used in both surface and wastewater for determining organic pollution in water. Analysis of dissolved oxygen consumed by the microorganisms is related to the biochemical oxygen demand. Additionally, the BOD test is applied to determine the efficiency of various purification treatments, to find out the needed quantity or amount of oxygen, which is vital for the aquatic and organic species present in the water, and to estimate the capacity of wastewater treatment plant appliances (12).

2.2 Dissolved Oxygen

Dissolved oxygen is crucial for the life of aerobic species thought respiration process, in which these microorganisms' intake oxygen to produce energy. Furthermore, dissolved oxygen is affected by water volume and flow velocity, weather, season, type and quantity of organisms in the water, elevation, dissolved and dry residues, organic wastes, coastal vegetation, and groundwater runoff.

Aquatic animals and species are stressed when the amount of dissolved oxygen in the water is less than 5 mg/L. When the oxygen level is between 1-2 mg/L for a few hours, fish cannot survive and dies. Many aerobic organisms, which require oxygen in their vital functions cannot survive when the dissolved oxygen content falls below a certain level (17).

As a matter of fact, with the decrease of the dissolved oxygen level in river and streams, the biochemical reaction rate or deoxygenation rate increases (12).

2.3 BOD Reaction or Deoxygenation Rate Coefficient

Determination of the deoxygenation rate coefficient *k* is crucial for calculating the ultimate biochemical oxygen demand (eq. 1), which is a 20-day period of biochemical oxygen demand. Furthermore, theoretically the biochemical oxidation process never reaches 100 percent complete, due to the assumption of the proportionality of the oxidation rate with the number of organic matter presence in water. Therefore, the oxidation of the ultimate carbonaceous BOD for the 20-day period is identified to be completed between 95 to 99 percent, and for the 5-day period it is known to be oxidized between 60 to 70 percent (12).

2.4 BOD Reaction Rate Coefficient k_1 Determination, First Order Method

$$BOD_t = UBOD(1 - e^{-k_t t}) \qquad \text{Eq. (1)}$$

$$k_t = -ln(1 - \frac{BOD_t}{UBOD})/t \qquad \text{Eq. (2)}$$

$$k(base\ 10) = \frac{k(base\ e)}{2.3} \qquad \text{Eq. (3)}$$

BOD_t = amount of organic waste presence at t time (mg/L)

UBOD = carbonaceous ultimate BOD (mg/L)

k_t = deoxygenation rate coefficient (1/d)

t = time

2.5 BOD Reaction Rate Coefficient *k_1* Determination, Thomas Slope Method

Thomas method has been developed to evaluate the coefficient rate *k* of the biochemical oxygen demand using the slope and intercept values from the linear graph, where time (t) in vertical axis versus [t/BOD (t)]$^{1/3}$ in horizontal axis (18),(19).

$$\left(\frac{t}{y}\right)^{\frac{1}{3}} = \frac{1}{(L_0 k)^{\frac{1}{3}}} + \left(\frac{(k)^{\frac{2}{3}}}{(6L_0)^{\frac{1}{3}}}\right) t \qquad \text{Eq. (4)}$$

Where:

$$\frac{1}{(L_0 k)^{\frac{1}{3}}} = intercept\ (a) \qquad \frac{(k)^{\frac{2}{3}}}{(6L_0)^{\frac{1}{3}}} = slope\ (b)$$

$$k = \frac{6b}{a} \quad or \quad k = 6 \times \frac{slope}{intercept} \qquad \text{Eq. (5)}$$

$$L_0 = \frac{1}{ka^3} \quad or\ L_0 = \frac{1}{k*intercept^3} \qquad \text{Eq. (6)}$$

$$k(base\ e) = (k\ base\ 10)x2.3 \qquad \text{Eq. (7)}$$

t = time

y = BOD at time t

L_0 = Ultimate BOD at t=0

k = deoxygenation rate

2.6 Reaeration Rate Coefficient k_2 Determination

The reaeration rate is the amount at which oxygen is transferred from the air to the water. Fast-moving, shallow, turbulent streams are more effectively reaerated. When the rate of reaeration equals the rate of deoxygenation, the stream has the lowest dissolved oxygen level (20).

Determination of the reaeration rate cannot be modeled by a single equation. Therefore, several models for the estimation of the reaeration rate coefficient k_2 are used. The main variables for finding reaeration rate are the velocity, depth and slope of the river or stream. And the models can be grouped as velocity, depth involved models and velocity depth and slope involved models (21).

A) Reaeration rate models involving velocity (U) and depth (H): Eq. (8)

i. $O'Connor\ and\ Dobbins (1958): K_a = 3.93 \frac{U^{0.5}}{H^{1.5}}$; where depth is between 0.3 m to 9 m, and velocity is between 0.15 m/s to 0.5 m/s

ii. $Churchill\ et\ al. (1962): K_a = 5.026 \frac{U}{H^{1.67}}$; where depth is between 0.6 m to 3 m, and velocity is between 0.55 m/s to 1.5 m/s

iii. $Owens\ et\ al. (1964): K_a = 5.32 \frac{U^{0.67}}{H^{1.85}}$; where depth is between 0.1 m to 3 m, and velocity is between 0.03 m/s to 1.5 m/s

iv. $Langbein\ and\ Durum (1967): K_a = 5.134 \frac{U}{H^{1.33}}$

v. $Bennett\ and\ Rathburn (1972): K_a = 5.5773 \frac{U^{0.607}}{H^{1.689}}$

vi. $Bansal (1973): K_a = 4.1528 \frac{U^{0.6}}{H^{1.4}}$

vii. $Baecheler\ and\ Lazo (1999): K_a = \frac{1.923 U^{1.325}}{H^{2.006}}$

viii. $Jha\ et\ al. (2001): K_a = 5.792 \frac{\sqrt{U}}{H^{0.25}}$

ix. $Isaacs\ and\ Gaudy (1968): K_a = 4.7531 \frac{U}{H^{1.5}}$

x. $Eloubaldy (1969): K_a = 4.05 \frac{U}{H^{1.5}}$

xi. $Isaacs\ et\ al. (1969): K_a = 3.6 \frac{U}{H^{1.5}}$

xii. $Negulescu\ and\ Rojanski(1969)\colon K_a = 10.9[\frac{U}{H}]^{0.85}$

xiii. $Padden\ and\ Gloyna(1972)\colon K_a = 4.54\left[\frac{U}{H^{1.5}}\right]^{0.703}$

B) Reaeration rate models involving depth (H), velocity (U) and slope (S): Eq. (9)

i. $Krenekl\ and\ Orlob(1962)\colon K_a = 173(SU)^{0.404}H^{-0.66}$
ii. $Cadwallader\ and\ McDonnel(1969)\colon K_a = 186(SU)^{0.5}H^{-1}$
iii. $Tsiovoglou\ and\ Neal(1976)\colon K_a = 3170S$
iv. $Grant(1976)\colon K_a = 22700SU$
v. $Thyseen\ et\ al.(1987)\colon K_a = 8784\frac{U^{0.7344}S^{0.93}}{H^{0.42}}$
vi. $Smoot(1988)\colon K_a = 543S^{0.6236}U^{0.5325}H^{-0.7258}$
vii. $Mogg\ and\ Jirka(1998)\colon K_a = 1740S^{0.79}U^{0.46}H^{0.74}$
viii. $Melching\ and\ Flores(1999)\colon K_a = 88(US)^{0.313}H^{-0.353}$ in channel control streams, where Q ≤ 0.556 m^3/s
ix. $Tsivoglou\ and\ Wallace\ (1972)\colon K_a = 31000US$; where depth is between 0.3 m to 0.9 m, and discharge is between 0.03 m^3/s to 0.3 m^3/s

U = velocity (m/s)
H = depth (m)
S = slope (%)
Q = discharge (m^3/s)
K_a = reaeration rate

2.7 Streeter-Phelps Model Equation, Oxygen Sag Curve

The Streeter–Phelps' equation is used to calculate downstream distance and oxygen deficit in streams and rivers. This equation is based on the premise that there are only two processes occurring: deoxygenation from BOD and reaeration at the surface via oxygen transmission. In Figure 4, the difference between the saturation DO level and the critical oxygen deficit is the minimum DO in the stream (20).

$$D_i = saturation\ DO - initial\ DO \qquad \text{Eq. (10)}$$

$$t_c = \frac{1}{k_2 - k_1} \times log\left[\frac{k_2}{k_1} \times \left(1 - D_i \times \frac{k_2 - k_1}{k_1 \times BOD_L}\right)\right] \qquad \text{Eq. (11)}$$

$$D_c = \frac{k_1 \times BOD_L}{k_2 - k_1} \times \left(10^{-k_1 t_c} - 10^{-k_2 t_c}\right) + D_i \times \left(10^{-k_2 t_c}\right) \qquad \text{Eq. (12)}$$

$$x = t_c \times U \qquad \text{Eq. (13)}$$

t_c = time it takes for a critical oxygen deficit (d)

D_c = critical oxygen deficit (mg/L)

D_i = initial oxygen deficit at time t = 0 (mg/L)

BOD_L = ultimate BOD (mg/L)

k_1 = deoxygenation rate (d^{-1})

k_2 = the reaeration rate (d^{-1})

x = distance for minimum DO (m)

U = velocity (m/s)

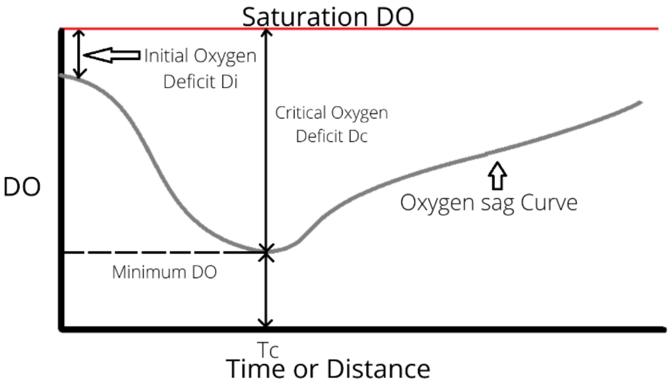

Figure 4 Oxygen Sag Curve (20)

3 Method And Methodology

3.1 Sampling Area

The water sample for laboratory measurement were collected from seven different points totally in the Selbe River, including Altai town (47°54'13.33" N, 106°52'44.06" E), Ikh Nayad Plaza (47°54'23.20" N, 106°55'44.10" E), Chingis Hotel (47°55'23.25" N, 106°55'54.21" E), 100 ail (47°55'56.45" N, 106°55'52.41" E), Dambadarjaa (47°58'36.77" N, 106°55'33.64" E), Jigjid (48°2'59.09" N, 106°54'10.23" E) and Sharga Morit (48°4'42.94" N, 106°53'47.27" E). And the distance length between the first point to the last sampling point is about 30 km, which was estimated using Google Earth Pro (Figure 5).

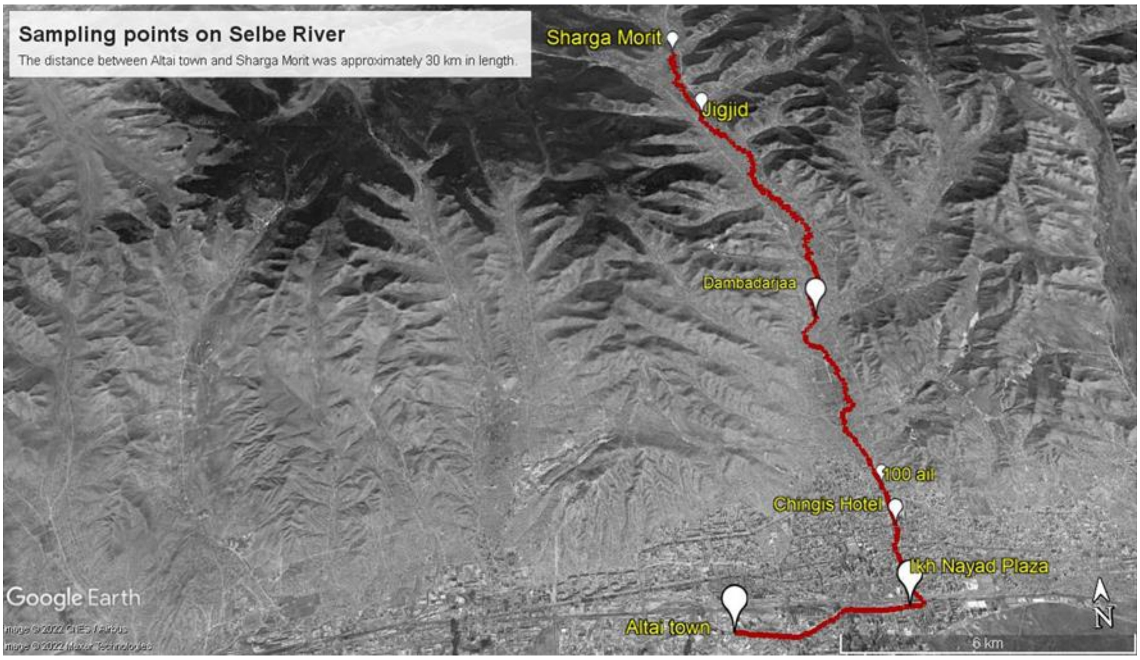

Figure 5 Selbe River Sampling Points (Author)

During the thesis study period, the sample collection process was done three times in November, March and April. The first samples were gathered on November 16th, 2021 from the Chingis Hotel and Ikh Nayad Plaza sample points on the Selbe River (Figure 6).

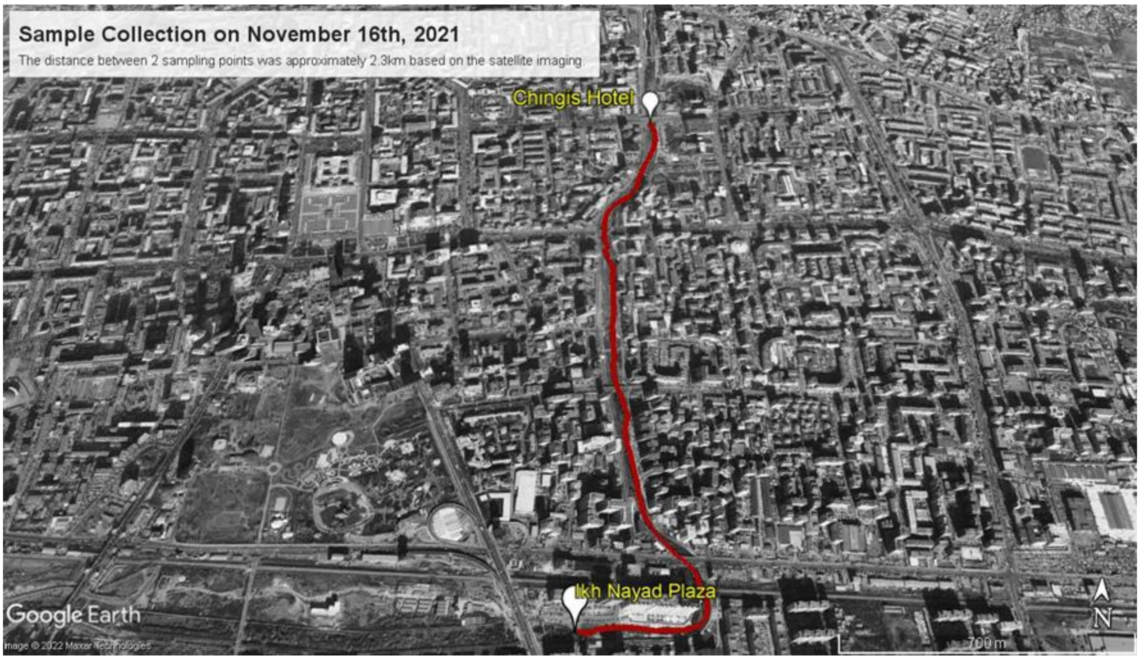

Figure 6 First Sample Collection Points on Selbe River (Author)

The second sample collection process was implemented on March 18th, 2022 from Chingis Hotel and 100 ail sample points. As a matter of fact, during this period the river was fully frozen near Ikh Nayad Plaza point (Figure 7).

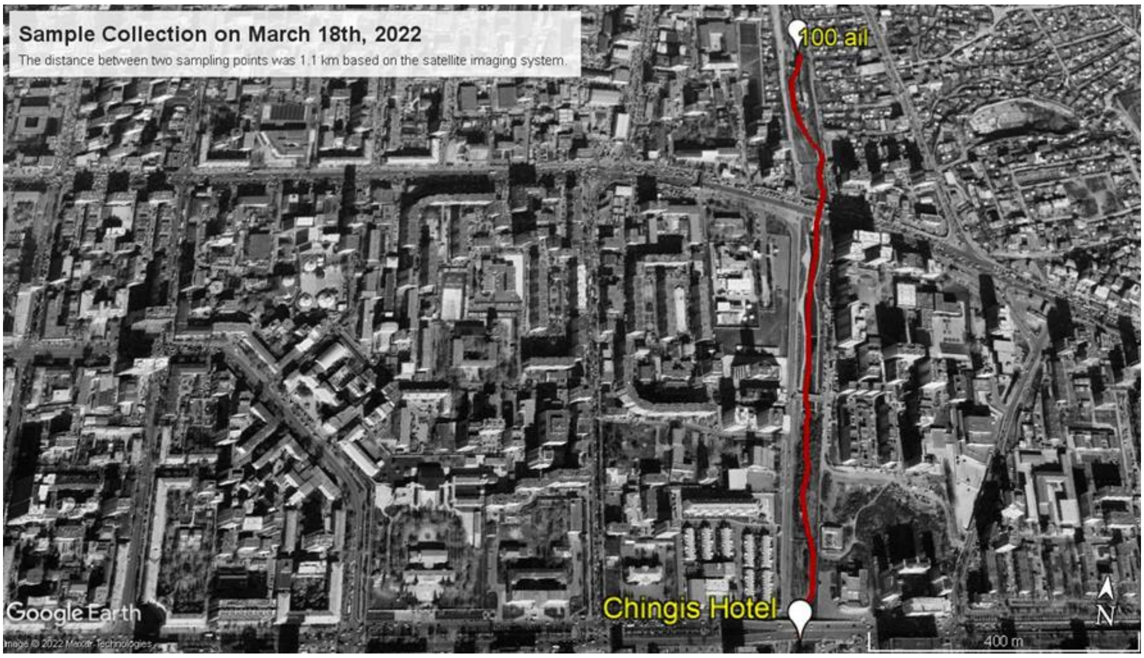

Figure 7 Second Sample Collection Points on Selbe River (Author)

The third sample collection field work was completed on 15th April, 2022 from Altai town, 100 ail, Dambadarjaa, Jigjid, and Sharga Morit sampling points located on the Selbe river (Figure 8).

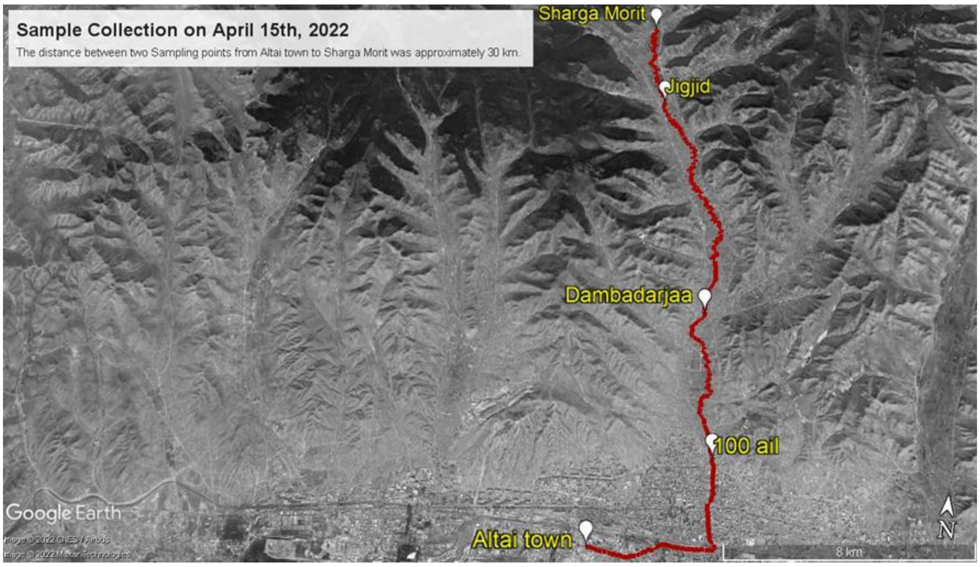

Figure 8 Third Sample Collection Points on Selbe River (Author)

The last sample collection field work was completed on 5th May, 2022 from Ikh Nayad, Chingis Hotel, and 100 ail sampling points located on the Selbe river (Figure 9).

Figure 9 Fourth Sample Collection Points on Selbe River (Author)

Additionally, the pictures that were taken in the field during the November 16th, March 18th, and April 15th are in Annex 1 of this report.

3.2 Determination Of Biochemical Oxygen Demand

The BOD is measured using the Lovibond BD 600 respirometric device (22), which allows to easily measure the direct values of BOD automatically recorded for several days, that can record the results up to 28 days. Additionally, the Lovibond BD 600 can accurately evaluate 6 different samples simultaneously. Most importantly, the principle of the BOD measurement is based on the consumption of the oxygen uptake of microorganisms such as bacteria, algae, fungus, protozoa and archaea that play a crucial role in the natural purification process of stream and river water. For instance, the oxygen digestion process causes the pressure change in the system, meanwhile sustaining the constant volume of the water samples. Last but least, the BOD value is directly proportional to the pressure drop in the water, and because of modern pressure sensors the pressure drop in the water is recorded (22).

Figure 10 Lovibond BD600 (Author)

3.3 Determination Of Chemical Oxygen Demand

Determination of the chemical oxygen demand can be performed in two different ways, including the open flux and closed reflux method. In practice, closed reflux methods are more economically beneficial, because it use less hazardous metallic salt reagents during the procedure (23). Therefore, the COD was determined using the Hach DR/870 (24) portable datalogging closed reflux colorimeter. Additionally, the working principle of this method is related to oxygen depletion in the water sample using the potassium dichromate solution ($K_2Cr_2O_7$). However, this method requires homogenization of the samples with reagents to obtain accurate results. In order that, the prepared water samples must be digested and heated for 2-hour duration at 150°C degree in Digital Reactor Block DRB 200 (25). Thereafter, after the cooling of the LCK 114 test cuvettes in the block heater, the COD is measured with Hach DR/870 colorimeter. As a matter of fact, the COD laboratory procedure can be done around 2-to-3-hour duration in contrast with the BOD determination of 5 or more days.

Figure 11 Hach DR/870 (Author)

3.4 Determination Of Dissolved Oxygen

The dissolved oxygen can be determined by various methods, including Winkler titration method, colorimetric method, and electrochemical method. Besides, the most modern, widely used method is the diaphragm electrode method or optical method, which is done much faster compared to the other methods of measurement. Thus, validation of the DO was done by the YSI-ProODO optical meter (26). As a result, this instrument automatically provides not only the DO measurements, but also other variables such as the temperature and pressure of the water sample.

Figure 13 YSI ProODO (Author)

Figure 12 Digital Reactor Block DRB 200 (Author)

3.5 Determination Of Volumetric Flow Rate of Selbe River

To monitor the river, discharge, the March-McBirney Flo-Mate 2000 flow rate measuring device is used (27). Genuinely, the operation of this device, results in instantaneous velocity of the river and stream using open channel modern velocity sensor. Therefore, the depth and width of the river or stream must be measured using the depth gauge rod and surveyors' rope, where flow rate of the stream can be calculated with the continuity equation Eq. (14). In fact, flow rates in rivers are crucial for studying natural restoration and biodiversity in the environment.

$$Q = \bar{v} \times A \qquad \text{Eq. (14)}$$

Q = discharge (m^3/s)

$\bar{v}$ = average velocity (m/s)

A = cross sectional area (m^2)

Figure 14 March-McBirney Flo-Mate 2000 (Author)

4 Results and Discussion

4.1 Selbe River Deoxygenation Rate Constant k_1: Thomas Slope Method and First Order Equation Method

Table 1 Deoxygenation rate of Selbe River

Sample Point	Deoxygenation rate constant (BOD oxidation)				
	First order function		Thomas Slope		
	k_1 [log 10]	k_1 [ln]	k_1 [log 10]	k_1 [ln]	R^2
	Unit: (d^{-1})	(d^{-1})	(d^{-1})	(d^{-1})	
Sharga Morit					
Jigjid					
Dambadarjaa	0.1206	0.2777	0.2471	0.5683	0.74
100 ail	0.1276	0.2937	0.3653	0.8402	0.97
Chingis hotel	0.0744	0.1714	0.6245	0.8402	0.16
Ikh Nayad Plaza	0.1056	0.2431	0.2663	0.6125	0.15
Altai town					
Selbe River Mean k	**0.1070**	**0.2465**	0.3758	0.7153	
Standard deviation P	0.0204	0.0471	0.1504	0.1259	
Standard deviation S	0.0236	0.0543	0.1737	0.1453	

The deoxygenation rate of Selbe river is determined using two different models, including the first order function method Eq. (2) and Thomas slope Method Eq. (5). The conversion between the natural logarithmic value (ln) and the common logarithmic value (log10) is shown in Eq. (3), and the reverse equation is shown in Eq. (7).

From the Table 1, it can be seen that the deoxygenation rate is evaluated at four sampling points: “Dambadarjaa”, “100 ail”, “Chingis Hotel” and “Ikh Nayad Plaza” out of seven sampling points, because at the other sampling points the BOD measurement data of “Altai Town”, “Sharga Morit”, “Jigjid” sampling points were not able to use enough data for model estimation. The detailed BOD data is available in Annex 2 of this report.

The sample points are ordered from an upstream point to a downstream point, so that “Sharga Morit” is the upstream point and “Altai town” is the downstream point.

The first order function method is more suitable than Thomas slope method. Because, the mean value of the Selbe river showed the most accurate value based on the statistical analysis.

The first order method had the population standard deviation of 0.0204 in natural logarithmic base and 0.0471 in common logarithmic base, while Thomas method had values of 0.1504 and 0.1259. The sample standard deviation in first order function method resulted 0.0236 in natural logarithmic base and 0.0543 in common logarithmic base, where Thomas method had values of 0.1737 in natural logarithmic base and 0.1453 in common logarithmic base.

Additionally, to validate the evaluated value of Thomas slope method deoxygenation rate k_1, the coefficient of the determination must be closer to 1, because the graph of [t/BOD(t)]^(1/3) with respect to the function time should be linear. However, applying Thomas slope method to Selbe river measured BOD data resulted in very low coefficient of determination at Chingis Hotel and Ikh Nayad Plaza sampling points with values of 0.16 and 0.15.

Therefore, the Selbe river deoxygenation rate value k_1 is 0.1070 in the common logarithmic base and 0.2465 in the natural logarithmic base.

4.2 Hydrological Characteristics of Selbe River

Table 2 Hydrological Characteristics of Selbe River

Sample Point	Depth	Width	Velocity	Elevation	Elevation difference	Distance	Slope	Flowrate
	Unit: (m)	(m)	(m/s)	(m)	(m)	(m)	%	(m^3/s)
Sharga Morit	0.20	4.5	0.19	1448				0.220
Jigjid	0.25	3.5	0.27	1418	30	3236	0.00927	0.355
Dambadarjaa	0.33	4.0	0.08	1349	69	8219	0.00840	0.159
100 ail	0.19	3.5	0.30	1311	38	4973	0.00764	0.364
Chingis hotel	0.15	4.5	0.31	1304	7	974	0.00719	0.350
Ikh Nayad Plaza	0.30	4.2	0.19	1291	13	1918	0.00678	0.412
Altai town	0.17	2.5	0.19	1281	10	3758	0.00266	0.146
Mean:	0.2	3.8	0.22	1343	28	3846	0.00699	0.286

The hydrological data were collected on April 15th and May 5th, 2022. Because, from November, 2021 to April, 2022 the Selbe river was fully frozen. Therefore, the hydrological data, including depth, width, and velocity were collected only in April and May 2022.

The sample points in Table 2 are ordered from an upstream point to a downstream point, so that “Sharga Morit” is the upstream point and “Altai town” is the downstream point.

The data of the sampling points elevation and distance between points were analyzed using satellite imaging systems Google Earth Pro and ArcGIS at each point in the Selbe river. Applying these data, the slope of the river area can be determined by dividing the elevation difference to the distance between the sampling points.

For the flowrate estimation of the Selbe river, Eq. (14) was used on each sampling point using the depth, width and velocity measurements. Detailed calculations are available in Annex 3 of this report.

Table 3 Flowrate Data 2008-2019 from Meteorological Agency of Mongolia

Sample Point	2008 (m^3/s)	2009 (m^3/s)	2010 (m^3/s)	2011 (m^3/s)	2012 (m^3/s)	2013 (m^3/s)	2014 (m^3/s)	2015 (m^3/s)	2016 (m^3/s)	2017 (m^3/s)	2018 (m^3/s)	2019 (m^3/s)
Sanzai	0.11	0.12	0.14	0.16	0.16	0.16	0.24	0.06	0.17	0.08	0.20	0.18
Dambadarjaa	0.41	0.09	0.17	0.33	0.60	0.62	0.67	0.20	0.33	0.23	0.58	0.93
Mean:	0.26	0.11	0.16	0.25	0.38	0.39	0.46	0.13	0.25	0.16	0.39	0.56

Using flowrate data at Selbe-Sanzai and Selbe-Dambadarjaa water stations from National Agency for Meteorology, Hydrology and Environmental Monitoring the annual average Selbe river discharge is generated in Table 3. The flowrate from 2008 to 2019 varied from 0.11 m^3/s minimum mean in 2011 and 0.56 m^3/s maximum mean discharge in 2019.

Therefore, for 2022, the measured and estimated value of Selbe river mean discharge of 0.286 m^3/s in Table 2, which fall within the range of twelve-year annual range from 2008 to 2019.

4.3 BOD$_5$, UBOD, DO, COD and Temperature of Selbe River

Table 4 BOD$_5$, UBOD, DO and COD comparison of Selbe river

Sample Point	BOD$_5$	UBOD	DO	COD	Temperature
	Unit:(mg/L)	(mg/L)	(mg/L)	(mg/L)	˚C
Sharga Morit					
Jigjid Dambadarjaa	8.00	19.00	9.61	907	10.7
100 ail	6.00	9.00	9.15	985	9.1
Chingis hotel	38.00	71.00	9.14	803	7.9
Ikh Nayad Plaza	73.50	102.00	10.86	415	6.0
Altai town			101.80	842	8.9
Mean:	31.38	50.25	9.79	790.40	8.52

The biochemical oxygen demand of five-day value (BOD$_5$) an ultimate biochemical oxygen demand (UBOD) are extracted from the detailed BOD data in Annex 2 of this report. And to check the accuracy of biochemical oxygen demand measurement, chemical oxygen demand (COD) is measured using closed-reflux colorimetric method. Because COD test shows the dissolved oxygen consumption by both inorganic compounds and organic matters, and can be determined in two-to-three-hour duration, while BOD test takes several days to show the dissolved oxygen consumption of bacteria, algae, fungus, protozoa and archaea in the water sample.

As a result, the mean Selbe river ultimate BOD is 50.25 mg/L, while BOD$_5$ is 31.38 mg/L, COD is 790.40 mg/L, which indicates that Selbe river is mostly polluted by inorganic chemical compounds. And the mean dissolved oxygen in Selbe river is 9.79 mg/L at average temperature of 8.52 ˚C degree.

In the Annex 4 of this report, Selbe river water monitoring stations measurement, detailed data of the BOD$_5$ and DO at Selbe-Ulaanbaatar, Selbe-Dambadarjaa, Selbe-Dund river and Selbe-Sanzai stations from 2013-2019 is available. The average BOD$_5$ ranged between 1.1 mg/L to 33.53 mg/L, where maximum BOD$_5$ was 98.8 mg/L at Selbe river. And the average DO ranged between 6.44 mg/L to 11.95 mg/L, where maximum DO was 12.20 mg/L in the data through 2013 to 2019.

4.4 Selbe River Reaeration Rate Constant k_2

Table 6 Reaeration Rate Constant Calcultion with Depth and Velocity involved Model

Sample Point	O'Connor and Dobbins	Churchill	Owens	Langbein and Durum	Bennet and Rathburn	Bansal	Baecheler and Lazo	Jha	Isaacs and Gaudy	Eloubaldy	Isaacs et. Al	Neguleseu and Rojanski	Padden and Gloyna
Sharga Morit	19.15	14.04	34.34	8.3	30.85	14.59	5.38	3.78	10.1	8.6	7.65	10.43	7.71
Jigjid	16.21	13.52	28.45	8.62	25.94	13.06	5.36	4.22	10.11	8.61	7.65	11.48	7.71
Dambadarjaa	5.72	2.43	7.36	1.7	7.59	4.18	0.58	2.11	1.91	1.62	1.44	3.13	2.39
100 ail	26.07	24.29	51.48	14.11	44.54	20.7	11	4.82	17.32	14.76	13.12	16.15	11.27
Chingis hotel	39.38	38.7	85.7	20.5	70.93	30.48	19.28	5.19	26.36	22.46	19.96	20.57	15.14
Ikh Nayad Plaza	10.37	7.06	16.11	4.79	15.46	8.22	2.35	3.39	5.44	4.64	4.12	7.33	4.99
Altai town	24.15	17.98	45.64	10.05	40	18.06	7.22	3.88	12.58	10.72	9.53	11.74	9
Mean	20.15	16.86	38.44	9.73	33.62	15.61	7.31	3.91	11.97	10.2	9.07	11.55	8.32
Standard deviation P	10.292	11.062	24.01	5.699	19.37	7.98	5.786	0.934	7.434	6.334	5.63	5.246	3.829
Standard deviation S	11.116	11.948	25.94	6.156	20.922	8.619	6.249	1.009	8.03	6.842	6.082	5.666	4.135

Table 5 Reaeration Rate Constant Calcultion with Depth, Velocity and Slope involved Model

Sample Point	Krenekl and Orlob	Gadwallader and McDonnel	Tsiovoglou and Neal	Grant	Thyseen	Smoot	Mogg and Jirka	Melching and Flores	Tsivoglou and Wallace	k_2 (20°C), Tsivoglou and Wallace
Sharga Morit	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jigjid	38.16	36.93	29.39	55.93	76.48	39.59	8.40	21.91	76.37	125.15
Dambadarjaa	18.41	14.24	26.61	14.48	24.76	15.62	5.36	13.01	19.78	24.88
100 ail	44.53	47.01	24.22	52.35	78.72	45.83	6.24	23.64	71.49	93.57
Chingis hotel	52.23	60.17	22.78	49.95	84.18	54.09	4.90	25.63	68.21	91.96
Ikh Nayad Plaza	25.93	22.14	21.49	28.95	41.09	23.74	6.40	16.72	39.54	55.86
Altai town	25.71	24.31	8.44	11.21	21.64	19.86	2.00	15.18	15.30	20.13
Mean	34.16	34.13	22.15	35.48	54.48	33.12	5.55	19.35	48.45	68.59
Standard deviation P	11.814	15.747	6.653	18.187	26.123	14.219	1.933	4.635	24.837	38.275
Standard deviation S	12.941	17.250	7.287	19.923	28.617	15.576	2.117	5.077	27.208	41.928

Reaeration rate is calculated using the collected hydrological data at Selbe river sampling points, which is available in Table 2. Using the several methods from group A, thirteen model equations Eq. (8) and group B, nine models Eq. (9) the reaeration rate is determined in Table 5 and Table 6. The main variables in Table 5 were depth and velocity at each sampling point in Selbe river, and the main variables in Table 6 were depth, velocity and slope at each sampling point from Sharga Morit to Altai town sample location.

The sample points in Table 5 and Table 6 are ordered from an upstream point to a downstream point, so that “Sharga Morit” is the upstream point and “Altai town” is the downstream point.

As a result, the mean reaeration rate k_2 in Selbe river ranged from 3.91 using Jha model to 68.59 using Tsivoglou and Wallace model. Analyzing the standard deviation in Selbe river k_2 on each model, the lowest value resulted in Jha model with population standard deviation of 0.934 and sample standard deviation of 1.009.

Therefore, the mean reaeration rate k_2 on Selbe river is 3.91 based on statistical analysis.

4.4 Determination of Minimum Dissolved Oxygen in Selbe River and Distance of Self-Purification, Streeter-Phelps Model

Table 7 Self-Purification Distance at Ikh Nayad Plaza

Sample Point	**k_1 [log10]**	**k_2**	**DO [mg/L]**	**D_i [mg/L]**	**L_0 [mg/L]**	**t_c (d)**	**D_c (mg/L)**	**Velocity (m/s)**	**Distance (km)**
Ikh Nayad Plaza	0.107	3.910	10.86	2.14	102.00	0.25	2.43	0.19	4.14

The self-purification of the Selbe river is calculated using Streeter Phelps model Eq. (12) on “Dambadarjaa”, “100 ail”, “Chingis Hotel” and “Ikh Nayad Plaza” sampling points. However, due to seasonal variations at the Selbe river during the study period, mean velocity increased gradually.

At the sampling points “Dambadarjaa”, “100 ail” and “Chingis Hotel” the oxygen deficit and the purification distance cannot be modeled with Streeter Phelps equation. However, assumptions can be made that at these sampling locations Selbe river water is self-purified directly.

From Table 7, the self-purification at “Ikh Nayad Plaza” is modeled by using Streeter-Phelps’ equation Eq. (11), Eq. (12) and Eq. (13) to determine the critical time, critical oxygen deficiency, and self-purification distance.

The saturation of dissolved oxygen is examined as 13 mg/L, and the initial oxygen deficit using Eq. (10) resulted 2.14 mg/L in “Ikh Nayad Plaza” sampling point.

As a result, at “Ikh Nayad Plaza” sampling point, the critical oxygen distance is 4.14 km, the critical oxygen deficit is 2.43 mg/L and the critical time is 0.25 days.

5 Conclusion

The main objective of this thesis study is to describe the self-purification system of Selbe river by creating Streeter Phelps oxygen sag curve model. To achieve the main objective, the deoxygenation rate constant k_1 and reaeration rate constant k_2 of Selbe river are calculated.

First, to determine the deoxygenation rate k_1, the measurement of biochemical oxygen demand is done using closed respirometric device Lovibond BD600 in the GMIT environmental laboratory. Using the measured BOD, the deoxygenation rate k_1 is evaluated with two different models, including Thomas slope and first-order function model. However, due to the deficiency of organic matter in water samples at “Sharga Morit”, “Jigjid” sampling locations, the BOD data are not satisfying for the deoxygenation rate k_1 model estimation.

Secondly, to determine the reaeration rate k_2, the hydrological measurements of depth, width and with using March-McBirney Flo-Mate 2000 the velocity are measured at seven sampling points at Selbe river. And the slope of the Selbe river is determined using satellite imaging systems Google Earth Pro and ArcGIS. Using the hydrological measured data, the mean reaeration rate constant of Selbe river is calculated using the total of 22 reaeration rate k_2 models. Additionally, during the thesis study period from November to May, the hydrological measurement of Selbe river was conducted only in April and May 2022, because during the winter months the Selbe river was fully frozen.

In conclusion, the Selbe river self-purification process is analyzed at four sampling points using the hydrological data, deoxygenation k_1, and reaeration rate constant k_2. Due to the seasonal variations at the Selbe river during the study period, the mean velocity is high for short width, which raises the assumption that at sampling at sampling locations “Dambadarjaa”, “100 ail”, “Chingis Hotel” the Selbe river water is self-purified directly. But, at the “Ikh Nayad Plaza” sampling point, the critical oxygen deficit, distance and critical time are calculated.

6 Recommendation

Recommendations for researchers to further study in future:

- Determination of bacteria in BOD water sample
- Seasonal sample collection
- Determination of deoxygenation and reaeration rate in Tuul river
- Repurchase the reagents for Lovibond BD600, which are expired
- Determine the reaeration rate in Selbe river, when velocity is stable and lower

7 Reference

1. Davaa G. Results of the Surface Water Resources Survey of Mongolia. 2016;
2. Shiklomanov IA. Appraisal and Assessment of World Water Resources. Water International. 2000 Mar;25(1):11–32.
3. Dolgorsuren G. JBW van der L. Integrated Water Management National Assessment Report of Mongolia. 2012.
4. Davaa G. GP, BD. Climate change impact on water resources in Mongolia. . Scientific proceedings of Institute of Meteorology and Hydrology. 2008;15–23.
5. Asian Development Bank. Overview of Mongolia’s Water Resources System and Management. A Country Water Security Assessment. 2020 Jul.
6. Ш. Баатарулуун МДБАБА. Далайд дусал нэмэр. 2014.
7. AQUASTAT database. Food and Agriculture Organization, AQUASTAT data. [Internet]. 2014 [cited 2022 May 7]. Available from: https://www.fao.org/aquastat/statistics/query/index.html?lang=en.
8. Oyunbaatar D. Runoff and rainfall distribution in the Selbe river basin. In: In Proceedings of the International Workshop on GAME-ANN/Radiation. Phunket; 2001. p. 102–6.
9. Klein Tank AMG, Peterson TC, Quadir DA, Dorji S, Zou X, Tang H, et al. Changes in daily temperature and precipitation extremes in central and south Asia. Journal of Geophysical Research. 2006;111(D16):D16105.
10. Meilawati Yustiani Y, Wahyuni S, Ringga Alfian M. INVESTIGATION ON THE DEOXYGENATION RATE OF WATER OF CIMANUK RIVER, INDRAMAYU, INDONESIA. Rasayan Journal of Chemistry. 2018;11(2):475–81.

11. Manab Maiti SMCS. A Comparative Study of BOD Rate Constant of Two Waste Water Samples. International Journal of Engineering Technology Science and Research. 2018 Jan;5(1).

12. Metcalf & Eddy Inc and GT and HS and RT and FB. Wastewater engineering: Treatment and resource recovery. 5th ed. McGraw-Hill Education; 2014.

13. Ministry of Environment and Green Development of Mongolia. State of The Environment Report MONGOLIA. 2013.

14. Oke IAAAA. A Statistical Evaluation of Methods of Determining BOD Rate. Journal of Applied Sciences Research. 2005 Jul;

15. Hendriarianti E and KN. Deoxygenation Rate of Carbon in Upstream Brantas River in the City of Malang. Journal of Applied Environmental and Biological Sciences. 2015;

16. Yustiani YM. THE STUDY OF DEOXYGENATION RATE OF RANGKUI RIVER WATER DURING DRY SEASON. International Journal of GEOMATE. 2018 Jul 1;15(47).

17. Ministry Of Environment And Green Development. TUUL RIVER BASIN INTEGRATED WATER MANAGEMENT PLAN. 2012.

18. H. A. Thomas. The Slope Method for Evaluating the Constants of the First-Stage Biochemical Oxygen Demand Curve. Sewage Works Journal. 1937;9:425–30.

19. Snoeyink VL JD. Water chemistry. New York: Wiley; 1980.

20. Jerry Nathanson RSMSPE. Basic Environmental Technology: Water Supply, Waste Management and Pollution Control. 6th ed. Pearson; 2015.

21. Haider H, Ali W, Haydar S. Evaluation of various relationships of reaeration rate coefficient for modeling dissolved oxygen in a river with extreme flow variations in Pakistan. Hydrological Processes. 2013 Dec 30;27(26):3949–63.

22. GmbH T. BOD determination: BD 600 series: Waste water treatment [Internet]. 2022 [cited 2022 May 7]. Available from: https://www.lovibond.com/en/PW/Water-Testing/Products/Lab-Portable-Instruments/BOD-determination/BD-600-GLP

23. LaPara TM, Alleman JE, Pope PG. Miniaturized closed reflux, colorimetric method for the determination of chemical oxygen demand. Waste Management. 2000 Jul;20(4):295–8.

24. Cole-Parmer. DR/870 Portable Datalogging Colorimeter [Internet]. 2022 [cited 2022 May 8]. Available from: https://archive-resources.coleparmer.com/Manual_pdfs/99573-00.pdf

25. USA Hach. DRB200: Digital Reactor Block; 30 X 16 mm Vial Wells, 230 vacs [Internet]. 2022 [cited 2022 May 7]. Available from: https://www.hach.com/drb200-digital-reactor-block-30-x-16-mm-vial-wells-230-vac/product-details?id=7640453275

26. ProODO optical dissolved oxygen instrument. YSI ProODO - Optical Dissolved Oxygen Meter. [Internet]. 2022 [cited 2022 May 7]. Available from: https://www.ysi.com/proodo

27. Marsh-McBirney Flo-mate^{TM} Portable Velocity Flow Meter. Marsh McBirney model 2000. 2022 [cited 2022 May 7]; Available from: http://www.tttenviro.com/wp-content/uploads/Datasheet-Flo-Mate-2000.pdf

28. Kottek M, Grieser J, Beck C, Rudolf B, Rubel F. World Map of the Köppen-Geiger climate classification updated. Meteorologische Zeitschrift. 2006 Jul 10;15(3):259–63.

Annex 1: Pictures from The Sample Collection on Selbe River

Figure 16 Ikh Nayad Plaza on November 16th, 2021

Figure 15 Chingis Hotel on November 16th, 2021

Figure 18 100 ail on March 18th, 2022

Figure 17 Chingis Hotel on March 18th, 2022

Figure 19 Ikh Nayad Plaza on March 18th, 2022

Figure 22 100 ail on April 15th, 2022

Figure 24 Jigjid on April 15th, 2022

Figure 21 Altai town on April 15th, 2022

Figure 23 Dambadarjaa on April 15th, 2022

Figure 20 Sharga Morit on April 15th, 2022

Annex 2: Biochemical Oxygen Demand Detailed Data

Table 8 Lovibond BD600 results

Sample Point	Date	Time	BOD (mg/L)
Jigjid	4/15/2022	20:46:20	0
	4/15/2022	21:46:20	0
	4/15/2022	22:46:20	0
	4/15/2022	23:46:20	15
	4/16/2022	0:46:20	23
	4/16/2022	1:46:20	26
	4/16/2022	2:46:20	28
	4/16/2022	3:46:20	30
	4/16/2022	4:46:20	29
	4/16/2022	5:46:20	29
	4/16/2022	6:46:20	28
	4/16/2022	7:46:20	27
	4/16/2022	8:46:20	26
	4/16/2022	9:46:20	26
	4/16/2022	10:46:20	25
	4/16/2022	11:46:20	25
	4/16/2022	12:46:20	24
	4/16/2022	13:46:20	24
	4/16/2022	14:46:20	23
	4/16/2022	15:46:20	23
	4/16/2022	16:46:20	23
	4/16/2022	17:46:20	22
	4/16/2022	18:46:20	22
	4/16/2022	19:46:20	22
	4/16/2022	20:46:20	22
	4/16/2022	22:46:20	21
	4/17/2022	0:46:20	21
	4/17/2022	2:46:20	21
	4/17/2022	4:46:20	20
	4/17/2022	6:46:20	20
	4/17/2022	8:46:20	25
	4/17/2022	10:46:20	35
	4/17/2022	12:46:20	28
	4/17/2022	14:46:20	33
	4/17/2022	16:46:20	35
	4/17/2022	18:46:20	31
	4/17/2022	20:46:20	40
	4/18/2022	20:46:20	0

Sample Point	Date	Time	BOD (mg/L)
Dambadarjaa	4/15/2022	20:46:20	0
	4/15/2022	21:46:20	7
	4/15/2022	22:46:20	22
	4/15/2022	23:46:20	26
	4/16/2022	0:46:20	29
	4/16/2022	1:46:20	30
	4/16/2022	2:46:20	28
	4/15/2022	3:46:20	25
	4/16/2022	4:46:20	22
	4/16/2022	5:46:20	18
	4/16/2022	6:46:20	14
	4/16/2022	7:46:20	10
	4/16/2022	8:46:20	7
	4/16/2022	9:46:20	7
	4/16/2022	10:46:20	7
	4/16/2022	11:46:20	8
	4/16/2022	12:46:20	8
	4/16/2022	13:46:20	8
	4/16/2022	14:46:20	8
	4/16/2022	15:46:20	8
	4/16/2022	16:46:20	8
	4/16/2022	17:46:20	8
	4/16/2022	18:46:20	8
	4/16/2022	19:46:20	8
	4/16/2022	20:46:20	8
	4/16/2022	22:46:20	9
	4/17/2022	0:46:20	9
	4/17/2022	2:46:20	10
	4/17/2022	4:46:20	10
	4/17/2022	6:46:20	11
	4/17/2022	8:46:20	12
	4/17/2022	10:46:20	12
	4/17/2022	12:46:20	12
	4/17/2022	14:46:20	12
	4/17/2022	16:46:20	12
	4/17/2022	18:46:20	12
	4/17/2022	20:46:20	12
	4/18/2022	20:46:20	13
	4/19/2022	20:46:20	14
	4/20/2022	20:46:20	8
	4/21/2022	20:46:20	9
	4/22/2022	20:46:20	11
	4/23/2022	20:46:20	15
	4/24/2022	20:46:20	13
	4/25/2022	20:46:20	11
	4/26/2022	20:46:20	18
	4/27/2022	20:46:20	16
	4/28/2022	20:46:20	18

	4/29/2022	20:46:20	7
	4/30/2022	20:46:20	19
	5/1/2022	20:46:20	16
	5/2/2022	20:46:20	14
	5/3/2022	20:46:20	12
	5/4/2022	20:46:20	16

Sample Point	Date	Time	BOD (mg/L)
100 ail	4/15/2022	20:46:20	0
	4/15/2022	21:46:20	2
	4/15/2022	22:46:20	4
	4/15/2022	23:46:20	3
	4/16/2022	0:46:20	1
	4/16/2022	18:46:20	0
	4/16/2022	19:46:20	0
	4/16/2022	20:46:20	1
	4/16/2022	22:46:20	1
	4/17/2022	0:46:20	2
	4/17/2022	2:46:20	2
	4/17/2022	4:46:20	3
	4/16/2022	18:46:20	3
	4/16/2022	19:46:20	3
	4/16/2022	20:46:20	3
	4/16/2022	22:46:20	3
	4/17/2022	0:46:20	3
	4/17/2022	2:46:20	4
	4/17/2022	4:46:20	4
	4/16/2022	18:46:20	4
	4/16/2022	19:46:20	4
	4/16/2022	20:46:20	4
	4/16/2022	18:46:20	4
	4/16/2022	19:46:20	4
	4/16/2022	20:46:20	4
	4/16/2022	22:46:20	4
	4/17/2022	0:46:20	4
	4/17/2022	2:46:20	4
	4/17/2022	4:46:20	4
	4/17/2022	6:46:20	5
	4/17/2022	8:46:20	5
	4/17/2022	10:46:20	5
	4/17/2022	12:46:20	5
	4/17/2022	14:46:20	5
	4/17/2022	16:46:20	5
	4/17/2022	18:46:20	5
	4/17/2022	20:46:20	5
	4/18/2022	20:46:20	6
	4/19/2022	20:46:20	5
	4/20/2022	20:46:20	6
	4/21/2022	20:46:20	8
	4/22/2022	20:46:20	8
	4/23/2022	20:46:20	8

	4/24/2022	20:46:20	8
	4/25/2022	20:46:20	8
	4/26/2022	20:46:20	9
	4/27/2022	20:46:20	9
	4/28/2022	20:46:20	9
	4/29/2022	20:46:20	9
	4/30/2022	20:46:20	9
	5/1/2022	20:46:20	9
	5/2/2022	20:46:20	8
	5/3/2022	20:46:20	9
	5/4/2022	20:46:20	8
	5/5/2022	20:46:20	9

Sample Point	Date	Time	Bottle 1 BOD (mg/L)	Bottle 2 BOD (mg/L)
Chingis Hotel	11/30/2021	13:52:41	0	0
	11/30/2021	14:52:32	1	2
	11/30/2021	15:52:32	0	3
	11/30/2021	16:52:32	2	4
	11/30/2021	17:52:32	3	4
	11/30/2021	18:52:32	6	5
	11/30/2021	19:52:32	8	7
	11/30/2021	20:52:32	10	8
	11/30/2021	21:52:32	11	9
	11/30/2021	22:52:32	14	11
	11/30/2021	23:52:32	15	12
	12/1/2021	0:52:32	17	14
	12/1/2021	1:52:32	18	15
	12/1/2021	2:52:32	19	16
	12/1/2021	3:52:32	21	17
	12/1/2021	4:52:32	22	18
	12/1/2021	5:52:32	22	19
	12/1/2021	6:52:32	23	19
	12/1/2021	7:52:32	24	20
	12/1/2021	8:52:32	25	21
	12/1/2021	9:52:32	25	21
	12/1/2021	10:52:32	26	22
	12/1/2021	11:52:32	26	22
	12/1/2021	12:52:32	26	22
	12/1/2021	13:52:32	25	22
	12/1/2021	15:52:32	19	19
	12/1/2021	17:52:32	20	18
	12/1/2021	19:52:32	21	19
	12/1/2021	21:52:32	23	20
	12/1/2021	23:52:32	24	21
	12/2/2021	1:52:32	24	22
	12/2/2021	3:52:32	24	22
	12/2/2021	5:52:32	22	22
	12/2/2021	7:52:32	20	21
	12/2/2021	9:52:32	18	20

	12/2/2021	11:52:32	17	19
	12/2/2021	13:52:32	13	18
	12/3/2021	13:52:32	14	16
	12/4/2021	13:52:32	22	7
	12/5/2021	13:52:32	45	71

	Date	**Time**	**BOD (mg/L)**
	3/18/2022	16:55:30	0
	3/18/2022	17:55:30	0
	3/18/2022	18:55:30	0
	3/18/2022	19:55:30	1
	3/18/2022	20:55:30	0
	3/18/2022	21:55:30	0
	3/18/2022	22:55:30	0
	3/18/2022	23:55:30	1
	3/18/2022	0:55:30	3
	3/18/2022	1:55:30	3
	3/18/2022	2:55:30	5
	3/19/2022	3:55:30	6
	3/19/2022	4:55:30	7
	3/19/2022	5:55:30	7
	3/19/2022	6:55:30	7
	3/19/2022	7:55:30	7
	3/19/2022	8:55:30	6
	3/19/2022	9:55:30	6
	3/19/2022	10:55:30	6
	3/19/2022	11:55:30	6
	3/19/2022	12:55:30	6
	3/19/2022	13:55:30	6
	3/19/2022	14:55:30	7
	3/19/2022	15:55:30	7
	3/19/2022	16:55:30	7
	3/19/2022	18:55:30	6
	3/19/2022	20:55:30	4
	3/19/2022	22:55:30	2
	3/19/2022	0:55:30	1
	3/20/2022	4:55:30	0
	3/20/2022	6:55:30	0
	3/20/2022	8:55:30	0
	3/20/2022	10:55:30	0
	3/20/2022	12:55:30	0
	3/20/2022	14:55:30	0
	3/20/2022	16:55:30	4
	3/21/2022	16:55:30	11
	3/22/2022	16:55:30	21
	3/23/2022	16:55:30	18
	3/24/2022	16:55:30	9
	3/25/2022	16:55:30	4
	3/26/2022	16:55:30	3

Sample Point	Date	Time	Bottle 1 BOD (mg/L)	Bottle 2 BOD (mg/L)
Ikh Nayad Plaza	11/30/2021	13:52:41	0	0
	11/30/2021	14:52:32	0	1
	11/30/2021	15:52:32	0	2
	11/30/2021	16:52:32	0	2
	11/30/2021	17:52:32	1	3
	11/30/2021	18:52:32	12	5
	11/30/2021	19:52:32	18	7
	11/30/2021	20:52:32	22	9
	11/30/2021	21:52:32	17	10
	11/30/2021	22:52:32	29	12
	11/30/2021	23:52:32	24	14
	12/1/2021	0:52:32	29	16
	12/1/2021	1:52:32	32	18
	12/1/2021	2:52:32	32	19
	12/1/2021	3:52:32	54	20
	12/1/2021	4:52:32	38	21
	12/1/2021	5:52:32	41	21
	12/1/2021	6:52:32	41	23
	12/1/2021	7:52:32	43	23
	12/1/2021	8:52:32	46	24
	12/1/2021	9:52:32	47	25
	12/1/2021	10:52:32	48	26
	12/1/2021	11:52:32	50	26
	12/1/2021	12:52:32	49	26
	12/1/2021	13:52:32	46	24
	12/1/2021	15:52:32	33	20
	12/1/2021	17:52:32	36	20
	12/1/2021	19:52:32	39	21
	12/1/2021	21:52:32	42	22
	12/1/2021	23:52:32	44	23
	12/2/2021	1:52:32	42	23
	12/2/2021	3:52:32	45	24
	12/2/2021	5:52:32	56	23
	12/2/2021	7:52:32	36	22
	12/2/2021	9:52:32	19	21
	12/2/2021	11:52:32	26	19
	12/2/2021	13:52:32	23	18
	12/3/2021	13:52:32	35	19
	12/4/2021	13:52:32	46	34
	12/5/2021	13:52:32	45	102

Annex 3: Detailed Flowrate Calculation of Selbe River

Table 9 Selbe River Discharge Detailed Calculation

Sample Point	**(1) * Width**	**(2) Width of subsection**	**(3) * Depth**	**(4) * Velocity (m/s)**	**(5) Vi x Di (4)x(3)**	**(6) Qi (5)x(2)**	**(7) Q ∑(6)**
	(m)	(m)	(m)	(m/s)	m^2/s	m^3/s	m^3/s
Sharga Morit	0	0	0.1	0.090	0.009	0.000	0.2196
	1	1	0.2	0.154	0.031	0.031	
	2	1	0.2	0.230	0.046	0.046	
	3	1	0.3	0.456	0.137	0.137	
	4.5	1.5	0.2	0.020	0.004	0.006	
Jigjid	0.5	0.5	0.10	0.050	0.005	0.003	0.3554
	1.5	1.0	0.30	0.483	0.145	0.145	
	2.5	1.0	0.40	0.510	0.204	0.204	
	3.5	1.0	0.20	0.020	0.004	0.004	
Dambadarjaa	0.0	0	0.20	0.010	0.002	0.000	0.1589
	1.0	1	0.55	0.125	0.069	0.069	
	2.0	1	0.50	0.113	0.057	0.057	
	3.0	1	0.30	0.102	0.031	0.031	
	4.0	1	0.10	0.030	0.003	0.003	
100 ail	0.0	0.0	0.10	0.040	0.004	0.000	0.3636
	1.0	1.0	0.20	0.365	0.073	0.073	
	2.0	1.0	0.30	0.492	0.148	0.148	
	3.0	1.0	0.25	0.562	0.141	0.141	
	3.5	0.5	0.10	0.050	0.005	0.003	
Chingis Hotel	0.0	0.0	0.05	0.017	0.001	0.000	0.3504
	1.0	1.0	0.03	0.407	0.012	0.012	
	2.0	1.0	0.07	0.380	0.027	0.027	
	3.0	1.0	0.34	0.509	0.173	0.173	
	4.0	1.0	0.31	0.437	0.135	0.135	
	4.5	0.5	0.07	0.087	0.006	0.003	
Ikh Nayad Plaza	0.0	0.0	0.20	0.085	0.017	0.000	0.4116
	1.0	1.0	0.35	0.244	0.085	0.085	
	2.0	1.0	0.40	0.380	0.152	0.152	
	3.0	1.0	0.45	0.340	0.153	0.153	
	4.0	1.0	0.30	0.070	0.021	0.021	
	4.2	0.2	0.10	0.010	0.001	0.000	
Altai town	0.0	0.0	0.10	0.03	0.0030	0.0000	0.1457
	1.0	1.0	0.20	0.29	0.0584	0.0584	
	2.0	1.0	0.23	0.36	0.0828	0.0828	
	2.5	0.5	0.15	0.06	0.0090	0.0045	

Mean discharge: 0.2864

Annex 4: Detailed BOD5 and DO data from NAMHEM

Table 10 Biochemical Oxygen Demand and Dissolved Oxygen data from 2013-2019 in Selbe river

Sample Point	Year	DO	BOD_5	Max DO	Max BOD_5
		Unit:(mg/L)	(mg/L)	(mg/L)	(mg/L)
Selbe - Ulaanbaatar	2013	0.00	0.00	0.00	0.00
	2014	6.44	33.53	8.36	98.80
	2015	0.00	2.50	0.00	4.00
	2016	9.52	1.93	10.80	2.60
	2017	10.34	12.20	12.20	3.00
	2018	7.17	10.90	12.17	28.00
	2019	8.19	2.11	9.30	4.50
Selbe - Dund river	2013	0.00	4.00	0.00	6.90
	2014	7.94	1.45	9.12	2.00
	2015	0.00	1.52	0.00	3.50
	2016	8.91	2.40	10.94	3.60
	2017	11.70	1.50	11.70	3.60
	2018	11.37	1.77	11.37	2.90
	2019	8.10	3.50	9.55	5.10
Selbe - Dambadarjaa	2013	0.00	0.50	0.00	0.50
	2014	7.20	8.15	9.58	20.00
	2015	0.00	1.10	0.00	1.10
	2016	8.40	3.80	8.40	3.80
	2017	8.67	3.20	8.96	5.10
	2018	8.26	3.57	11.06	7.60
Selbe - Sanzai	2013	0.00	2.50	0.00	3.20
	2014	7.56	22.02	4.20	12.23
	2015	0.00	2.00	0.00	1.33
	2016	11.95	5.00	11.95	5.00
	2017	7.67	1.10	9.63	1.20
	2018	10.38	5.17	11.85	12.00