



**The present work was submitted to the Faculty of Engineering**

# **DISSOLVED OXYGEN AND BOD ASSIMILATIVE CAPACITY OF THE SELBE RIVER**

**Bachelor Thesis**

by

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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

“DISSOLVED OXYGEN AND BOD ASSIMILATIVE OF THE SELBE  
RIVER”

I did not use any sources other than those stated. In case the work is additionally submitted on a data medium, I declare that the written and the electronic form are completely identical. The work was not submitted in the same or similar form to any examination authority.

\_\_\_\_\_  
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## List of Abbreviations

BOD- Biochemical Oxygen Demand

UBOD- Ultimate Biochemical Oxygen Demand

COD-Chemical Oxygen Demand

DO-Dissolved Oxygen

Bsk- Cold Semi-Arid Climate

MNS- Mongolian National Standard

UNFCCC – United Nation’s Framework Convention on Climate

UV-Ultra violet

$K_2Cr_2O_7$ - Potassium Dichromate

KOH- Potassium Hydroxide

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## Executive summary

Selbe River is a small river that flows through Ulaanbaatar city, which is one of the main tributaries to the Tuul River. Ulaanbaatar is an overpopulated city that is home to almost half of the Mongolian population. Due to overpopulation and unorganized urbanization, plenty of ambient pollution entered to Selbe river which declined the quality of Selbe river water.

The Self-Purification system of Selbe river is defined with Streeter-Phelps Model to describe the current condition of Selbe river's water quality and efficiency of the Self-Purification system. To estimate the model, deoxygenation rate, reaeration, and other parameters were measured both in Laboratory and in Field. With the test results, the critical time, critical distance, and critical oxygen deficit of the Selbe river were calculated.

Moreover, for further study, the indicator bacteria plus pathogenic bacteria Salmonella and Shigella were tested in Laboratory with two different methods, the petri-dish method, and the IDEXX tray method.

The deoxygenation rate of Selbe River was estimated with the First order method by using the Biochemical Oxygen Demand (BOD) value of five different sampling points. The mean deoxygenation rate was calculated as  $0.235 d^{-1}$ . As for the reaeration rate, it was calculated with five different models that are dedicated to small rivers by using the hydrologic data that are measured on the field. As a result, the mean reaeration rate of the Selbe River was estimated as  $4.77 d^{-1}$ .

Finally, the critical time is 0.696 d, the critical distance is 8.8 km and the critical oxygen deficit is 2.322 mg/L with a modified Streeter-Phelps model. As a result, the Self-Purification system of the Selbe River is not efficient enough for clearing the river water before it tributes to the Tuul River.

# 1. Introduction

Mongolia is a landlocked country in Central Asia with a land area of 1'564'116 square km that shares borders with both China and Russia to the north and south, respectively. The total surface water source in Mongolia is around 599 km<sup>3</sup>, about 0.00004% of the world's total water resource. 83.7% of it is accumulated in lakes, 10.5% in glaciers, and 5.8% in river and river systems. (1) Water source in Mongolia is limited and unevenly distributed throughout the whole country, most of the surface water sources are located in Northern Mongolia, as for the Gobi Desert zone majority of the water source is from groundwater. The Mongolian water resource is divided into three main continental basins which are the Northern Arctic Ocean basin, the Pacific Ocean basin, and the Central Asian Internal basin. Furtherly, these three basins are divided into 29 river basins which are both surface and subsurface water basins, shown in Figure 1. (2).

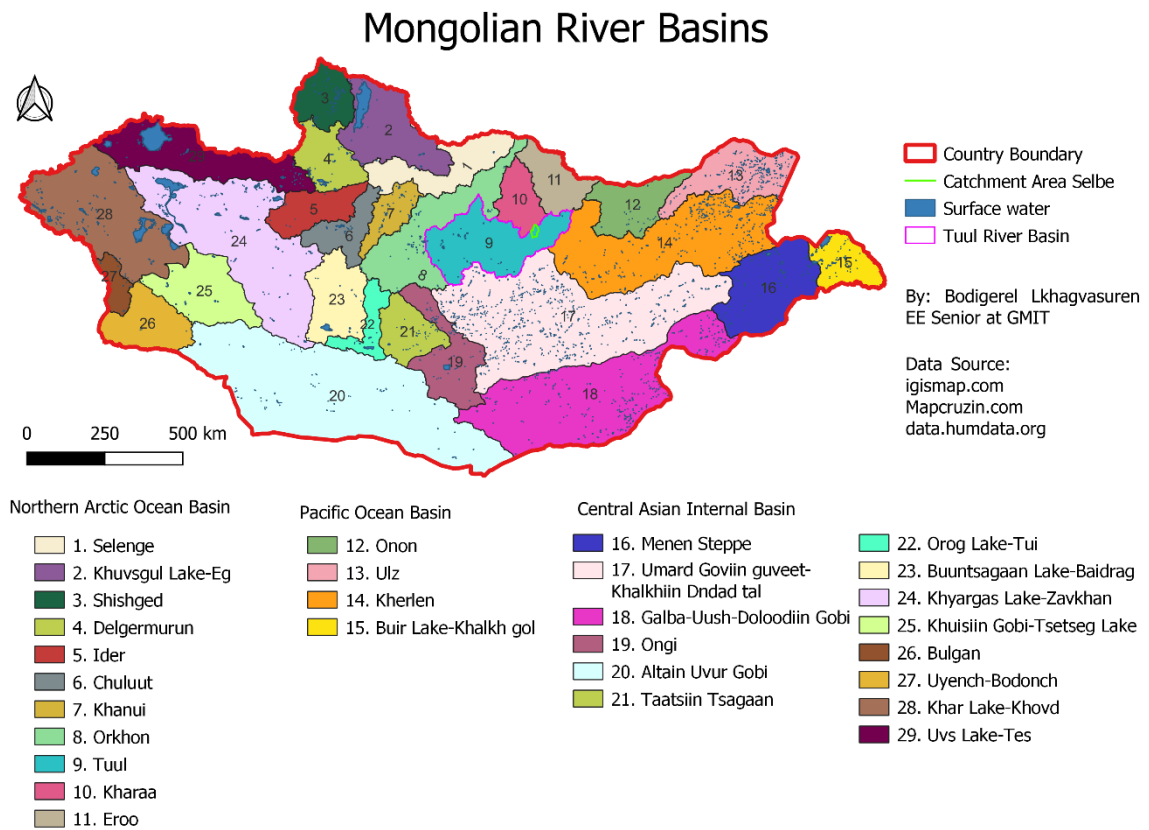


Figure 1 *Continental Basins of Mongolia (Author)*

As a country with a Semi-Arid climate, precipitation in Mongolia is relatively small and the evaporation of the surface water is rather high. Annual average precipitation is about 200-250mm, 350mm in the northern part of Mongolia and 80 mm in the southern part of Mongolia which makes the recovery rate of the groundwater in Mongolia smaller (2).

Mongolia is one of the least densely populated countries in the world, which states only two people in one square kilometer area. Even if the annual precipitation along the country territory is small, the available water source per capita is about 10000 cubic meters per year (2). However, according to the 2022 report of the Mongolian National Statistics Office, the total population of Mongolia is counted as 3'456'548 people. However, 1'691'766 people which is 48.9% of the total population lives in Ulaanbaatar city (3). As an overpopulated region, the surface and subsurface water along the Ulaanbaatar area is highly affected by the ambient pollution caused by human activities. For example, it is possible that the surface water and the soil can be influenced by the pit latrines of the Ger district area of Ulaanbaatar city. In 2022, the Institute of Geography and Geoecology, Mongolian Academy of Science reported that a total of 144'992 pit Latrines were counted (4). And from soil samples, E. coli, Salmonella, and Citrobacter bacteria are detected from the Ulaanbaatar soil sample (5).

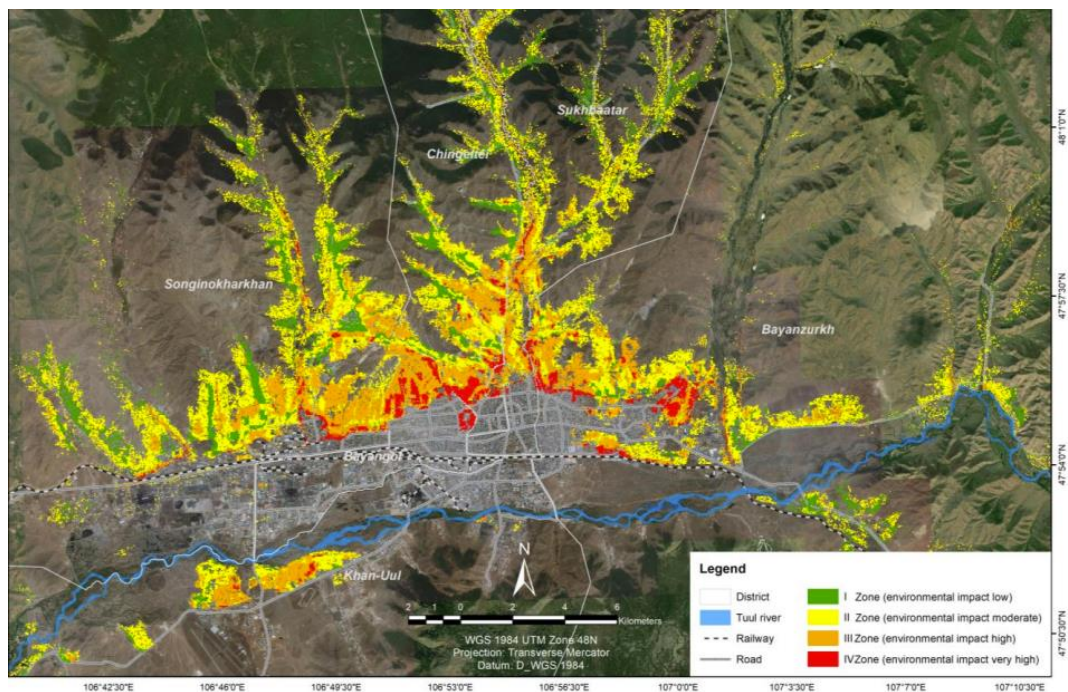


Figure 2 Pit Latrines and Environmental Impact zones in the Ger area in Ulaanbaatar, (Source: Institute of Geography and Geoecology)

Due to numerous different reasons like global warming and urbanization, the drinking water source is declining more and more (6). Therefore, it is important to monitor the condition of the surface water and protect the water source for future use.

## 1.1 Objectives of the Research

The Main objectives of the study:

- Estimate the Self-Purification system of the Selbe River with the Streeter-Phelps model.
- Compare the estimated result with the last year's study data.
- Define the condition of the Bacterial infection in the Selbe River water with laboratory experiments.

The Sub-objectives:

- Determine the Deoxygenation rate  $k_1$  with ultimate and 5 days BOD value
- Determine the Reaeration rate  $k_2$  with the hydrological data of the Selbe River

## 1.2 Expected outcomes

- Evaluation of the Bacterial infection and contamination level of the Selbe River.
- Determination of critical time, critical oxygen deficit, distance of oxygen depletion, and oxygen Sag curve

## 2. State of art

The study area of this thesis work is the Selbe and Dund River area, which are major tributaries to the Tuul River, which is 26.2 km long and has a draining area of around 220  $km^2$  in the Tuul River basin. It originates from mainly Khentii mountain ranges (56-76%) and includes the contribution of groundwater (15-40%) (7). The Selbe River flows through the center of Ulaanbaatar from north to south. When Selbe River enters Ulaanbaatar, after passing Narnii Road, it turns sharply to the west side, which makes it flow parallel to the Tuul River, and this part is called the Dund River.

According to the Köppen-Geiger climate classification system, Ulaanbaatar is classified as a “BSk” which is a Cold semi-arid region, the average temperature of Ulaanbaatar is  $-0.6^{\circ}C$  and the annual precipitation is around 279.15 mm (9).

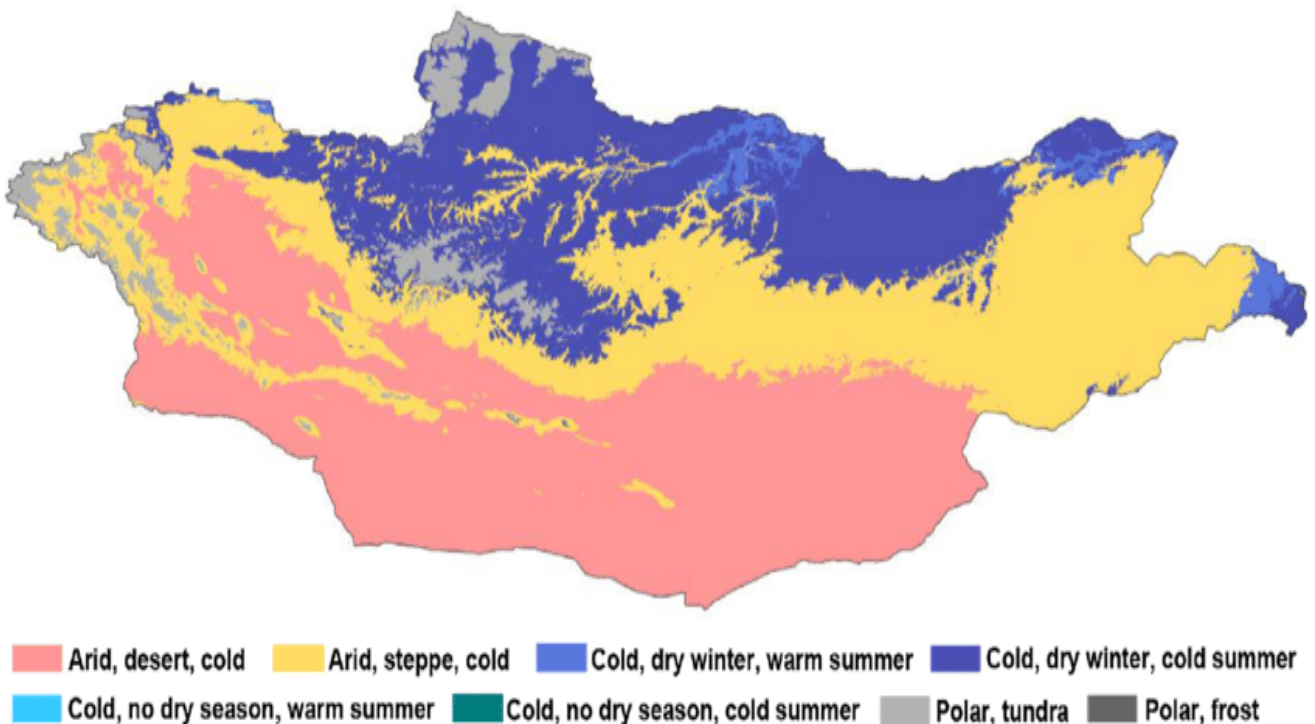


Figure 3 Köppen-Geiger climate classification map of Mongolia

Originally Selbe River area was the main picnic zone for the citizens of Ulaanbaatar. However, under the influence of climate change and global warming, the annual precipitation and the temperature pattern changed which causes extreme weather events like drought and flood. It is reported in Mongolian Third National Communication to United Nation’s Framework Convention on Climate (UNFCCC) reported that between 1940-2015 the average temperature rose by  $2.24^{\circ}C$  and the annual precipitation declined by around 7% (10). Additionally, the interviews among the Herders from Certain parts of Mongolia reported that the rain pattern has changed and the number of short and intense rainfall increased (11). From 2012 until 2022, the population of Ulaanbaatar

increased by 373'636 people, 2.5% on average (12). Due to the increase in population, private houses near its resources, and urbanization around the part of the river that flows through Ulaanbaatar, the Selbe River is gradually losing its natural state and appearance.

The Selbe River discharges to the Tuul River basin, which flows from the northern part of Ulaanbaatar to the southern part and then tributaries to the Tuul River. The northern part of the Selbe River is covered by the private house region followed by the Ger district of Ulaanbaatar which has numerous latrines which can be dispersed pollution sources because the river is perennial and feeds underground flows. As of 2020, 207'347 households do not have access to sanitation in Ulaanbaatar (12). More or less, due to the construction of the houses and the latrines around this region the river water quality is declined. Concerning the MNS 4586:1998 "Water Quality. General Requirements" Standard, in 2012, an assessment of surface water quality was done on a total of 85 rivers and 13 lakes. According to the assessment, Selbe and Dund rivers are assessed as moderately polluted rivers with a pollution index between 0.9 to 2.49 (13).

In 2005, the Statistical Evaluation of Methods of Determining BOD rate was done in Nigeria, which compared the Least Square, Thomas, Non-Linear regression, Fujimoto, Ratio, Logarithms Difference, and Two-Point method by taking a sample from the influent of the waste stabilization pond and tested the deoxygenation rate of the sample. As a result, the best methods for estimating the deoxygenation rate were Non-Linear regression and the Thomas method, with an accuracy of 100% and 98% respectively compared to the other methods. However, the Ratio method and Fujimoto method are the least suggested methods which have an accuracy of 33% and 45% (14).

In 2013, the case study was done by comparing the result of the determination of the deoxygenation rate of the Citepus River in Indonesia using the empirical method which considers only the physical condition, and the laboratory method. The result was the deoxygenation rate that estimated by the empirical method was 0.509-0.643  $d^{-1}$  at the upstream and 0.423-0.543  $d^{-1}$  at the downstream which are relatively higher value than the laboratory method result which was 0.42-0.64  $d^{-1}$  at the upstream and 0.064-0.48  $d^{-1}$  downstream. This shows that the empirical method is not suitable for the rivers that are polluted. Because it does not consider the external influences that can affect the activity of the microorganism in the water (15).

In the case of determining the deoxygenation rate, several different methods can be used for analyzing the obtained data from the laboratory experiment and the field measurements. The methods include the Thomas method, Fujimoto, Ratio method, Two-Point method, etc. It takes at least 10 days to obtain data from laboratory experiments, some empirical methods use the physical condition like the depth of the river water. Based on the last year's evaluation of the Selbe River, 1<sup>st</sup> order method is more suitable for modeling the Selbe rivers self-purification system (8).

## 2.1 Dissolved Oxygen

Dissolved oxygen (DO) is one of the most important parameters that indicate the quality of the water. It is the critical part of the respiration of the aerobic microorganisms in the water, which consumes oxygen to produce energy. When the water has 80% of DO and more oxygen or DO is saturated it is considered to be healthy. However, when the DO falls to less than 30% percent (hypoxia) most of the organisms in the water will not be able to survive (16).

The concentration of DO in water can be varied due to temperature change and the increasing temperature the reduction of DO makes pollution in the water. If there is a lot of organic waste in the water, the organic matter will be consumed by the microorganisms that used DO in the water. To decompose the organic wastes, the oxygen in the water will be used by the microorganisms, which leads to a decrease in oxygen concentration in the water. Oxygen content is very sensitive to the change in temperature. The increase in temperature of the water causes a decrease in the concentration of oxygen in the water and it can stimulate the activity of the microorganism (16).

## 2.2 BOD reaction rate or Deoxygenation rate coefficient $k_1$

To completely decompose the organic matter in the water, usually it takes around or over 20 days and the amount of oxygen that is consumed by the microorganisms in these 20 days to decompose or stabilize the biodegradable organic matter in a certain volume of water is called ultimate BOD (UBOD). BOD is a function of time; it increases as time increases till it reaches UBOD. Mathematically it increases with the rate of  $k_1$  which is called the deoxygenation rate coefficient. Therefore, this coefficient is important for predicting the ultimate BOD by using the BOD of 5 days. Moreover, the biochemical oxidation process never reaches 100%, during the 20 days of oxidation the ultimate BOD is completed around 95-99% and for the BOD of 5 days, it is identified to be oxidized around 60-70% (17).

- **Biochemical oxygen demand (BOD)**

Biochemical oxygen demand is the widely used parameter that defines water pollution. BOD is defined as the amount of oxygen ( $mg/L$ ) that is required for the biochemical oxidation of organic substances in water. And the dissolved oxygen consumed by the microorganisms is related to BOD (16).

Additionally, microorganisms decompose the organic matter into simpler compounds, like carbon dioxide and water by releasing energy after consuming oxygen. This characteristic of the microorganisms is used for wastewater treatment. Therefore, 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 (16).

- **Chemical oxygen demand (COD)**

Chemical oxygen demand is an indirect indicator of the pollutants in the water, which indicates the amount of oxygen that is required for degrading all the organic matter which is biodegradable and non-biodegradable materials that cannot be consumed by the microorganisms. Chemical oxygen demand can be tested in a short amount of time by using a strong oxidizing agent (potassium dichromate). However, since it includes all the organic matter present in the water, there is no general correlation between BOD and COD, which means the BOD cannot be defined by the COD. BOD is part of COD. COD is classified as biodegradable and non-biodegradable COD. Roughly, 1.6 BOD equals biodegradable COD (17).

- **BOD Reaction Rate Coefficient  $k_1$  Determination, First Order Method.**

$$BOD_t = BOD_L(1 - e^{-k_1 t}) \quad \text{Equation 1}$$

$$k_1 = -\frac{\ln(1 - \frac{BOD_t}{BOD_L})}{t} \quad \text{Equation 2}$$

$BOD_t$  – amount of organic waste presence in water at time  $t$  (mg/L)

$BOD_L$  – ultimate BOD (mg/L)

$k_1$  – BOD reaction rate coefficient ( $d^{-1}$ )

$t$  – time (d)

## 2.3 Estimation of Reaeration Rate Coefficient $k_2$

The Dissolved oxygen in water is constantly replenished as the stream flows down, by absorbing the oxygen in the atmosphere at the water's surface. And this process is called the reaeration process which is the natural process that is the crucial part that defines the dissolved oxygen profile. The reaeration rate is the rate that defines the amount of oxygen that enters the water body at a certain amount of time through the reaeration process. 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 (16).

Determination of the reaeration rate cannot be modeled by a single equation. Because, it can be varied under the influence of many different parameters like the velocity of the river, depth and width of the river, slope and kinematic viscosity, etc. Depending on these parameters, several empirical relations or models are used to estimate the reaeration rate. The main variables for finding the 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 (18).

Among the total 21 Models dedicated to the determination of the reaeration rate coefficient ( $k_2$ ), 5 models which are suitable for the small river are chosen for the Calculation of the Selbe River's reaeration rate (18).

- **Models involving Velocity (U) and Depth (H) of a river or stream.**

$$\text{Owens et al. (1964): } K_a = 5.32 \frac{U^{0.67}}{H^{1.85}} \quad \text{Equation 3}$$

$$\text{Jha et al. (2001): } K_a = 5.792 \frac{U^{0.5}}{H^{0.25}} \quad \text{Equation 4}$$

- **Models involving Velocity (U), Depth (H), and Slope (S)**

$$\text{Grant (1976): } K_a = 173(SU)^{0.404} H^{-0.66} \quad \text{Equation 5}$$

$$\text{Thyseen et al. (1987): } K_a = 8784 \frac{U^{0.7344} S^{0.93}}{H^{0.42}} \quad \text{Equation 6}$$

$$\text{Smoot (1988): } K_a = 543S^{0.6236} U^{0.5325} H^{-0.7258} \quad \text{Equation 7}$$

$S$  – slope (%)

$U$  – Velocity (m/s)

$H$  – Depth (m)

$K_a$  – Reaeration rate

## 2.4 Modified Streeter-Phelps model equation, Oxygen Sag Curve

The Streeter-Phelps model is the model that is used to predict and describe the behavior of the stream. In this model, it assumes that only 2 processes are occurring which are deoxygenation from BOD and the reaeration by oxygen transfer at the surface. However, the original Streeter-Phelps model was estimated in 1925 which is the period before the concept of Global warming occurs. As the influence of global warming is increasing last few decades, the water temperature is gradually increasing.

The Streeter-Phelps model consists of several temperature-dependent parameters like Dissolved Oxygen (DO), Reaeration rate, and Deoxygenation rate, etc. Therefore, the temperature change can affect the self-purification system of the river as well. According to the study made in 2021, which studied the influence of the temperature increase on the Self-Purification system of the waterbody, due to the temperature increase the Self-Purification of the waterbody declines as well as the oxygen depletion in water becomes faster than the Reaeration process (19). In Figure 4, some of the variables of the equation are presented.

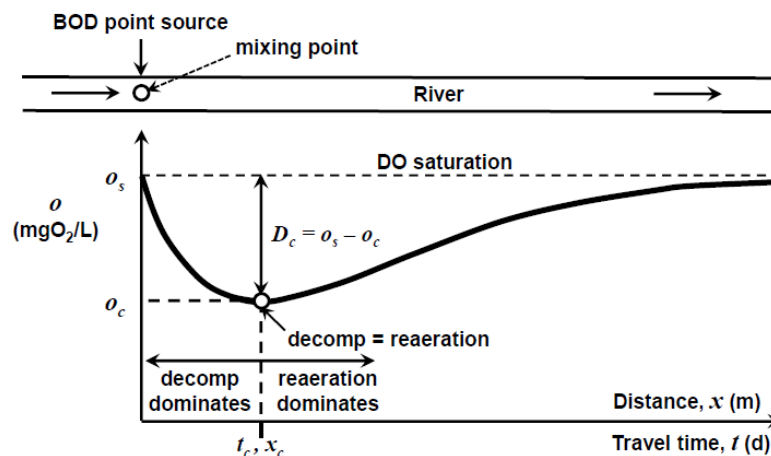


Figure 4 Oxygen Sag Curve of the river Under the point source pollution (19)

Where:

$t_c$  = time it takes for critical oxygen deficit or minimum DO develop, (d)

$D_c$  = critical oxygen deficit, (mg/L)

$x_c$  = critical distance, (m)

$o_s$  = saturation dissolved oxygen concentration, (mg/L)

$o_c$  = critical oxygen concentration, (mg/L)

In this model, it made several assumptions which are the starting point of the Oxygen Sag curve is under the Point-Source pollution mixing point, the initial oxygen deficit equals zero and the point is under the minimal plant activity.

## 2.5 Indicator Bacteria

The presence or the absence of microorganisms in water can be one of the most useful indicators of its quality. It is important to keep water free of pathogenic organisms which cause the disease. Therefore, to determine whether water is polluted or not, the experiment should be done which mostly tests the presence of a single species of microorganism that can signal the possible contamination in the water. This kind of microorganism is called an indicator organism.

The commonly used water quality indicator microorganism is the bacteria called Coliform which is harmless and easy to detect. The bacteria exit the human indigestion tract. When the coliform is detected from water bodies it indicates pollution of human feces. Coliforms are the bacteria that are always present in the intestinal tract of the human body which is wasted all the time with the body wastes. The presence of coliforms simply means the water could be containing pathogenic organisms in it. Some groups of coliforms are mainly tested in the laboratory, which are Total Coliform, Fecal Coliform, and E.coli. Total Coliform includes all the coliforms from all different sources. However, Fecal Coliform refers to the coliforms that are from the intestine of the warm-blooded animal and the E.coli is the sub-group of Fecal coliforms (16).

Salmonella is the one type of pathogenic bacteria that causes food-borne diseases like diarrhea. A possible source that can cause salmonella infection is the consumption of food that originated from animals like eggs, chicken and meats, etc. Also, it can be transmitted through the food chain (20). Once Salmonella is released from the host body by its feces, it can reach the surface water through run-off and rainfall. Moreover, Salmonella can survive under many different types of environmental conditions like lack of nutrients, UV-light, changes in temperature and pH, etc. After reaching the waterbody, it can be transmitted to many different food sources for both humans and animals (21).

Additionally, Shigella is also a type of pathogenic bacteria that causes foodborne diseases by transmitting through food and water. The disease caused by the Shigella bacteria is called Shigellosis. The water can be infected through the feces and contact with the infected body. Same to Salmonella it is delivered to the waterbody by the rain and runoff (22). The most effective way to prevent these bacterial infections is simply the hygiene of the individuals, like washing hands and cooking food fully, etc.

### 3. Methodology

#### 3.1 Sampling points

Selbe River water samples were taken from 5 different points along the Selbe River which are the same location as last year's research. From the Altai Town sampling point to the Dambadarjaa sampling points it is a total of 13.7 km. Average sampling points are 2.91 km away from each other. Sampling points are listed below in Table 1 and estimated on a map using QGIS in Figure 5.

Table 1: Sampling points along the Selbe River

No.	Sampling point	Location (Latitude, Longitude)
1	Dambadarjaa (Upstream)	47°58'36.77" N, 106°55'33.64" E
2	Zuun Ail	47°55'56.45" N, 106°55'52.41" E
3	Chinggis Khan Hotel	47°55'23.25" N, 106°55'54.21" E
4	Ikh Nayad Plaza	47°54'23.20" N, 106°55'44.10" E
5	Altai Town (Downstream)	47°54'13.33" N, 106°52'44.06" E

The first sample was only taken from the Ikh Nayad Plaza sampling point on the 10th of April due to the weather condition which was cold and stormy weather and we could not continue to take the samples from other sampling points.

The second sampling was done on the 12th of April from the other 4 points which are Altai Town, Chinggis Khan Hotel, Zuun Ail, and Dambadarjaa. The location of the sampling points has shown in Google Earth Pro. map (see Figure 6.)

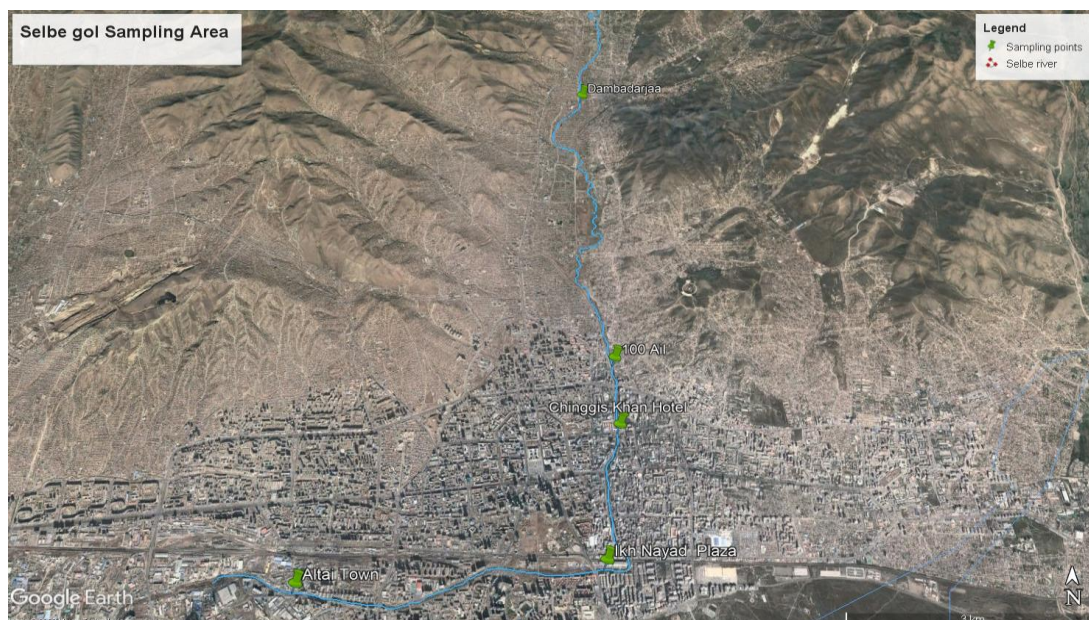


Figure 5 Location of Sampling points (Source: Google Earth Pro.)

### 3.2 Determination of Biochemical Oxygen Demand (BOD)

For this thesis work, the BOD was measured using the Lovibond BD600 BOD measuring instrument, which uses a straightforward method to measure and record the direct value of the BOD for up to 28 days. This instrument can test 6 samples at the same time.

The BOD measurement is based on the oxygen consumption of microorganisms like bacteria, fungi, protozoa, archaea, etc. which plays a huge role in water self-purification systems. Lovibond BD600 measurement is done in a closed system with a constant volume of sample. By digesting oxygen, microorganisms produce carbon dioxide simultaneously. In the closed system of the instrument produced carbon dioxide reacts with the potassium hydroxide ( $KOH$ ) which causes the pressure drop in the seal cup. And the sensor of the BD600 instrument measures this pressure drop and converts the data into the value of the BOD in mg/L (23).



Figure 6. Lovibond BD600 instrument (Author)

### 3.3 Determination of Chemical Oxygen Demand (COD)

Estimation of the Chemical Oxygen Demand can be performed in two different methods which are open-reflux and closed-reflux. In this thesis work the COD is determined by the closed-reflux colorimetric method which uses less hazardous reagents during the test. Compared to the BOD test which takes at least 5 days to complete, the COD test is quicker and simpler and can be done in 2-3 hours in a laboratory. When the sample is digested with the potassium dichromate ( $K_2Cr_2O_7$ ), dichromate ( $Cr_2O_7^{2-}$ ) ion oxidizes the COD in the sample which causes a change of chromium from hexavalent (VI) to trivalent (III) state. Both of these ions are colored and absorbed in the visible region of the spectrum. And with the different absorption of the chromium ion and dichromate ion, the amount of the COD is measured (24). For this thesis the Hach DR/870 portable data logging closed reflux colorimeter was used for COD measurement. For an accurate result, the reagent should be homogenized with the sample (25). So, the sample and the reagents should be prepared carefully, by digesting at 150 degrees Celsius for 2 hours in Digital Reactor Block (DRB) 200. After digesting and cooling, the sample COD is measured with the Hach DR/870.



Figure 7. Hach DR/870 Colorimeter



Figure 8. Digital Reactor Block DRB 200

### 3.4 Determination of Dissolved Oxygen (DO), Temperature, and pH

Determination of Dissolved Oxygen (DO) can be done in numerous different methods, such as the colorimetric method, Iodometric method, electrometric methods, etc. In addition, the modern widely used diaphragm electrode method is used for the measurement of dissolved oxygen. This method works like a battery, when the electrode and the counter electrode are connected electrically, the current is generated due to the oxygen reduction. The produced current value is the same as the dissolved oxygen value. So, the DO value can be determined by the measured current value. Also, this instrument provides not only DO value but temperature saturation percent. Additionally, the temperature and pH of the river water were measured by Hanna pH/ORP waterproof portable meter.

Real-time DO value measurements are measured with the device. As for the saturation DO, it can be obtained by using the table of saturation DO based on the water temperature. Furthermore, saturation DO can be calculated by the following equation (Eq.8) which depends on the temperature, salinity, and elevation of the water body. As most of the river and stream has little salinity the fractional reduction of freshwater at sea level saturation due to salinity ( $\phi_s$ ) will be zero (19).

$$o_s = \phi_{elev} \cdot \phi_s \cdot e^{\ln o_{sf}(T)} \quad \text{Equation 8}$$

$$\ln o_{sf}(T) = -139.34411 + \frac{1.575701 \times 10^5}{T_a} - \frac{6.642308 \times 10^7}{T_a^2} + \frac{1.2438 \times 10^{10}}{T_a^3} - \frac{8.621949 \times 10^{11}}{T_a^4} \quad \text{Equation 9}$$

$$T_a = T(^{\circ}\text{C}) + 273.15 \quad \text{Equation 10}$$

$$\phi_s = e^{-S(1,7674 \times 10^{-2} + \frac{10.754}{T_a} - \frac{2140.7}{T_a^2})} \quad \text{Equation 11}$$

$$\phi_{elev} = 1 - 0.11988elev + 6.10834 \times 10^{-3}elev^2 - 1.60747 \times 10^{-4}elev^3 \quad \text{Equation 12}$$

Where:

$o_s$  – Dissolved oxygen saturation concentration [mg O<sub>2</sub>/L]

$\phi_{elev}$  – the fractional reduction of freshwater at sea level saturation due to

*elevation above sea level [dimensionless]*

$\phi_s$  – *the fractional reduction of freshwater at sea level saturation due to salinity*  
[dimensionless]

$o_{sf}$  – *dissolved oxygen saturation concentration of sea level freshwater [mg O<sub>2</sub>/L]*

$T_a$  – *water temperature [K]*

$S$  – *Salinity [ppt]*

*elev* – *elevation above sea level [km]*



Figure 9. YSI ProODO DO measurement device



Figure 10. Hanna pH/ORP waterproof portable meter

### 3.5 Determination of Volumetric flow rate

To determine the volumetric flow rate, the depth of the river, the width of the river, and the stream velocity are measured. For the stream velocity measurement, the Marsh-McBirney Flo-Mate 2000 flow rate measuring instrument which uses the Faraday principle for its measurement was utilized. The instrument measures the stream velocity two times every second and calculates the average velocity after 30 seconds of measurements (26). For further calculation stream velocity was measured at least 6 times with the constant distance between the measuring points. Using the measured depth and width the cross-section area was calculated. After estimating the area and the velocity, the volumetric flow rate was calculated as follows with a continuity equation (Eq.13).

$$Q = V \times A \quad \text{Equation 13}$$

Where:

$Q$  – Volumetric flow rate ( $m^3/s$ )

$V$  – Average Velocity ( $m/s$ )

$A$  – Cross section area ( $m^2$ )



Figure 11. Marsh-McBirney Flo-Mate 2000 Flowmeter



Figure 12. April 10th measurement at Ikh Nayad Plaza sampling point

### 3.6 Determination of Indicator Bacteria

In this study, Total Coliform, Fecal coliform, and E.coli were determined with the Colilert-18 IDEXX tray method which is a simple and accurate method, that estimates the result within 24 hours. This method uses the nutrients that change color after being metabolized by the coliform bacteria. To estimate the Total coliform and E.coli bacteria the nutrient is digested by the bacteria at a constant temperature of 35.5 degrees Celsius and for the Fecal coliform, it is stored at 45.5 degree Celsius for 18-24 hours. After fully digesting the nutrient, the blocks of the tray which has total coliform and Fecal coliform change its color from colorless to yellow and the tray with E.coli changes its color to fluorescence that can be detected by the UV light (27).

Other than the IDEXX tray method, E.coli was determined with the Petri-Dish method. Petri-dish method grows the E.coli bacteria in a desired environment and counts the colons that are grown on the dish.



Figure 13. Petri Dish method



Figure 14. IDEXX Tray Method

### 3.7 Self-Purification system modified Streeter-Phelps model

The Self-Purification system Streeter-Phelps model mainly depends on the DO, BOD, deoxygenation rate, and reaeration rate, then indicates the critical oxygen deficit, critical time, and distance. In this model, dissolved oxygen, reaeration rate, and deoxygenation rate are temperature-dependent parameters which means that the Self-purification system of a certain waterbody can be changed following a slight temperature change. The main assumption of this model is that the calculation is done at the mixing point of the point-source pollution and the initial oxygen deficit ( $D_i$ ) is zero (19).

After determining the necessary parameters using Eq. 14 the Oxygen Sag Curve of the Selbe River will be generated. From the Oxygen Sag Curve, it is possible to obtain the critical time ( $t_c$ ) and critically dissolve oxygen concentration ( $o_c$ ). As for the critical distance, it will be computed by Eq.16.

$$o = o_s - \frac{k_1 \times BOD_L}{k_1 - k_2} \times (e^{-k_2 t} - e^{-k_1 t}) \text{ Equation 14}$$

$$D_c = o_s - o_c \text{ Equation 15}$$

$$x = Ut \text{ Equation 16}$$

Where:

$o_c$  = dissolved oxygen concentration (mg/L)

$o_s$  = dissolved oxygen saturation concentration, (mg/L)

$D_c$  = critical oxygen deficit, (mg/L)

$BOD_L$  = Ultimate BOD in stream, (mg/L)

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

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

$x$  = distance, (m)

$U$  = flow velocity, (m/s)

$t_c$  = Critical time (d)

## 4. Discussion and Result

For this research work, the Hydrologic characteristics, BOD, COD, DO, Temperature, pH, and indicator bacteria of the Selbe River were studied both on-site and in Laboratory. Based on the result of the laboratory and field test, critical time, critical distance, critical oxygen deficit, and the Sag curve of the Selbe River were estimated by the modified Streeter-Phelps model, which included global warming and its influence on DO and BOD of the river. Furthermore, all the obtained data were compared with the previously measured data by the 2022's Environment Engineering (EE) senior student Usukhbayar Puntsagsuren. In addition to the comparison, the indicator bacteria of the Selbe River were studied in Laboratory with two different methods.

### Study Area Along Selbe River, Ulaanbaatar Mongolia

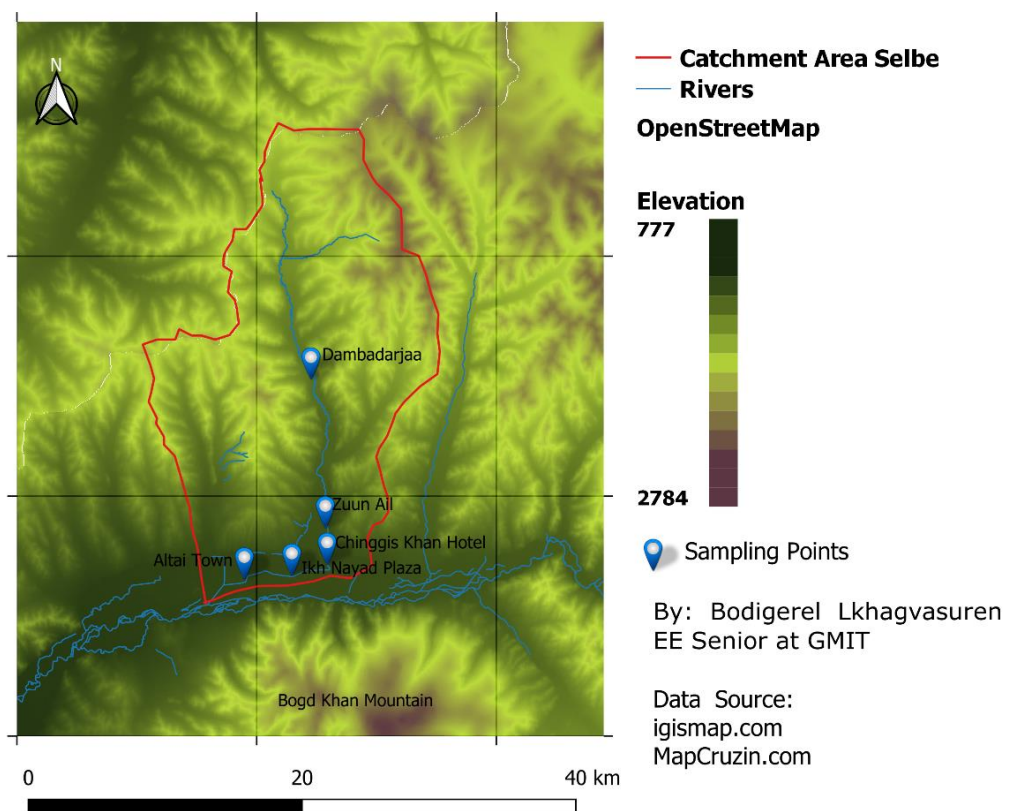


Figure 15. Study area along Selbe River

## 4.1 Hydrological characteristics of Selbe River

All the hydrologic data were collected on the 10th of April and the 12th of April. The hydrologic data, including the width of the river, depth of the river, flow velocity, elevation, slope, and flow rate were measured on the field with a suitable measurement device. The depth and the velocity were measured at least 6 times along the width of the river with a constant distance between each measurement. The data are listed in Table 2. This is the average value of each hydrologic data that is measured on the field. Sample points are ordered from the upstream point to the downstream point, which is upstream point Dambadarjaa and downstream point Altai Town.

Table 2. Hydrologic data of Selbe River

Location	Width (m)		Depth (m)		Velocity (m/s)		Flow rate (m <sup>3</sup> /s)		Elevation (m)	Elevation difference (m)	Distance (m)	Slope (%)
	2022	2023	2022	2023	2022	2023	2022	2023				
			2022	2023	2022	2023	2022	2023	-	-	-	-
Dambadarjaa	4	8.2	0.33	0.26	0.08	0.10	0.159	0.082	1353	-	-	-
Zuun Ail	3.5	27.7	0.19	0.35	0.3	0.22	0.364	1.233	1315	38	5025	0.76
Chinggis Khan Hotel	4.5	-	0.15	1	0.31	0.12	0.350	-	1307	8	1003	0.80
Ikh Nayad Plaza	4.2	6.8	0.3	0.28	0.19	0.18	0.412	0.213	1293	14	1865	0.75
Altai Town	2.5	5.2	0.17	0.35	0.202	-	0.146	-	1284	9	3757	0.24
<b>Mean</b>	<b>3.740</b>	<b>11.98</b>	<b>0.228</b>	<b>0.448</b>	<b>0.214</b>	<b>0.15</b>	<b>0.286</b>	<b>0.509</b>	<b>1310.4</b>	<b>17.25</b>	<b>2912.5</b>	<b>0.64</b>

On the 10th of April, the Ikh Nayad Plaza measurements were done. Due to stormy and cold weather, the measurement stopped after the sampling at Ikh Nayad Plaza. During the measurement in some parts of the river, a thin layer of ice was formed due to cold weather which was disturbing some of the sampling and measurement procedures.

On the 12th of April, the measurements of the other four sampling points were done. Even though the weather was warmer than the first sampling day, at some points ice layers were still there. Before sampling day, it snowed several times. It is reported that the total precipitation that occurred in UB from the 1st of April until the 21st of April is 22 mm. Due to this reason, the water level of the Selbe River was generally higher than last year's measurement. The width and the depth of the river were mainly greater than the last year's measured value. As for the average flow velocity, it was lower than 2022's data. During the measurement at Zuun Ail, even if the flow velocity were high, the bottom of the river was still frozen which means that the depth of the river can be higher than the currently measured data.

The elevation and the distance between the sampling points were analyzed using Google Earth Pro. and QGIS at each sampling point along the Selbe River. Using these values, the slope between the points was estimated by dividing the elevation difference by the distance.

The flow rate determination was done using Eq.13 by using the width, depth, and velocity of the river. Detailed data is available in ANNEX 3.

#### **4.2 $BOD_5$ , $BOD_L$ , COD, DO, and Temperature of Selbe River**

Biochemical oxygen demand and Chemical oxygen demand values were estimated through the laboratory test as mentioned in the methodology right after the sampling. Dissolved oxygen and temperature were estimated by the onsite measurement value. Saturation DO values were generated from the Saturation DO value table (24) based on the water temperature also calculated with the Modified Streeter-Phelps model (19).

Table 3.  $BOD_5$ , UBOD, COD, DO, and Temperature of Selbe River

The BOD test was done in a laboratory for 15 days to determine the 5 days BOD and ultimate BOD (UBOD). During the measurement, due to the cold temperature, the bacterial activity was lower which caused the failure of the first test of the BOD. Therefore, the second test was done with a lower measurement range (0-200 mg O/L) after adding the bacteria from the external source. As a result, the maximum BOD was measured at the Chinggis Khan Hotel sampling point and the lowest BOD was measured at the Zuun Ail sampling point. Both 5 days BOD and UBOD were lower at the upstream point and increasing downward. Generally, the test result was higher than the last year's value except for the Ikh Nayad Plaza sampling point, which might be caused by the precipitation that make the pollution around the upstream point washed and delivered to the river water. Detailed data are available in ANNEX (2).

The COD value indicates both organic and inorganic impurities in water. Therefore, to check the accuracy of the BOD value COD test was done in the laboratory. Compared to the BOD test COD test requires about 2-3 hours to complete the test and the result of the test can be generated in less time. The average value of COD was 416.8 mg/L and the highest value 660 mg/L was noted at the Zuun Ail sampling point which was closer to the dumping site. Additionally, a sample at Zuun Ail was taken from the part of the river where people cross the river with their car which caused the pollution in river water. Furthermore, the overall COD value was lower than last year's estimated value. As mentioned before, there was more precipitation before the sampling. Due to the precipitation, the water level of the Selbe River increased compared to the general baseflow of the river, which means that the amount of water that flows through the river increased and diluted the river water. For this reason, the concentration of the COD decreased compared to last year's measurement.

Due to cold weather, the average temperature of the river water was 1.42 degree Celsius which increased the concentration of the Dissolved Oxygen value. The highest saturation was

measured at the Zuun Ail sampling point. At the Zuun Ail sampling point, despite the high COD value, due to its high flow velocity, reaeration was proceeding faster than the other points. Moreover, if we compare the saturation concentration of the DO and the measured DO value, the saturation of the DO is an average of 82%.

Table 4. Dissolved Oxygen Saturation calculation

Location	T (°C)	Elev (m)	Elev (km)	$T_{\text{ref}}$ (K)	$\alpha$ (K <sup>-1</sup> )	$\phi$	Saturation DO (mg/L)		DO (mg/L)
							Calculated	Table	
Dambadarjaa	0.9	1353	1.353	274.05	2.657	0.849	12.097	14.3	9.35
Zuun Ail	1.7	1315	1.315	274.85	2.635	0.853	11.888	13.9	11.48
Chinggis Khan Hotel	0.9	1307	1.307	274.05	2.657	0.853	12.166	14.3	10.1
Ikh Nayad Plaza	-0.1	1293	1.293	273.05	2.685	0.855	12.534	14.6	9.64
Altai Town	3.7	1284	1.284	276.85	2.581	0.856	11.307	13.2	8.48

DO saturation concentration was obtained by using two different methods. First, the saturation concentration value was taken from the table value that only depends on the temperature of the river water. Second, it was calculated using Eq.8 which includes salinity, temperature, and the elevation of the sampling point. The calculation is done on rivers, as the salinity is almost zero the fractional reduction of freshwater at sea level saturation due to salinity becomes one.

From Table 4 it can be seen as the table value is not reliable and only depends on the temperature. As for the Calculated value, it includes several different parameters that can affect the saturation of the DO, which means that the calculated value is more accurate than the table value.

### 4.3 Deoxygenation rate $k_1$ of Selbe River

Deoxygenation rate  $k_1$  was determined by the 1<sup>st</sup> order method with Eq.1 at each sampling point. The Deoxygenation rate of sampling points were ranging from 0.088 to 0.354 ( $d^{-1}$ ), the highest value was calculated at the Chinggis Khan Hotel sampling point and the lowest value occurred at the Zuun Ail sampling point. The mean value of the Deoxygenation rate was lower than the last year's value, due to the temperature difference.

Table 5. Estimation of Deoxygenation rate  $k_1$

No.	Location	BOD <sub>5</sub> (mg/L)	UBOD (mg/L)	time (d)	k <sub>1</sub> [ln] ( $d^{-1}$ .)	
					2022	2023
1	Dambadarjaa	15	22	5	0.278	0.229
2	Zuun Ail	8	14	5	0.294	0.169
3	Chinggis Khan Hotel	60	82	5	0.171	0.263
4	Ikh Nayad Plaza	57	76	5	0.243	0.277
5	Altai Town	42	66	5	-	0.202
	<b>Mean</b>	<b>36.4</b>	<b>52</b>	<b>5</b>	<b>0.246</b>	<b>0.228</b>

#### 4.4 Reaeration rate $k_2$ of Selbe River

For the Reaeration rate calculation, five different models are dedicated to the small river used. The result of the calculation was evaluated by the sample Standard deviation and Standard error of the mean of the data from the five sampling points. Due to safety reasons, the measurement at Altai town sampling points was not able to proceed. So, the reaeration rate of the Altai Town sampling point was estimated with the last year's measurement value. The estimation of the reaeration rate was shown in Table 6.

Table 6. Calculation of Reaeration rateNo.	Location	U	H	S	Owens et al. (1964)	Jha et al. (2001)	Grant (1976)	Thyseen et al. (1987)	Smoot (1988)
1	Dambadarjaa	0.1	0.26	0.0076	13.747	2.565	23.121	30.490	25.547
2	Zuun Ail	0.22	0.35	0.008	13.453	3.532	26.678	50.365	34.598
3	Chinggis Khan Hotel	0.12	1	0.0075	1.285	2.006	10.176	19.555	10.692
4	Ikh Nayad Plaza	0.18	0.28	0.0024	17.771	3.378	17.525	15.580	18.906
	<b>Mean</b>	<b>0.155</b>	<b>0.4725</b>	<b>0.006375</b>	<b>11.564</b>	<b>2.870</b>	<b>19.375</b>	<b>28.997</b>	<b>22.436</b>

Two out of these five methods which are Owens et al. (1964) and Jha et al. (2001) use only the velocity and depth of the river water. However, the other three methods use velocity, depth, and slope to estimate the reaeration rate.

Table 7. Estimation of Reaeration rate k <sub>2</sub>	Dambadarjaa	Zuun Ail	Chinggis khan hotel	Ikh Nayad Plaza	Average (k(t))	Average (k(20))	St.dev.	St. error
Owens et al. (1964)	13.75	13.45	1.29	17.77	11.564	17.967	7.130	3.565
Jha et al. (2001)	2.56	3.53	2.01	3.38	2.870	4.460	0.715	0.358
Grant (1976)	23.12	26.68	10.18	17.52	19.375	30.103	7.198	3.599
Thyseen et al. (1987)	30.49	50.37	19.55	15.58	28.997	45.054	15.578	7.789
Smoot (1988)	20.20	25.58	8.31	12.76	16.712	25.965	7.684	3.842

With these chosen five models, the Reaeration rate value was between 2.87-28.997d<sup>-1</sup>. The maximum value was estimated with the Thyseen et al. (1987) model and the minimum value was estimated with the Jha et al. (2001) model. Based on the standard deviation calculation, the Reaeration rate value of Selbe River was chosen as 2.87 d<sup>-1</sup> with Jha et al. (2001) model with a sample standard deviation of 0.715 and a standard error of the mean of 0.358.

All the calculated values are calculated at the temperature of 1.42 degree celsius. So, for further calculation the calculated reaeration rate values were transformed into the 20-degree Celsius value with the Arrhenius equation (Eq.17). Therefore, the overall reaeration rate of Selbe River is 4.46.

$$k(T) = k(20)\theta^{T-20} \quad \text{Equation 17}$$

#### 4.5 Determination of Critical Oxygen Deficit, Critical Time, and Critical Distance of Selbe River with Streeter-Phelps Model

Using Eq.14 the Oxygen Sag Curve of Selbe River was generated with the internet graph sketching tool (28). With the deoxygenation rate, reaeration rate, UBOD, and dissolved oxygen saturation concentration, Eq.14 becomes a function of time and the dissolved oxygen concentration. According to the Streeter-Phelps model, critical time and critical dissolved oxygen concentration are at the minimum point of the Oxygen Sag Curve. Therefore, from the graph, the

critical time and the minimum dissolved oxygen concentration were generated for each sampling point. Using Eq. 16 the critical distance and with Eq.15 the critical oxygen deficit for each sampling point was calculated.

Table 8. Streeter-Phelps model calculations

No.	Location	UBOD	K1	K2	K2 (20C)	O_S	t_c, d	O_c	D_c	U [m/s]	U [km/d]	X
1	Dambadarjaa	22	0.229	2.56	3.98	12.097	0.761	11.034	1.063	0.10	8.40	6.391
2	Zuun Ail	14	0.169	3.53	5.48	11.888	0.655	11.501	0.387	0.22	18.68	12.235
3	Chinggis Khan Hotel	82	0.263	2.01	3.12	12.166	0.866	6.661	5.505	0.12	10.20	8.829
4	Ikh Nayad Plaza	76	0.277	3.38	5.25	12.534	0.592	7.903	4.631	0.18	15.55	9.207
5	Altai Town	66	0.202	3.88	6.03	11.307	0.583	9.342	1.965	0.15	12.96	7.556
	<b>Mean</b>	<b>52</b>	<b>0.235</b>	<b>3.07</b>	<b>4.77</b>	<b>11.999</b>	<b>0.696</b>	<b>9.677</b>	<b>2.322</b>	<b>0.15</b>	<b>13.21</b>	<b>9.192</b>

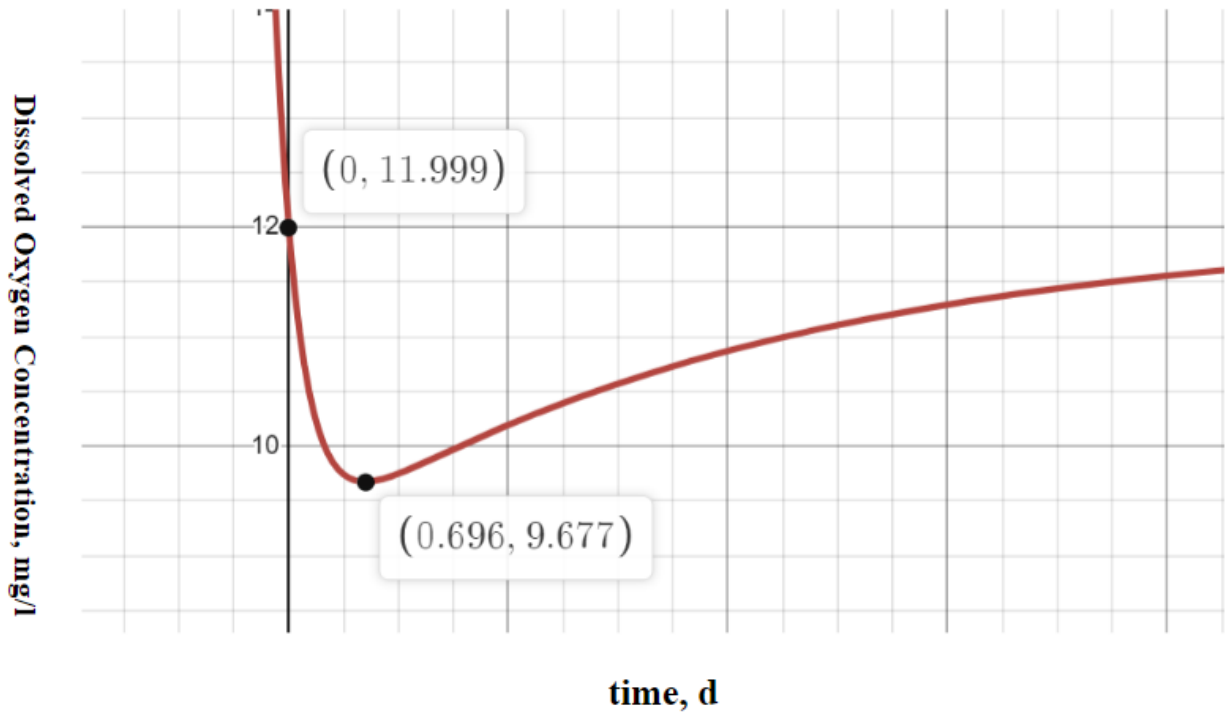


Figure 16 Oxygen Sag Curve of Selbe River

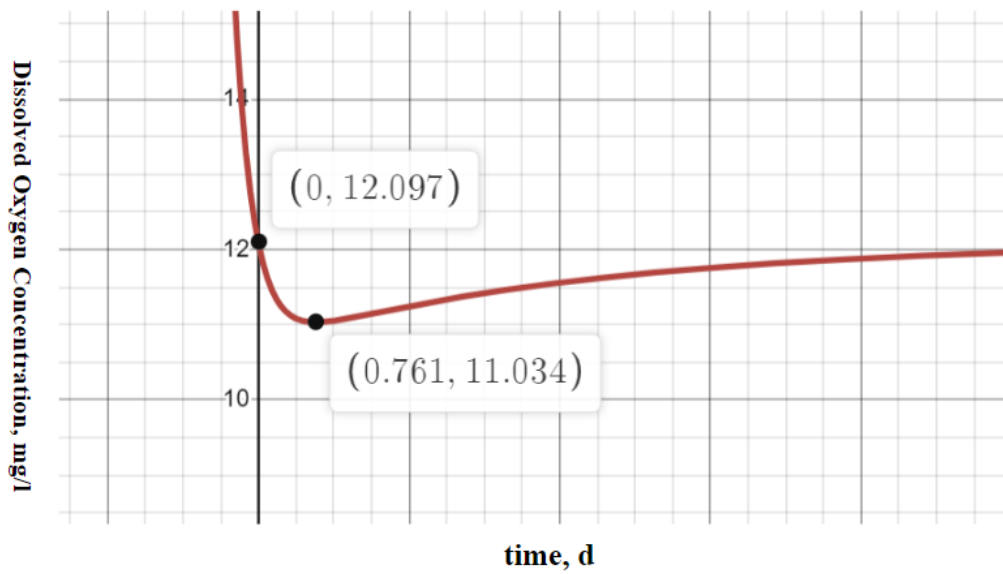
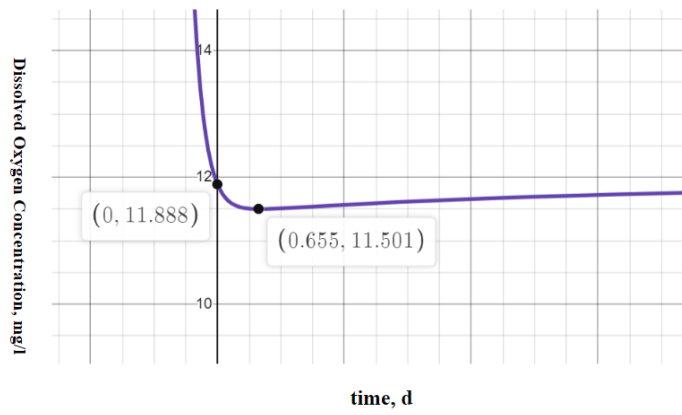
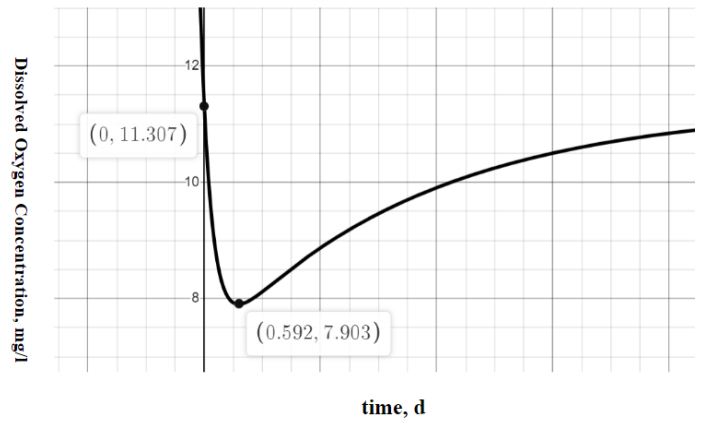


Figure 17. Oxygen Sag Curve of Dambadarjaa Sampling point  
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Figure 18. Oxygen Sag Curve of Zuun Ail sampling point

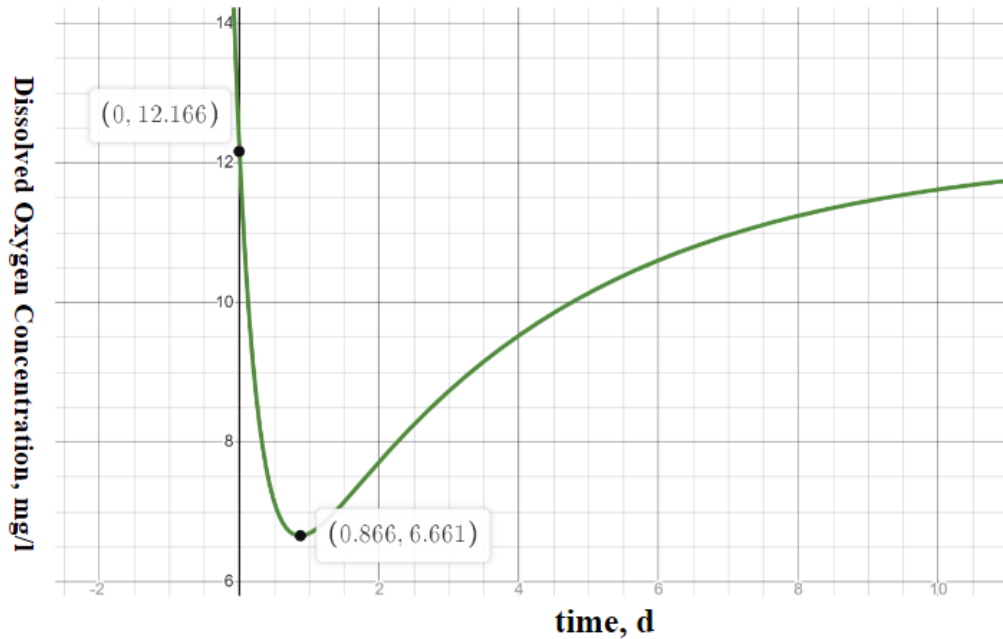
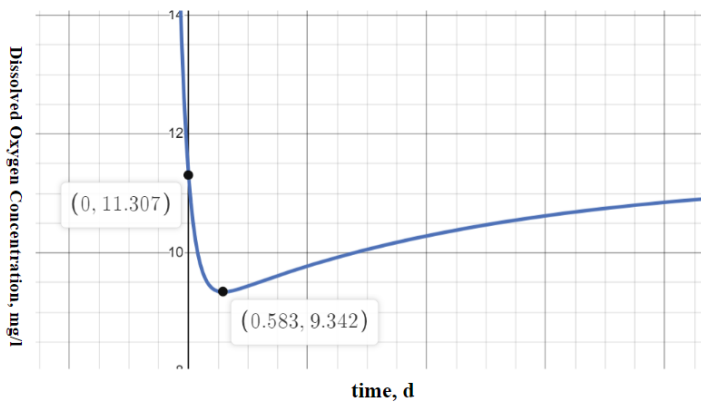


Figure 19.

Oxygen Sag Curve of Chinggis Khan Hotel sampling point

Figure 20. Oxygen Sag Curve of Ikh Nayad Plaza sampling point

Figure 21. Oxygen Sag Curve of Altai Town sampling point



Using the Oxygen Sag Curve of each sampling point, the General Selbe River's Self-Purification system parameters were defined. Compared to the other sampling points critical time and Critical oxygen deficit of the Chinggis Khan Hotel sampling point was higher than the other sampling points. However, the Zuun Ail sampling points critical time and critical oxygen

deficit was lowest, due to the high flow velocity and the lower BOD value.

Table 9. Comparison between the distance between the sampling points and the Critical distance

No.	Location	Distance (km)	Critical Distance
1	Dambadarjaa	-	-
2	Zuun Ail	5.025	6.39
3	Chinggis Khan Hotel	1.003	12.24
4	Ikh Nayad Plaza	1.865	8.83
5	Altai Town	3.757	9.21
6	Tuul river tributary point	5.98	7.56

	<b>Total</b>	<b>17.63</b>	<b>44.22</b>
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If we compare the critical distance with the calculated critical distance, the critical distance is higher than the actual distance between the sampling points which means that the Reaeration process is not able to fully proceed before the Selbe River tribute to the Tuul River. From the result, it can be seen that even if the reaeration rate is higher than the deoxygenation rate it is not enough to fully clean the river before it tributes to the Tuul river.

Table 10. Comparison of Streeter-Phelps model data

	K1	K2	t_c, d	D_c	x
2022	0.2465	3.91	0.25	2.43	4.14
2023	0.235	4.77	0.696	2.322	9.190

The calculated data was greater than the last year's calculation, due to the different models that are used for the calculation. Last year the original Streeter-Phelps model was used. However, this year the modified Streeter-Phelps model is considered global warming.

## 4.6 Indicator Bacteria test of Selbe River

Indicator Bacteria of the Selbe River were tested with two different methods in the laboratory. The first method is the Colilert-18 IDEXX tray method which counts the bacteria colony in a special sealed capsule after adding the nutrition that changes color after being decomposed by the bacteria. The IDEXX tray method tests were done in a laboratory right after the sampling process. For each sample, the total coliform, fecal coliform, and E.Coli are counted and the most probable number of the bacteria in the 100 ml sample was indicated. We assume that the river water is pure when the water sample does not contain any indicator bacteria. However, each sample from the Selbe River contained a certain number of indicator bacteria in it. The test results are shown in Table 11.

Table 11. Indicator Bacteria test with IDEXX tray method

Location	IDEXX tray Method		
	Total Coliform	Fecal Coliform	E.Coli
	The most probable number in the 100 ml sample		
Dambadarjaa	164.0	13.7	32.4
Zuun Ail	137.0	7.5	40.6
Chinggis Khan Hotel	64.0	16.4	65.9
Ikh Nayad Plaza	99.0	5.3	22.2
Altai Town	42.0	4.2	50.4
<i>Mean</i>	<i>101.2</i>	<i>9.4</i>	<i>42.3</i>

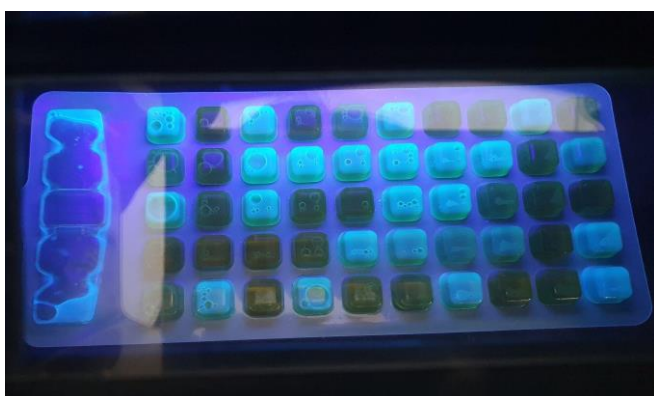


Figure 22. IDEXX tray method E.coli



Figure 23. IDEXX tray method Fecal Coliform

To prove the test result of the IDEXX tray method, the E.coli was grown on a petri dish with a special culture. Tests were done by using 10 ml water from the sample from 5 sampling points with 3 repetitions with 3 different dilutions, 1:2, 1:1, and no dilution. Moreover, to compare the data from the two tests, after counting the colonies of E.coli from each dish the results were multiplied by 10 which indicates the number of Bacteria in the 100 ml sample. The results are available in Table 12.

Additionally, the pathogenic bacteria Salmonella and Shigella were counted by using the Petri dish method. For the Salmonella and Shigella, the water sample was diluted 2 times, 1:1 and no dilution. The results are shown in Table 12.

The colonies on the Petri dish were counted every 24 hours four times for determining the final number of the colonies. First 24 hours, there was no growth of the bacteria on the dish, then after 48 hours it started to grow. On some of the dishes, the bacteria did not grow even after 96 hours. Therefore, it is assumed that there were no Salmonella or E.coli on the dish.

Table 12. Petri Dish Test Result

Location	Bacteria growth on Petri dish (colon forming Unit)						
	E.Coli in 100 ml sample				Salmonella and Shigella in 100 ml Sample		
	1:2 dilution	1:1 dilution	No dilution	Average	1:1 dilution	No dilution	Average
Dambadarjaa	20	20	60	33.3	0	10	5
Zuun Ail	0	10	30	13.3	0	0	0
Chinggis Khan Hotel	10	50	80	46.7	30	70	50
Ikh Nayad Plaza	10	40	40	30.0	0	20	10
Altai Town	20	40	70	43.3	0	0	0
<b>Mean</b>	<b>12</b>	<b>32</b>	<b>56</b>	<b>33.3</b>	<b>6</b>	<b>20</b>	<b>13</b>

From the Result of the Petri dish method, some of the measurements of E.Coli bacteria can be seen as the error that occurred during the measurement. Based on the dilution ratio the colon-forming unit should be resulted same. However, at Dambadrjaa and Ikh Nayad Plaza sampling points, some of the colons were counted the same, even if the dilution ratio is different. This could be caused, due to during the test the sample was not diluted completely. Therefore, the bacteria grown on the dish unequally.

Table 13. Comparison of two methods for indicator bacteria

From the result of these two methods, it can be seen that the 2 results were closer to each other. However, the Petri-dish method test result was lower than the IDEXX method result. And the greatest number of Bacteria were counted from the Chinggis Khan Hotel sampling point water sample from the two tests. And at Zuun ail sampling point the E.coli bacteria data was high which is 40.6 million cells in 100 ml sample. However, with the petric dish test the value was lower which is 13.3. Based on the COD test, at Zuun ail sampling point, it not possible to have a high number of bacteria with high COD. Therefore, at some ex

At the Chinggis Khan Hotel sampling point, the maximum number of E.coli bacteria was detected. It is conceivable that the bacteria and the contamination accumulated at the sampling

point due to the blockage caused by the big ice. As mentioned before, before the sampling day the precipitation occurred several times which increased the water level of the Selbe River from its baseflow. At the upstream of the Selbe River, Dambadarjaa, there are the Ger district households that use pit-latrines which are a huge source of the bacteria that occurs in the feces of warm-blooded animals. Due to the precipitation and the spring flood, bacteria from the pit latrines were delivered to the river water. From three out of the five sampling points, the Salmonella and Shigella bacteria were detected which means that the water from Selbe River can be one of the sources for the waterborne diseases.



Figure 24. E.Coli in Petri-Dish Altai Town



Figure 25.E.Coli in Petri-Dish Dambadarjaa



Figure 26. Salmonella Petri-dish test (Author)

## 5. Conclusion

The primary objective of this study was to assess the effectiveness of the Self-Purification system in the Selbe River by utilizing the Streeter-Phelps model. Additionally, the study aimed to establish a correlation between the Selbe River's pollution levels and the presence of indicator bacteria in the water. To estimate the Streeter-Phelps model, the deoxygenation rate and reaeration rate of the Selbe River water were determined through field measurements and laboratory tests at five distinct sampling points along the river. Furthermore, the estimated data

were compared with the calculated values from the previous year to identify any changes in the Self-Purification system's efficiency and determine the factors contributing to these changes.

The study's results indicated that both organic and inorganic pollution levels in the Selbe River were lower than the previous year's measurements due to the precipitation. However, comparing the efficacy of the Self-Purification system with the previous year was not feasible due to the different models used for calculation. Furthermore, with these tests, it was possible to see the correlation between bacterial growth and the type of contamination in river water.

The bacterial test revealed that additional runoff to the river had a noticeable impact. Besides the increase in water level in Selbe River, the test showed that bacterial contamination originating from pit latrines at the upstream point had spread to downstream points.

In conclusion, the results of the study demonstrated that during spring floods, both chemical and biological pollutants are added to the Selbe River through additional runoff from the entire catchment area. The bacterial tests conducted as part of this study revealed that bacterial contamination originating from pit latrines at the upstream point had spread to downstream points, showing that the risk of the Selbe River water can be the source of water-borne bacterial diseases. The Oxygen Sag Curve analysis also showed that the Self-Purification system of the Selbe River was not effective enough to remove the added pollutants from external sources. As a result, the Selbe River water is being added to the Tuul River without proper purification.

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## ANNEX 1. Sample Collection



Figure 27. Ikh Nayad plaza sampling point



Figure 28. Altai Town Sampling point

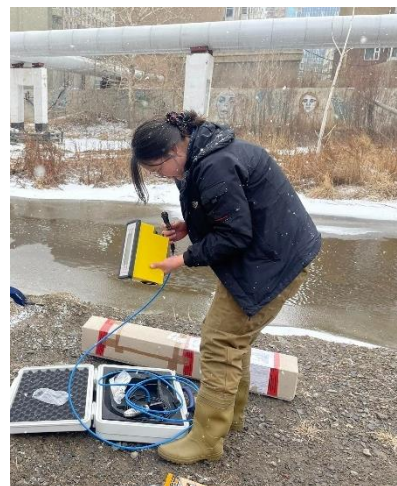


Figure 29. Chinggis Khan Hotel sampling point

Figure 30. Ikh Nayad Plaza sampling point

## ANNEX 2. Biochemical Oxygen Demand

Table 14. BOD measurement Dambadarjaa Sampling Point

Bottle position:	5		
Range:	0-200 mg/l		
Sample volume / ATH:	244 ml / 5 dr.		
Measurement duration:	15 days		
Measurement	Date	Time	BOD \ mg\l
0	23.4.2023	20:05:17	UNDERRANGE
1	23.4.2023	21:05:17	UNDERRANGE
2	23.4.2023	22:05:17	UNDERRANGE
3	23.4.2023	23:05:17	UNDERRANGE
4	23.4.2023	0:05:17	UNDERRANGE
5	24.4.2023	1:05:17	UNDERRANGE
6	24.4.2023	2:05:17	UNDERRANGE
7	24.4.2023	3:05:17	UNDERRANGE
8	24.4.2023	4:05:17	UNDERRANGE

9	24.4.2023	5:05:17	UNDERRANGE
10	24.4.2023	6:05:17	UNDERRANGE
11	24.4.2023	7:05:17	0
12	24.4.2023	8:05:17	2
13	24.4.2023	9:05:17	3
14	24.4.2023	10:05:17	4
15	24.4.2023	11:05:17	5
16	24.4.2023	12:05:17	6
17	24.4.2023	13:05:17	7
18	24.4.2023	14:05:17	9
19	24.4.2023	15:05:17	8
20	24.4.2023	16:05:17	8
21	24.4.2023	17:05:17	8
22	24.4.2023	18:05:17	8
23	24.4.2023	19:05:17	8
24	24.4.2023	20:05:17	9
25	24.4.2023	22:05:17	9
26	24.4.2023	0:05:17	9
27	25.4.2023	2:05:17	10
28	25.4.2023	4:05:17	10
29	25.4.2023	6:05:17	11
30	25.4.2023	8:05:17	11
31	25.4.2023	10:05:17	11
32	25.4.2023	12:05:17	12
33	25.4.2023	14:05:17	13
34	25.4.2023	16:05:17	13
35	25.4.2023	18:05:17	14
36	25.4.2023	20:05:17	15
37	26.4.2023	20:05:17	14
38	27.4.2023	20:05:17	14
39	28.4.2023	20:05:17	15
40	29.4.2023	20:05:17	18
41	30.4.2024	20:05:17	19
42	1.5.2023	20:05:17	21
43	2.5.2023	20:05:17	22
44	3.5.2023	20:05:17	22
45	4.5.2023	20:05:17	22
46	5.5.2023	20:05:17	UNDERRANGE
47	6.5.2023	20:05:17	UNDERRANGE
48	7.5.2023		

Table 15. BOD measurement Zuun Ail

Range:	0-200 mg/l		
Sample volume / ATH:	244 ml / 5 dr.		
Measurement duration:	15 days		
Measurement	Date	Time	BOD \ mg/l

0	23.4.2023	20:02:51	UNDERRANGE
1	23.4.2023	21:02:51	UNDERRANGE
2	23.4.2023	22:02:51	UNDERRANGE
3	23.4.2023	23:02:51	UNDERRANGE
4	23.4.2023	0:02:51	UNDERRANGE
5	24.4.2023	1:02:51	UNDERRANGE
6	24.4.2023	2:02:51	UNDERRANGE
7	24.4.2023	3:02:51	UNDERRANGE
8	24.4.2023	4:02:51	UNDERRANGE
9	24.4.2023	5:02:51	UNDERRANGE
10	24.4.2023	6:02:51	UNDERRANGE
11	24.4.2023	7:02:51	UNDERRANGE
12	24.4.2023	8:02:51	UNDERRANGE
13	24.4.2023	9:02:51	UNDERRANGE
14	24.4.2023	10:02:51	UNDERRANGE
15	24.4.2023	11:02:51	0
16	24.4.2023	12:02:51	0
17	24.4.2023	13:02:51	1
18	24.4.2023	14:02:51	1
19	24.4.2023	15:02:51	1
20	24.4.2023	16:02:51	2
21	24.4.2023	17:02:51	3
22	24.4.2023	18:02:51	4
23	24.4.2023	19:02:51	4
24	24.4.2023	20:02:51	5
25	24.4.2023	22:02:51	5
26	24.4.2023	0:02:51	6
27	25.4.2023	2:02:51	6
28	25.4.2023	4:02:51	6
29	25.4.2023	6:02:51	6
30	25.4.2023	8:02:51	7
31	25.4.2023	10:02:51	7
32	25.4.2023	12:02:51	7
33	25.4.2023	14:02:51	8
34	25.4.2023	16:02:51	8
35	25.4.2023	18:02:51	8
36	25.4.2023	20:02:51	8
37	26.4.2023	20:02:51	8
38	27.4.2023	20:02:51	8
39	28.4.2023	20:02:51	8
40	29.4.2023	20:02:51	8
41	30.4.2024	20:02:51	10
42	1.5.2023	20:02:51	10
43	2.5.2023	20:02:51	11
44	3.5.2023	20:02:51	13
45	4.5.2023	20:02:51	14
46	5.5.2023	20:02:51	14

47	6.5.2023	20:02:51	UNDERRANGE
48	7.5.2023		

Table 16. BOD measurement Chinggis khan Hotel

Bottle position:	3		
Range:	0-200 mg/l		
Sample volume / ATH:	244 ml / 5 dr.		
Measurement duration:	15 days		
Measurement	Date	Time	BOD \ mg\l
0	23.4.2023	20:06:20	UNDERRANGE
1	23.4.2023	21:06:20	UNDERRANGE
2	23.4.2023	22:06:20	UNDERRANGE
3	23.4.2023	23:06:20	0
4	23.4.2023	0:06:20	4
5	24.4.2023	1:06:20	6
6	24.4.2023	2:06:20	7
7	24.4.2023	3:06:20	9
8	24.4.2023	4:06:20	11
9	24.4.2023	5:06:20	12
10	24.4.2023	6:06:20	13
11	24.4.2023	7:06:20	15
12	24.4.2023	8:06:20	15
13	24.4.2023	9:06:20	16
14	24.4.2023	10:06:20	19
15	24.4.2023	11:06:20	22
16	24.4.2023	12:06:20	24
17	24.4.2023	13:06:20	27
18	24.4.2023	14:06:20	30
19	24.4.2023	15:06:20	31
20	24.4.2023	16:06:20	32
21	24.4.2023	17:06:20	34
22	24.4.2023	18:06:20	35
23	24.4.2023	19:06:20	37
24	24.4.2023	20:06:20	40
25	24.4.2023	22:06:20	40
26	24.4.2023	0:06:20	41
27	25.4.2023	2:06:20	44
28	25.4.2023	4:06:20	44
29	25.4.2023	6:06:20	45
30	25.4.2023	8:06:20	46
31	25.4.2023	10:06:20	48
32	25.4.2023	12:06:20	50
33	25.4.2023	14:06:20	50
34	25.4.2023	16:06:20	53
35	25.4.2023	18:06:20	55
36	25.4.2023	20:06:20	57
37	26.4.2023	20:06:20	58

38	27.4.2023	20:06:20	58
39	28.4.2023	20:06:20	60
40	29.4.2023	20:06:20	63
41	30.4.2024	20:06:20	67
42	1.5.2023	20:06:20	70
43	2.5.2023	20:06:20	75
44	3.5.2023	20:06:20	77
45	4.5.2023	20:06:20	80
46	5.5.2023	20:06:20	80
47	6.5.2023	20:06:20	82
48	7.5.2023		

Table 17. BOD measurement Ikh Nayad Plaza

Range:	0-200 mg/l		
Sample volume / ATH:	244 ml / 5 dr.		
Measurement duration:	15 days		
Measurement	Date	Time	BOD \ mg\l
0	23.4.2023	19:54:34	UNDERRANGE
1	23.4.2023	20:54:34	UNDERRANGE
2	23.4.2023	21:54:34	UNDERRANGE
3	23.4.2023	22:54:34	UNDERRANGE
4	23.4.2023	23:54:34	UNDERRANGE
5	24.4.2023	0:54:34	UNDERRANGE
6	24.4.2023	1:54:34	UNDERRANGE
7	24.4.2023	2:54:34	UNDERRANGE
8	24.4.2023	3:54:34	UNDERRANGE
9	24.4.2023	4:54:34	UNDERRANGE
10	24.4.2023	5:54:34	5
11	24.4.2023	6:54:34	7
12	24.4.2023	7:54:34	9
13	24.4.2023	8:54:34	10
14	24.4.2023	9:54:34	12
15	24.4.2023	10:54:34	13
16	24.4.2023	11:54:34	15
17	24.4.2023	12:54:34	16
18	24.4.2023	13:54:34	16
19	24.4.2023	14:54:34	17
20	24.4.2023	15:54:34	20
21	24.4.2023	16:54:34	21
22	24.4.2023	17:54:34	21
23	24.4.2023	18:54:34	22
24	24.4.2023	19:54:34	25
25	24.4.2023	21:54:34	26
26	24.4.2023	23:54:34	28
27	25.4.2023	1:54:34	29
28	25.4.2023	3:54:34	30
29	25.4.2023	5:54:34	33

30	25.4.2023	7:54:34	35
31	25.4.2023	9:54:34	38
32	25.4.2023	11:54:34	40
33	25.4.2023	13:54:34	44
34	25.4.2023	15:54:34	45
35	25.4.2023	17:54:34	45
36	25.4.2023	19:54:34	47
37	26.4.2023	19:54:34	51
38	27.4.2023	19:54:34	55
39	28.4.2023	19:54:34	57
40	29.4.2023	19:54:34	65
41	30.4.2024	19:54:34	68
42	1.5.2023	19:54:34	72
43	2.5.2023	19:54:34	75
44	3.5.2023	19:54:34	75
45	4.5.2023	19:54:34	76
46	5.5.2023	19:54:34	76
47	6.5.2023	19:54:34	76
48	7.5.2023		

Table 18. BOD measurement Altai Town

Bottle position:	2		
Range:	0-200 mg/l		
Sample volume / ATH:	244 ml / 5 dr.		
Measurement duration:	15 days		
Measurement	Date	Time	BOD \ mg/l
0	23.4.2023	19:51:20	UNDERRANGE
1	23.4.2023	20:51:20	UNDERRANGE
2	23.4.2023	21:51:20	UNDERRANGE
3	23.4.2023	22:51:20	UNDERRANGE
4	23.4.2023	23:51:20	UNDERRANGE
5	24.4.2023	0:51:20	UNDERRANGE
6	24.4.2023	1:51:20	UNDERRANGE
7	24.4.2023	2:51:20	UNDERRANGE
8	24.4.2023	3:51:20	0
9	24.4.2023	4:51:20	9
10	24.4.2023	5:51:20	9
11	24.4.2023	6:51:20	10
12	24.4.2023	7:51:20	11
13	24.4.2023	8:51:20	12
14	24.4.2023	9:51:20	13
15	24.4.2023	10:51:20	14
16	24.4.2023	11:51:20	15
17	24.4.2023	12:51:20	16
18	24.4.2023	13:51:20	18
19	24.4.2023	14:51:20	19

20	24.4.2023	15:51:20	20
21	24.4.2023	16:51:20	20
22	24.4.2023	17:51:20	21
23	24.4.2023	18:51:20	22
24	24.4.2023	19:51:20	22
25	24.4.2023	21:51:20	22
26	24.4.2023	23:51:20	23
27	25.4.2023	1:51:20	23
28	25.4.2023	3:51:20	24
29	25.4.2023	5:51:20	24
30	25.4.2023	7:51:20	25
31	25.4.2023	9:51:20	28
32	25.4.2023	11:51:20	30
33	25.4.2023	13:51:20	31
34	25.4.2023	15:51:20	32
35	25.4.2023	17:51:20	33
36	25.4.2023	19:51:20	37
37	26.4.2023	19:51:20	39
38	27.4.2023	19:51:20	39
39	28.4.2023	19:51:20	42
40	29.4.2023	19:51:20	45
41	30.4.2024	19:51:20	47
42	1.5.2023	19:51:20	52
43	2.5.2023	19:51:20	57
44	3.5.2023	19:51:20	61
45	4.5.2023	19:51:20	64
46	5.5.2023	19:51:20	66
47	6.5.2023	19:51:20	66
48	7.5.2023		

### ANNEX 3. Detailed Calculations

Table 19. detailed data of Field measurement

No.	Sample location	Flow velocity [m/s]	Depth [m]	Width [m]	Dissolved Oxygen [mg/L]	pH	Temperature
1	Altai town	-	0.35	5.2	8.48	6.5	3.7
2	Ikh Nayad Plaza	0.054	0.1	6.8	9.64	7.2	-0.1
		0.201	0.2				
		0.29	0.27				
		0.268	0.25				
		0.26	0.28				
		0.07	0.17				
3	Chinggis hotel	0.054	0.9		10.1	8	0.9

		0.182	1				
4	100 Ail	0.026	0.15	27.7	11.48	7.8	1.7
		0.117	0.21				
		0.292	0.31				
		0.705	0.35				
		0.153	0.29				
		0.025	0.12				
5	Dambadarjaa	0.058	0.1	8.2	9.35	8	0.9
		0.113	0.07				
		0.052	0.05				
		0.031	0.03				
		0.176	0.15				
		0.153	0.25				
		0.12	0.15				

Table 20. Calculation of Reaeration rate

No.	Location	U	H	S	Owens et al. (1964)	Jha et al. (2001)	Grant (1976)	Thyseen et al. (1987)	Smoot (1988)
1	Dambadarjaa	0.1	0.26	0.0076	13.747	2.565	23.121	30.490	25.547
2	Zuun Ail	0.22	0.35	0.008	13.453	3.532	26.678	50.365	34.598
3	Chinggis Khan Hotel	0.12	1	0.0075	1.285	2.006	10.176	19.555	10.692
4	Ikh Nayad Plaza	0.18	0.28	0.0024	17.771	3.378	17.525	15.580	18.906
	Mean	0.155	0.4725	0.006375	11.564	2.870	19.375	28.997	22.436