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Master Program Hydro Science and Engineering

Integrated Water Resource Management-2

Report on

Application of WEAP mathematical model for water treatment in the context of Climate change and Urbanization

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Abstract

Integrated water resource IWRM is a process that promotes the coordinated development and management of water, land, and related resources to maximize the resulting economic and social welfare in an equitable manner while protecting vital ecosystems. There are several software tools available to help with the IWRM process. WEAP is one such tool, offering a comprehensive, adaptable, and user-friendly framework for policy analysis. WEAP can assist in simulating real-time scenarios and assisting decision-makers in making critical decisions with minimal physical consequences.

We are attempting to address water quality issues in the West Bug River catchment in Ukraine with this report. The Bug River, which is shared by Belarus and Poland, is one of the most polluted rivers in Ukraine. For this study, we will concentrate on the Poltva River Basin, which passes through the cities of Lviv and Busk. The main cause of river water pollution is the area's outdated wastewater treatment facilities.

We used data for various parameters from 2000 to 2010 to create a base model, and a future model for the period 2041-2050 is created to highlight the effects of urbanization taking climate, land use, and population changes into account.

The study's main focus is on the input and output pollutant loads of existing wastewater treatment plants, as well as the plants' current efficiencies. It discussed how to improve the existing WWTPs by comparing the forecasted water quality with the current scenario and recommendations were made based on the EU Water Framework Directive.

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Keywords

Cfb: Temperate oceanic climate

ECMWF: European Centre for Medium-Range Weather Forecasts

RCP: Representative Concentration Pathway

WCRP-CORDEX: Coordinated Regional Climate Downscaling Experiment

ESGF: Earth System Grid Federation

EUR-44: European-44

KNMI: Royal Netherlands Meteorological Institute

RACMO22E: Regional Atmospheric Climate Model version 2.2

NetCDF: Network Common Data Form

PET: Potential Evapotranspiration

WFD: Water Framework Directive

WWTP: Waste Water Treatment Plant

UWWTD: Urban Waste Water Treatment Directive

BOD: Biological Oxygen Demand

N: Nitrogen

p.e: Population equivalent

LC: Land Cover

LU: Land Use

1. Introduction

With global concerns pouring down over the increasing environmental issues relating to the natural water resources threatening humans and the ecosystem, extensive research characterizes anthropogenic activity itself as the foremost source (Odnorih et.al.,2020). Moreover, the future of our rapid development strategies innately holds the climate change influences which calls for relevant scenarios to better encompass the possible augmentation of water issues in the upcoming decades. (Kozhakhmetova et al.,2019)

The Western Bug River falls in the top 5 most polluted rivers of Ukraine being polluted by the urban and rural discharges along the vicinity of its 60 km stretch over Ukraine, Poland and Belarus. Poltva river originates from Lviv in Ukraine and is the tributary contributing the most to Bug River pollution. It collects sewage throughout 7 km alongside Lviv city, the quality of which is not up to mark, the wastewater treatment plants operating at half the capacity due to declining technology (Lviv City Council, 2020). Research suggested the outdated treatment technology to be the principal point source of the pollution, which is overloaded to serve a population of about 750,000 residing in the upstream reaches from the Poltva catchment (Ertel et al., 2012). Apart from the municipal and industrial wastewater discharged partially treated through the wastewater treatment plants, pollutants are ejected into the river system as surface runoffs from agricultural lands, built-up urban fabric and mining activities. (Blumensaat et al., 2013; Ertel et al., 2012; Hagemann et al., 2014; Tavares Wahren et al.,2012). Although population projections don't show significant changes, the change of arable land fabric to urban built-up surfaces show significant changes (Burmeister & Schanze, 2018), which is expected to alter the water balance parameters and rainfall-runoff characteristics of the catchment and in turn the pollutant loadings. The presence of the pollutants in rivers are shown by direct indicators of water quality like the elevated levels of BOD5, nitrites, phosphates and heavy metals. This also suggests that not all of the municipal wastewater connections go to the sewerage systems rather to individual septic tanks and sinkholes contributing to the pollution of aquifers in addition to the surface waters (Odnorih et.al.,2020) and the high nitrite/ phosphate concentrations indicating presence of diffuse runoff sources from agricultural and built-up lands (Gopchak et.al.,2020). Furthermore, the potential effects of climate change are projected as increased air, water temperatures and rainfall which could affect the mobility and dilution of contaminants and in turn affecting chemical kinetics, stream power, sediment transfer of rivers and ultimately the freshwater habitats (Whitehead et al.,2009). Further projections are done on the impact on water quality brought about by the increase in floods and droughts, rise in water temperature and pollution (Bates et.al.,2008).

The Poltva river basin of the Western Bug River shares territory of three nations – Poland (49.2% of the area), Ukraine (27.4%) and Belarus (23.4%). It flows 404 km over Ukrainian territory, 363 km of which is over the borders of the Republic of Poland, Ukraine itself and the Republic of Belarus, making it a transboundary watercourse (Odnorih et.al.,2020). Also, the Bug flows into the Zegrze Reservoir, serving as a source of water supply to Warsaw city, the water quality of the headwater at Poltva should be maintained within allowable standard (Khilchevskyi et al. 2016a; 2016b; Yatsyk et al. 2017a), and after flowing into the borders of Poland, the quality of the river water is subjected to EU Water Framework Directive (Hagemann, 2012) so meeting the water quality standard is not just a national requirement but a matter of transboundary relations.

Hence, this study is aimed at following the appropriate implementation approach of Integrated Water Resource Management (IWRM) to the study area to address the anthropological, hydrological, and climatological characteristics of the study basin focusing on parameters such as Water Temperature, Evapotranspiration, Precipitation, BOD, N, streamflow and the economic paradigm with a view on Climate change impacts.

2. Motivation and Objective

This study covers a large domain of water resource problems related to anthropogenic effects on surface and groundwater qualities, understanding the hydrological and meteorological coupling, potential impacts of climate change and socio-economic conditions with concerns of transboundary stakeholders to abide by the European Water Framework Directive (WFD; 2000/60/E.C.). The sustainability of our integrated impact assessment and comprehensive adaptation strategy depends on how well we address the understanding of the hydrological cycle and the relative impact of changing conditions of climate and catchment properties on its sensitivity. Not just the natural characteristics of the basin but the alterations in land use and pollutant loading onto the water resources change the overall system understanding. Recent research on different catchment areas due to precipitation and other related parameters has shown the dependency of climatic data impacts on the surface and subsurface hydrological and hydrogeological resources. (Pham, et al., 2017). Thus, the relevancy of modelling, monitoring and integrated management approaches in the interconnected surface and groundwater system functioning cannot be underestimated (Odnorih et.al.,2020).

Basically, the modelling approach is focused on establishing a proper runoff coefficient to simulate closely the system as well as the associated streamflow, groundwater, and water quality parameters. Since runoff and infiltrations are complex processes and cannot be analysed just by a simple rainfall-runoff coefficient, we use the WEAP model to encompass all the uncertainties associated with hydrology, catchment, demographic, socio-economic and climate change.

Following research questions are agitated in regards to the concerns of river water quality:

• The way in which the Poltva river water quality will be affected due to change in climate, population and land cover

• Measures that can be taken to improve the water quality

Steps carried out in the research using WEAP platform to address the above questions:

• Use of WEAP software to set up simplified hydrologic and water quality model for the base scenario (2000-2010)

• Predict the water quality parameters (BOD & N) using the validated model for the years 2041-2050 considering change in climate, population and landcover

• Propose and adopt suitable water treatment technology in WEAP modelling to abide by the water quality standards as per EU Water Framework Directive.

3. Materials & Method

3.1 Study Area

Our study area is the Northwestern Region of Ukraine i.e., Poltva River Basin (PRB) having Lviv city at its upstream side and Busk village at the downstream. Poltva River is a tributary of Western Bug (Western Bug is a major river mostly located in Eastern Europe that flows through Belarus, Poland, and Ukraine) (Khilchevskyi et al., 2018) and particularly our study lies along 60 km long reach of Poltva river and two Ukranian towns Lviv and Busk.

Figure 1 Poltva River Basin (Source: (Odnorih et al., 2020))

Lviv covers an area of 149 sq km with 717510 residents, whereas Busk covers a relatively smaller area of 9 sq. km (Lviv (Ukraine): Districts, Cities and Urban Settlements - Population Statistics, Charts and Map, 2022). The average altitude of Lviv is 296 m above sea level and for Busk is 218m. According to the Köppen-Geiger climate classification, Poltva catchment has warm and temperate climate and receives substantial rainfall throughout the year of about 705 mm in an average.

The land cover of the area is characterized by a high proportion of arable land with intense agriculture, forests at wetlands, and steep slopes and unevenly distributed urban areas, the most of which are in Lviv (Helm, et al.,2013). The topography of the study region varies from flat to hilly. The Poltva River (the left tributary of the Western Bug) is the most polluted river in this basin as it acts as a wastewater collector in Lviv (Odnorih, et al., 2020).

The situation in Ukraine remains tense, with the ongoing conflict in the eastern region of the country Despite several ceasefires, sporadic violence continues and a peaceful resolution to the conflict has yet to be achieved.

Ukraine faces several challenges in terms of water quality, particularly access to safe drinking water. Waterborne diseases and high levels of pollution in some areas have been exacerbated by the nation's poor water infrastructure and lack of investment in the sector. Furthermore, industrial activity and runoffs have contaminated water sources, putting public health and the environment at risk. The government is taking steps to address these issues, but much more work is needed to improve water quality in the country and ensure that all residents have access to safe drinking water. (Water security of Ukraine: war time and climate change, 2022), Since these scenarios are rare, the war situation in Ukraine is not considered in the scope of this report.

3.2 Data for Model Setup

After the schematic maps and drawings, to set up the model in WEAP, different types of data are required apart. Those data which were required in our model are listed below:

1. Hydrological: Variables like Precipitation, River Flow and Flow Stage width come under hydrological data where runoff coefficient is a constant parameter.

2. Climate: Under climate data, evapotranspiration and air temperature is taken.

3. Water Quality: Biological Oxygen Demand (BOD), Nitrogen and Water Temperature are the required data for water quality setup in the model.

4. Land Use: Catchment area is analyzed for land use data being crop coefficient as a constant.

5. Water Use: Population of an area and annual water use rate are used for overall water use data.

6. Ground Water: Several inputs are done regarding ground water data like Storage Capacity, Wetted Depth, Initial Storage, Storage at Water Level, Horizontal Distance and Transmission Losses. Meanwhile, Specific Yield and Hydraulic Conductivity are constant parameters.

The details of the data are listed here in tabular form:

Sr No	Type of Data	Variable	Parameter
1	Hydrological	Precipitation	Runoff Co-efficient
		River Flow	
		Flow Stage Width	
2	Climate	Evapotranspiration	
3	Water Quality	BOD	
		Nitrogen	
		Water Temperature	
4	Land Use	Catchment Area	Crop Co-efficient
5	Water Use	Population of Area	
		Annual Water Use Rate	
6	Ground Water	Storage Capacity	Specific Yield
		Wetted Depth	Hydraulic Conductivity
		Storage Capacity	
		Initial Storage	
		Storage at Water Level	
		Horizontal Distance	
		Transmission losses	

Table 1 Data type for model setup

The data values initially implemented into the model can be referred in Appendix 1: Input data

3.3 Model setup in WEAP

WEAP ("Water Evaluation and Planning" system): It is a user-friendly software program that uses an integrated strategy for planning water resources. The integrated approach of WEAP software, which provides a revolutionary way for conducting evaluations of integrated water resources planning, is one of its primary selling points. To drive a link-node architecture mass balancing model, water supply and demand data are kept in a database. Additionally, the software determines numerous parameters such as water demand, water quality, and various hydrologic conditions. Additionally, WEAP has a user-friendly interface that offers customizable model output as maps, tables, and other formats.

In order to setup a model in WEAP the catchment regions, their hydrological processes, water supply and demand, return flows, groundwater processes, climate, land use, wastewater treatment plants, and their connectivity and spatial linkages must be identified under WEAP Areas.

For the hydrological model, a simplified runoff-coefficient technique was used. The modeling of GW-SW flows also used head differences. For the surface water quality modeling, a BOD decay technique (explained in section Water Quality Parameters) is used. To address BOD and N treatment and reduction by WWTPs, a removal efficiency was implemented. The physical components of the water supply and demand system are laid out and shown using a simple "drag and drop" graphical interface, which is a key component of the WEAP program.

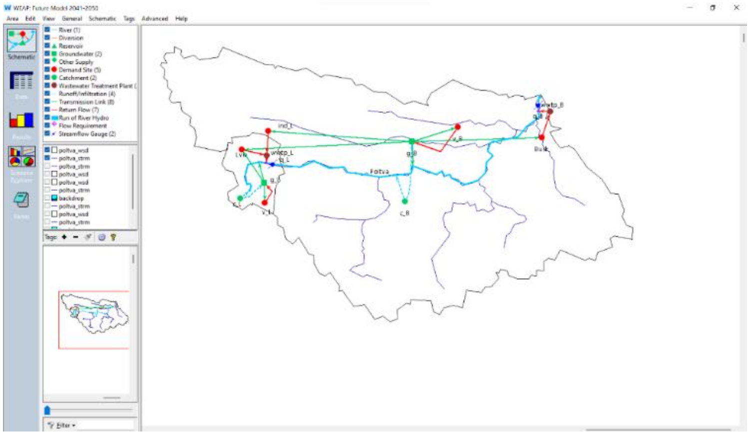

Figure 2 WEAP Model

3.4 Model Framework

The development of this report is divided into three critical phases, each of the phase has specific goals to obtained, the following is explained below:

Phase 1

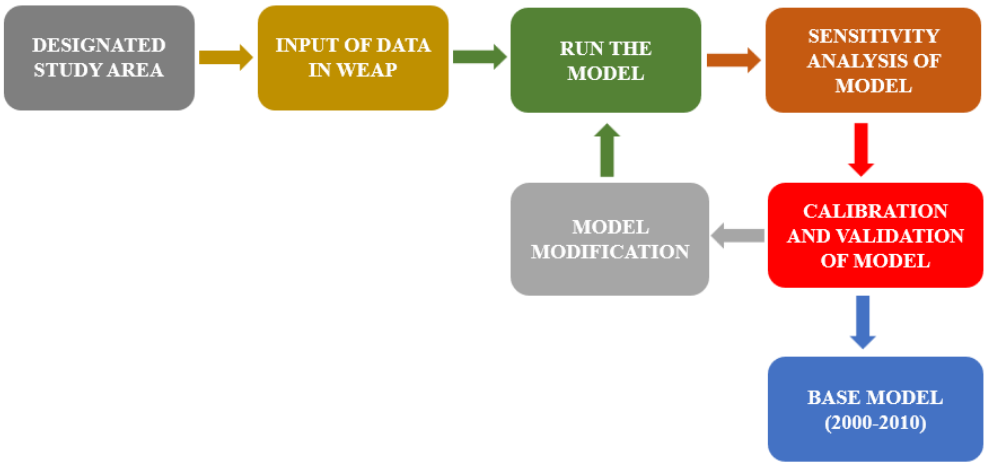

Figure 3 Model Development Phase 1 Flowchart

Figure 3 illustrates the Phase one of the model development, The main objective was to obtain a calibrated model that represent the real conditions in the region as accurately as possible, this was done using the calibration process as explained in section 3.5 Model Sensitivity and Calibration.

Phase 2

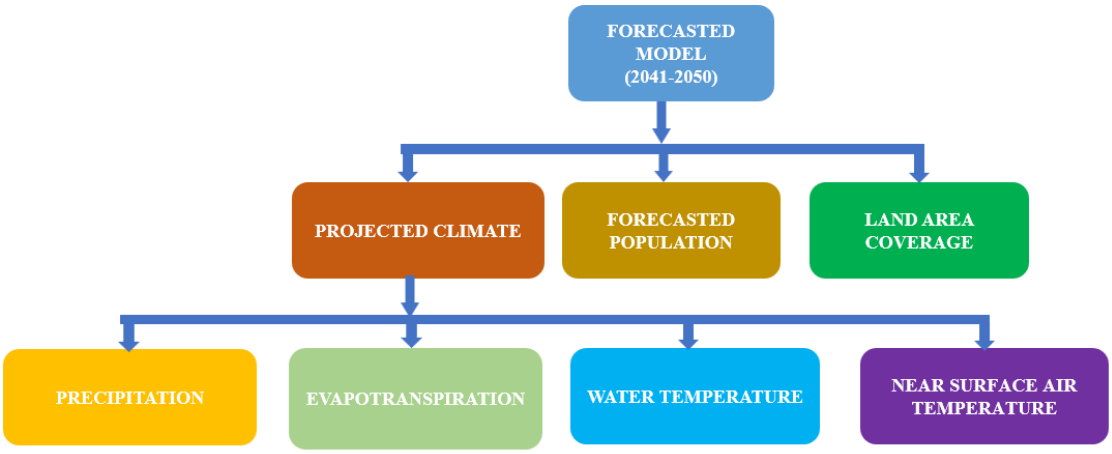

Figure 4 Model Development Phase 2 Flowchart

Figure 4 illustrates the Phase one of the model development, In this phase major data components required for the future model were obtained through analysis of historic data and by using various projection methods, the main objective was building a reliable model to display the future scenario.

Phase 3

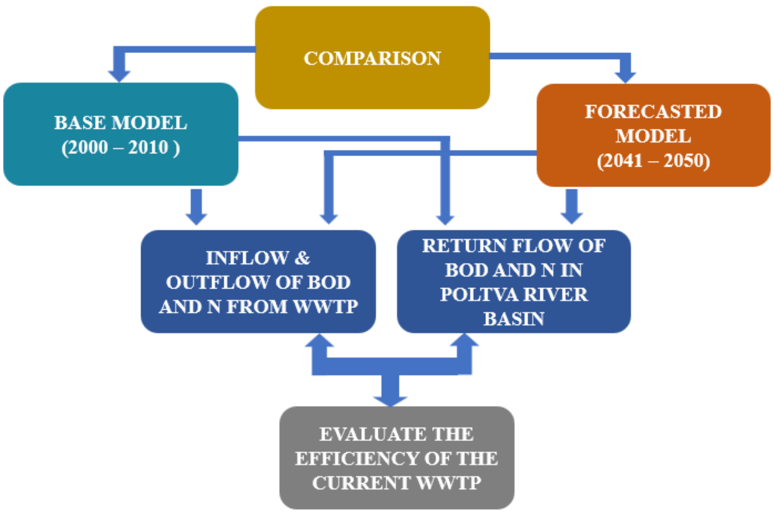

Figure 5 Model Development Phase 3 Flowchart

Figure 5, illustrates the Phase there of the model development in this phase a through comparison between the base model and future model was conducted based on various water quality constituents, to evaluate the effects of climate change and urbanization on river water quality.

3.5 Model Sensitivity and Calibration

The setup and development of the model was followed by a sensitivity analysis, calibration, and validation. To build a model that can reliably represent the real environment, a calibration procedure is required (Eryani, 2022). Because many of the parameters in hydrological models are totally hypothetical and challenging to measure in the field, the majority of them need some sort of calibration.

Even field-measurable variables might not always exist or be at the required spatial resolution (Kumarasamy & Belmont, 2018). Even the calibration cannot always resolve more fundamental problems relating to the model's structure, the availability of data, the beginning and boundary condition. It is necessary to boost dependability for the majority of hydrological model applications.

A hydrologic model can be calibrated by estimating model parameter values. Changing the parameters that indicate the greatest sensitivity is a frequent method, whether automated or manual calibration is used (Hill, 1998). Sensitivity analysis is a clever method because it allows for calibration improvements with the fewest number of modifications. After modifying individual parameters within acceptable limits, the mean absolute error (RMAE) and R^2 techniques were used to identify sensitive parameters. The parameter sensitivity study took into account the following parameters within the specified range are shown in Table 2. Finally, in order to construct the best simulation of hydrological processes, the parameter values must meet certain requirement: a) best R^2 and b) the lowest RMAE (Root of the Mean Absolute Error).

Instance	**Variable/Parameter**	**Range(Unit)**
Settlement	Annual activity level	40-120[m^3/cap*a]
	Consumption	0-30[%]
Watershed	Precipitation[1]	0.7-1.3
	ETref[2]	0.7-1.3
	Kcf[3]	0.5-1.5
	Effective Precipitation	0.5-1
Groundwater	Storage Capacity	Catchment area * 5-15m[10^6 m^3]
	Initial Storage	0-Storage Capacity[10^6 m^3]
	Hydraulic Conductivity	1-20[m/d]
	Specific Yield	0.2-0.5
	Horizontal Distance[4]	1000-10000[m]
	Wetted Depth	1-10[m]
	Storage at River Level	0-Storage Capacity[10^6 m^3]
Runoff and Infiltration	Runoff fraction to GW	10-90[90%]

Table 2 Parameters for Sensitivity Analysis and Calibration

Parameters for Sensitivity Analysis and Calibration

Before estimating the parameters, it is required to assess the sensitivity of the parameters in order to eliminate the least significant parameters and lower the parameter size. A crucial component of developing a hydrological model is sensitivity analysis and calibration (Eryani, 2022) This method is always essential if the simulation's results are to be considered.

To ensure uniformity, recorded observations were subdivided as 2000-2004 for calibration and 2005-2010 for validation.

In order to get satisfactory results, we employed a hierarchical approach to parameter adjustment, starting with the upstream gauge (Lviv) and moving downstream to the downstream gauge (Busk). We then followed high temporal aggregation to low temporal resolution. The characteristics on which we concentrated when calibrating the base model are listed in Table 3.

FLOW : Q	BOD	N
Activity Level	BOD Intensity in demand sites	N Intensity in demand sites
Consumption		
Effective Precipitation		
Precipitation	Removal Efficiency of WWTP	Removal Efficiency of WWTP
E_{tref}		
K_c	Pollutant decreases from agriculture to river removal efficiency	Pollutant decreases from agriculture to river removal efficiency
Specific Yield		
Wetted Depth		
Hydraulic Conductivity		Decay Rate

Table 3 Calibrated parameters.

The Values changed during the calibration process, and the total calibration score details can be found in **Error! Reference source not found.**

3.6 Population Forecasting

The design population is estimated considering all factors governing the future growth and development of the project area in the industrial, commercial, educational, social and administrative spheres. The design of water supply scheme is based on the projected population of a particular city or town and also estimate the design period of the components of all structures of water supply and sanitation are depends on projection of population. Changes in the population of the city over the years occur, and the system should be designed considering the population at the end of the design period (Mekonen, 2018).

The census population data of Busk and Lviv for the years 1989, 2001, 2014 and 2021 are collected and tabulated as below (Lviv (Ukraine): Districts, Cities and Urban Settlements - Population Statistics, Charts and Map, 2022):

Census Population		
Year	**Busk**	**Lviv**
1989	8404	790908
2001	8673	732818
2014	8484	729038
2021	8695	721510

*Table 4 Census Population Source (*Lviv (Ukraine): Districts, Cities and Urban Settlements - Population Statistics, Charts and Map*, 2022.)*

The forecasting methods adopted were Linforecast and GrowthFrom functions in expression builder built inside of WEAP. GrowthFrom function was used to forecast village population and LinForecast was used for the cities. By entering the census population data for previous years shown in Table 4 the city population trend for the years 2041-2050 were predicted.

In the case of the population of rural areas, a general downward trend was observed throughout Ukraine (Ukraine Rural Population 1960-2023, 2022). Using the Growthfrom function and the initial data from the Input Overview Appendix 1: Input data that were used for calibration, this annual trend of -0.91% was applied to the catchment's village areas. The Syntaxes used for all the population forecasting can be viewed in Appendix 2 : Data Forecasting.

3.7 Water Quality Parameters

Studies on water quality criteria indicate a high level of organic and microbial contamination in the Western Bug headwater, particularly after the inflow of the Poltva River and the downstream Bug River. This is primarily due to Lviv's outdated and inundated wastewater treatment plants (WWTP), which also results to a high biochemical oxygen demand (BOD) and a massive reduction in oxygen levels. High levels of nitrate in the Bug River headwaters indicate diffuse inputs from agricultural land use, for example ((Berendonk & Ertel, 2012). For this reason, the major quality parameters analyzed in this model are BOD and N.

Biochemical Oxygen Demand (BOD)

The biological oxygen demand, or BOD, is the quantity of dissolved oxygen required by aerobic biological organisms to decompose organic material present in a given water sample at a particular temperature over a certain time period. As a proxy for the level of organic contamination of water, the BOD value is frequently stated in milligrams of oxygen used per liter of sample after 5 days of incubation at 20 °C (Water Quality Monitoring in Aquaculture ScienceDirect, 2016). The efficiency of wastewater treatment facilities can be evaluated using BOD. In the U.S. Clean Water Act, it is classified as a conventional pollutant.

In that both BOD and COD determine the concentration of organic substances in water, they serve similar purposes. Although COD measures more than just amounts of biodegradable organic matter, it is less precise because it also measures anything else that can be chemically oxidized (Biochemical Oxygen Demand, Retrieved February 5, 2023). Typically, BOD removal is calculated in WEAP using Equation 1 (Jack Sieber, 2015)

$$BOD = BOD_{IN}\left(\exp^{-\mathrm{kBOD}(L/U)}\right)$$

Equation 1

Where L is the concentration of the pollutant at some distance downstream and U is the stream velocity, k_{BOD} is calculated in WEAP using the Equation 2

$$k_{BOD} = k_{d20}^{(1.047(T-20))} + \frac{v_s}{H}$$

Equation 2

where T is the water temperature (in degrees Celsius), H is the depth of the water, and v_s is the settling velocity and k_{d20} is calculated using Equation 3 .

$$\begin{aligned} k_{d20} &= 0.3\left(\frac{H}{8}\right)^{-0.434} \qquad 0 \le H \le 2.4m \\ k_{d20} &= 0.3 \qquad\qquad\qquad H > 2.4m \end{aligned}$$

Equation 3

Nitrogen:

Nitrogen or N is a colorless, odorless element. The ground beneath our feet contains nitrogen, as does the water we drink and the air we breathe. In fact, it is the element that is most plentiful in the atmosphere of Earth. It is an elemental nutrient that naturally occurs in aquatic habitats. Fish, shellfish, and other tiny aquatic species depend on algae and aquatic plants for food and habitat, which are supported by nitrogen. Algae, however, grows more quickly than ecosystems can handle when there is too much nitrogen in the water. Significant increases in algae degrade water quality, habitats, and food supplies while reducing the oxygen required for fish and other aquatic species to thrive.

Even at modest levels, nutrient pollution in ground water—the source of drinking water for millions can be dangerous. Nitrates, a chemical based on nitrogen that is present in drinking water, are dangerous for infants. Pollutants like ammonia and ozone, which can reduce sight, harm breathing, and disrupt plant growth, can be created when there is too much nitrogen in the air. It can be harmful to the health of forests, soils, and streams when too much nitrogen returns to earth from the sky (The Issue, 2022), Nitrogen is typically calculated in wastewater using Equation 4.

$$N(t) = N(t_0) \cdot e^{-k_N(t-t_0)} = N(t_0) \cdot e^{-k_N\left(l/\left(\frac{Q}{A}\right)\right)}$$

Equation 4

Equation 4 is an exponential decay equation for the number of particles or population size N at time t, given an initial population size $N(t_0)$ at time t_0, Where k_N is the decay constant, l represents the mean free path of the particles, Q represents the volumetric flow rate, and A represents the cross-sectional area of the pipe or container through which the particles are flowing.

3.8 Land Use Data

Changes in both land-cover (LC) and land-use (LU) play an important role in the development of human-environmental systems in general and in the water balance and matter fluxes in river and lake catchments in particular (Burmeister & Schanze, 2018).

The land-use cover of Ukraine's Bug River catchment is likely to change in the coming years. These changes could be caused by a variety of factors, such as population growth, urbanization, industrialization, and changes in agricultural practices (Burmeister & Schanze, 2018).

As more people move to cities and urban areas expand, urbanization is likely to have a significant impact on the catchment's land-use cover. This could result in the conversion of natural or agricultural lands into urban areas, resulting in wildlife habitat loss, increased impervious surfaces, and changes in water quality (Nuissl & Siedentop, 2021).

Agricultural practices may also change in the future, potentially leading to changes in crop types and management methods. This could influence the land-use cover, such as the conversion of forests to croplands or the intensification of existing agricultural lands (Zabel et al., 2019).

Another important factor to consider when projecting future land-use change in the catchment is water management. Changes in water management practices, such as dam construction or water allocation, could have an impact on the hydrology and vegetation patterns of the catchment.

To develop cross-sectoral projections of future land-use cover change in the Bug River catchment, it would be necessary to analyze historical data on land-use cover change, consider current trends and drivers of change, and use models or scenarios to simulate future changes. This information could be used to make informed decisions about how to manage the catchment and its resources in the future (Burmeister, 2022)

To forecast these changes, a thorough examination of historical data and trends, as well as the use of models or scenarios, are required. The Scenarios created based on the dynamic drivers are shown in **Error! Reference source not found.**

We considered Storyline A for this study since it has the highest LC change on the Artificial surfaces. considering a growth potential in the GDP and a total population decrease, this scenario is more market and industry oriented for that reason a detailed analysis on changes in land use is conducted based on its characteristics. Given that we're focusing on urbanization and its effect on water quality, we chose to pursue the storyline A.

	Storyline A	Storyline B	Storyline C	Storyline D
'rinciple characteristics	Market oriented, individualised, globalised	Market oriented, individualised, regionalised	Sustainable, solidarity, globalised	Sustainable, solidarity, regionalised
:conomy				
iDP (%/years)	Strong	Strong	Moderate	Weak
Expert 1				
Expert 2	6 to 10%	6 to 10%	3 to 6%	0 to 3%
Expert 3	9 to 12%	9 to 12%	6 to 9%	1%
Average	9.25%	7.5%*	6%	1.25%
Society/demography				
'opulation development [%/years]	Decrease	Decrease	Stagnant	Stagnant to weak increase
Expert 1	− 1.1 to − 0.5%	− 1.1 to − 0.5%	0%	0 to 0.2%
Expert 2	− 0.2 to − 0.5%	− 0.2 to − 0.5%	− 0.2 to 0%	0%
Expert 3	− 0.5%	− 0.5%	0%	0.2%
Average	− 0.55%	− 0.55%	− 0.1%	+0.1%

Table 5 Drivers under the scenarios A to D (Burmeister & Schanze, 2018)

				1989–2000				2000–2010			
LC	1989 (%)	2000 (%)	2010 (%)	Persistence (%)	Gross gain (%)	Gross loss (%)	Swap (%)	Persistence (%)	Gross gain (%)	Gross loss (%)	Swap (%)
AS	10.7	11.3	13.3	9.2	2.1	1.5	3.0	10.7	2.5	0.6	1.2
AL	47.2	47.2	44.3	39.0	8.2	8.2	16.4	36.0	8.3	11.2	16.6
BLF	15.0	17.0	13.9	13.7	3.4	1.4	2.7	12.5	1.4	4.5	2.7
CF	5.1	4.3	4.8	3.2	1.1	1.9	2.1	3.1	1.7	1.2	2.3
GL	20.6	19.9	23.5	11.5	8.4	9.1	16.8	11.3	12.1	8.6	17.1
WB	0.1	0.3	0.3	0.1	0.2	0.0	0.1	0.2	0.1	0.1	0.2

AS artificial surface, *AL* arable land, *BLF* broad-leaved forest, *CF* coniferous forest, *GL* grassland, *PB* peat bogs, *WB* water bodies

Table 6 Historical Data on LCC (Burmeister & Schanze, 2018)

Thus, it can be deduced from Table 6. that for Agricultural areas, there is no change in Land Use from 1989 to 2000 and a slight decrease to 2010, and further reading (Burmeister, 2022) predicts that Land use for Agricultural surfaces will decrease by 2.9% per year from 2010 to 2050. A similar analysis procedure was used for the other land cover types, and the future Land Use change predicted by Storyline A in (Burmeister & Schanze, 2018) is shown in the table below the Land use change from the year 2010 to 2025 is shown in Table 7.

Land Use Type	Change in Area (in %)
Arable Land	-2.9
Coniferous Forest	-1
Grass Land	-0.3
Artificial Surface	3.9

Table 7 Land Use Growth percentages (Burmeister & Schanze, 2018)

Since the occurrence of Broad Leaf Forest is rare in Lviv and Busk (V. Kubijovyč, B. Luchakovsky, n.d.), the broad leaf forest data is not used in the calculation for the category 'Other Land Type Data'.

All these trends are considered and entered into the WEAP model. Using the Linear Forecasting function, future data is forecasted and used for modeling the base areas the expressions used for different Land areas can be found in (Land Use Forecasting Functions) in Appendix.

3.9 Industrial Water Use Rate

The annual water use by industries will have a significant impact on the pollutant intensity in the nearby water body as well as the WWTP. Hence industrial annual water consumption rate must be forecasted.

To ascertain the growth rate of Industrial areas (here considered within the artificial surface) the relationship between GDP as an economic driver and population as a demographic driver are considered. From the years 2010- 2025, experts quantify an increase in the artificial surfaces by 3.92% (Burmeister & Schanze, 2018)

Hence for a period of 10 years the growth rate is 0.26% per year. This Growth rate was adopted to forecast the industrial annual water use rate using the expression builder in WEAP using the Growthfrom function.

3.10 Climate Data

The climate in the Poltva river basin is mild, warm, and temperate. Rainfall is considerable, with precipitation occurring even during the driest month. Köppen and Geiger classify this site as Cfb (Temperate oceanic climate). The average temperature is 9.0 degrees Celsius | 48.3 degrees Fahrenheit. The annual rainfall here is around 832 mm | 32.8 inch.

The Poltva river basin is in the northern hemisphere. Summer lasts from September until the end of June. January has the lowest precipitation, with an average of 48 mm | 1.9 inch. Precipitation peaks in July, with an average of 114 mm | 4.5 inch.

Climate change is anticipated to cause greater flooding and droughts, changes in water quality, decreased agricultural output, and consequences on the energy sector in Ukraine's Poltva River Basin.

Figure 6, represents the average weather characteristics of the Poltva basin throughout the span of the year.

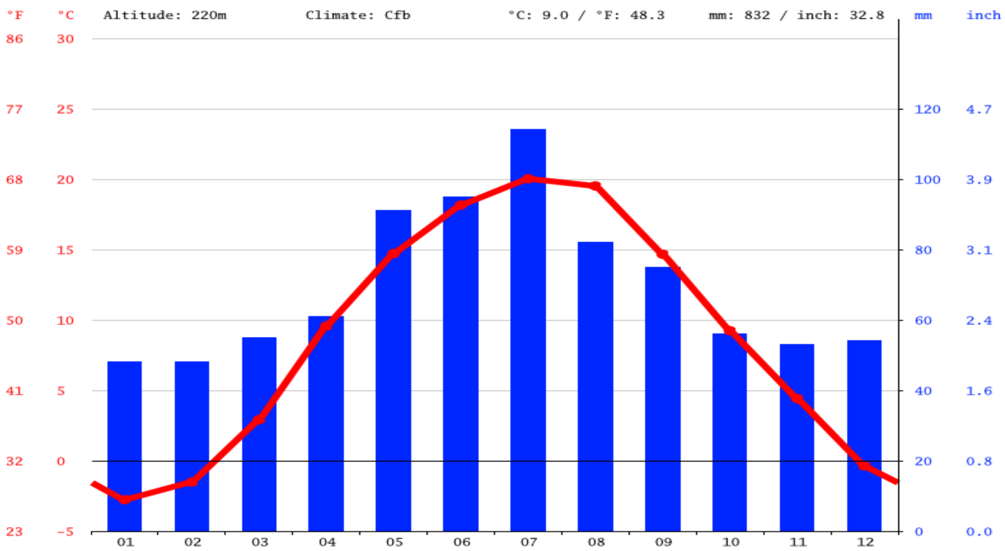

Figure 6 The average precipitation and temperature of the Poltva river basin. Source: Climate data org, 2021; ECMWF Data, 2021)

Data acquisition:

In order to improve the water quality, we need to comprehend the effects of climate change in our futuristic model. Therefore, the RCP 8.5 (Representative Concentration Pathway) scenario is considered where it portrays a future in which no major efforts are made to reduce greenhouse gas emissions in comparison to the scenario literature (Riahi et al. 2011; Fisher et al. 2007; IPCC 2008), and hence to the top bound of the RCPs. RCP8.5 is a 'baseline' scenario in which no specific climate mitigation objective is included. In this scenario, greenhouse gas emissions and concentrations rise dramatically over time, resulting in a radiative forcing of 8.5 W/m^2 by the end of the century (Riahi et al. 2011). Hence, RCP 8.5 is used as a worst-case scenario to assist policymakers and decision-makers in understanding the possible repercussions of failing to address climate change.

Precipitation:

The projected precipitation data was obtained from the WCRP-CORDEX (Coordinated Regional Climate Downscaling Experiment) webpage by the ESGF (Earth System Grid Federation). The model domain utilized was EUR-44 (European) from KNMI (Royal Netherlands Meteorological Institute), with ICHEC-EC-EARTH as the driving model. The RCP 8.5 scenario was adopted, along with the realization of r1i1p1. The RCM (Regional Climate Model) operated was RACMO22E (Regional Atmospheric Climate Model version 2.2) with v1 downscaling. The variable long name precipitation was used with a monthly time frequency. The precipitation data was retrieved using the aforementioned selection criteria.

Representation of Projected Climate data:

The extracted data are then uploaded into the Panoply software. It enables users to explore, display, and analyse massive and complex datasets with ease. The grid ranging is determined based on our region of interest. The spatial distribution of precipitation was carried out by taking into account that Lviv and Busk are situated on the same grid, i.e., Lviv and Busk are located on the grid ranging from 20E-25E and 45N-50N, therefore the same future precipitation data were retrieved for both cities.

To justify the visualization on the region of interest, different submenus were used. Precipitation data converted from kg/m2/s to mm/month. Converting NetCDF (Network Common Data Form) files into temporal horizontal line plots and adjusting latitude and longitude at the (spinning) pole grid is part of the visualization procedure. The final forecasted data for precipitation from 2041-2050 is obtained by extraction.

Evapotranspiration:

Thornthwaite equation was used to calculate potential evapotranspiration (PET). The Thornthwaite equation is a simple way for calculating potential evapotranspiration (PET), which is a measure of the amount of water that may be lost from the earth's surface through both plant transpiration and soil evaporation. The equation is based on the relationship of PET, temperature, and rainfall (Wayne et al. 1958).

The equation assumes that PET rises with increasing temperature and decreases with increasing rainfall. The equation's parameters were determined from empirical data, and they offer an estimate of PET under ideal water conditions. Although the equation is commonly used in climate and hydrology studies, it is a simplified depiction of the actual processes and may not be accurate in all regions or conditions.

The monthly Thornthwaite Heat Index is calculated using the mean monthly temperature as the first step. Assumptions include a month having 30 days and 12 theoretical sunlight hours each day. The following are the PET calculations. The monthly mean temperature data is first obtained by following the same method as precipitation in CORDEX website by just changing the variable name to near surface air temperature. Later data is then uploaded to Panoply and is set to justify the visualization on the region of interest and extracted for the grid ranging from 20E-25E and 45N-50N with adjusting latitude and longitude at the (spinning) pole grid for the part of the visualization procedure.

The yearly Heat Index was calculated by summing up the monthly heat indices given by Equation 5. PET estimate was done monthly. Corrections to acquired figures included utilizing the actual length of the month and the theoretical amount of sunlight hours for the sample latitude of the catchment.

$$I = \sum_{Jan}^{Dec} \left[\frac{\max(0, T_m)}{5} \right]^{1.514}$$

Equation 5

Where, T_m is monthly mean temperature [°C].

The exponent a is calculated by using Equation 6.

$$a = (6.75 \times 10^{-7} \times I^3) - (7.71 \times 10^{-5} \times I^2) + (0.01792 \times I) + (0.49239)$$

Equation 6

Lastly the potential Evapotranspiration is calculated using Equation 7.

$$PET_{Thorn} = \begin{cases} 0, & if\ T < 0 \\ 16 \times \frac{N}{360} \times \left(\frac{10 \times T_m}{I}\right)^a, & if\ 0 \leq T \leq 26 \\ \frac{N}{360}.(-415.85 + 30.5332\ \times 24\ \times T - .43 \times T^2), & if\ T > 26 \end{cases}$$

Equation 7

Where, N is the duration of sunlight in hours, varying with season and latitude, T average daily air temperature [°C], I is heat index and a is an exponent.

Water Temperature Data

Water Temperature affects the metabolic rate of microorganisms, which in turn affects the rate of BOD. As temperature increases, the metabolic rate of microorganisms increases, resulting in a higher BOD and vice versa (Singla, 2021). BOD in WEAP, for BOD calculation in WEAP oxygen saturation is taken into consideration, which is calculated by Equation 8

$$OS = 14.54 - (0.39T) + (0.01T^2)$$

Equation 8

OS: Oxygen Saturation, T: Water Temperature in Degree Celsius.

Therefore, future water temperature needs to be forecasted, to get accurate readings of BOD concentration in the future scenarios. To obtain the water temperature data a more of a statistical approach was taken to predict the data, A Multi-Layer Neural Perceptron (MLP) model has been chosen for the following function primarily due to its predictive advantages mentioned in (Graf et al., 2019).

MLP is a kind of an artificial neural network. MLP consists of multiple layers of interconnected nodes (neurons) that process and transmit information. The first layer of the network is the input layer, which receives the input variables (features). The intermediate layers, known as hidden layers, perform complex transformations on the input variables and transmit the results to the output layer, which produces the final prediction.(Multi-Layer Perceptron Neural Network Using Python – Machine Learning Geek, 2021).

In this project we used the sklearn.neural.network library to create the neural network model a base code mentioned in (Multi-Layer Perceptron Neural Network Using Python – Machine Learning Geek, 2021), the data implemented in MLP was calibrated using Trial and Error method for the time span of 2000-2010, Air temperature (obtained from European Climate Assessment and Dataset) and water temperature data previously which were available for (2000-2010) were divided into 2 parts training data and testing data , Data from the 2000:2006 (Training Data) was used to create a MLP model and this model was fitted onto the years 2007:2010 to see the accuracy of the MLP forecasted data.

This forecasted data was compared with the real data in the timespan of 2007:2010 (Testing Data) this process gave out a calibrated MLP which had an accuracy score of 0.89, the trend obtained from MLP was applied to the obtained 2041:2050 data and future water temperature data was predicted.

3.11 EU Water Framework Directive-Standard Water quality:

The EU Water Framework Directive (WFD) is important because it sets the standard for water quality in the European Union (EU) (Water Framework Directive, 2013). The WFD strives to safeguard and enhance the quality of all sorts of water bodies, including as rivers, lakes, groundwater, and coastal waters, as well as to ensure that all EU inhabitants have access to safe drinking water. The directive sets a framework for catchment-level integrated water management, which implies that all activities impacting water quality and availability, such as agriculture, industry, and urbanization, must be included (Water Framework Directive, 2014).

The standard levels of Biological Oxygen Demand (BOD) and Nitrogen (N) are set to protect the health of aquatic ecosystems and ensure the sustainable use of water resources.

BOD is a measure of the amount of oxygen required by microorganisms to break down organic matter in water. High levels of BOD can lead to low dissolved oxygen levels in water bodies, which can be harmful to aquatic life and reduce the quality of water for other uses such as recreation or drinking water supply. Setting standard levels of BOD helps to prevent excessive organic matter inputs into water bodies and maintain adequate oxygen levels to support healthy aquatic ecosystems (Evaluation of the UWWTD, 2019). According to the UWWTD, biochemical oxygen demand (BOD) in waste water output must be decreased to 25mg/l or a minimum reduction of 70-90% (Evaluation of the UWWTD, 2019).

Similarly, high levels of nitrogen can lead to excessive growth of aquatic plants and algae, leading to eutrophication, which can have negative impacts on water quality and aquatic life. Setting standard levels of nitrogen helps to prevent excessive inputs of nitrogen into water bodies and maintain the health of aquatic ecosystems (Evaluation of the UWWTD, 2019). The UWWTD requires a reduction of total nitrogen in wastewater discharges to concentrations of 15 mg/1 N (10,000 – 100,000 p.e.) and 10 mg/1 N (more than 100,000 p.e.) (Evaluation of the UWWTD, 2019)

4. Results and Discussion

4.1 Forecasted Climate Data

Figure 7 and Figure 8, illustrate the spatial distribution of the intended climatic variables i.e. precipitation for 01-01-2041 & 31-12-2050 respectively. These are the plots obtained from the Panoply. Over the years we can expect that the precipitation is expected to decrease.

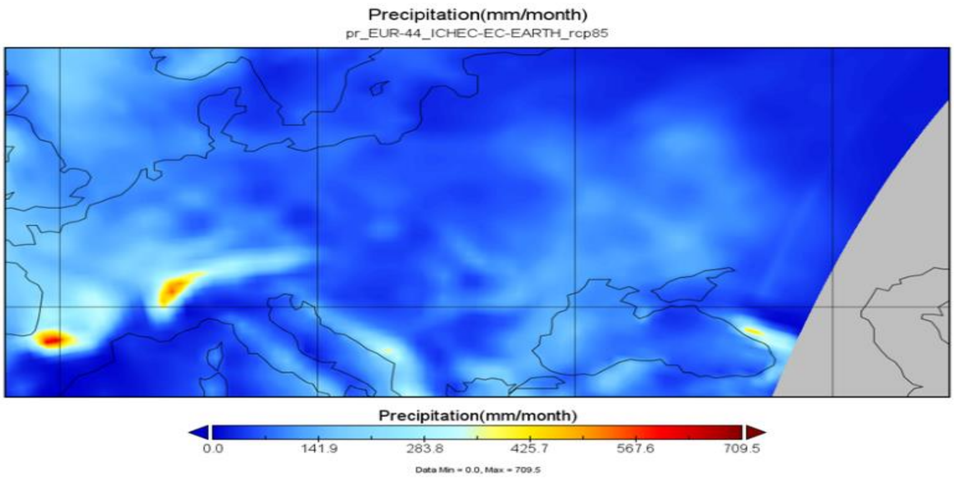

Figure 7 Forecasted precipitation 2041 from Panoply.

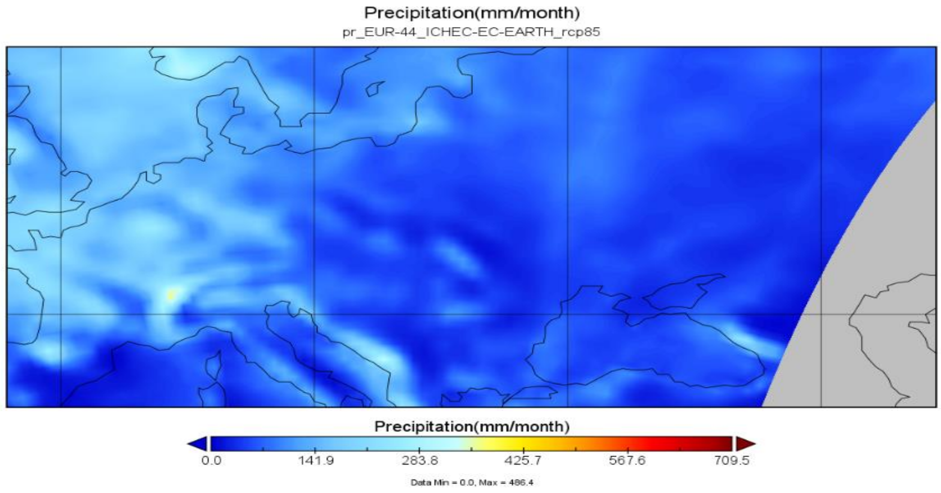

Figure 8 Forecasted precipitation 2050 from Panoply.

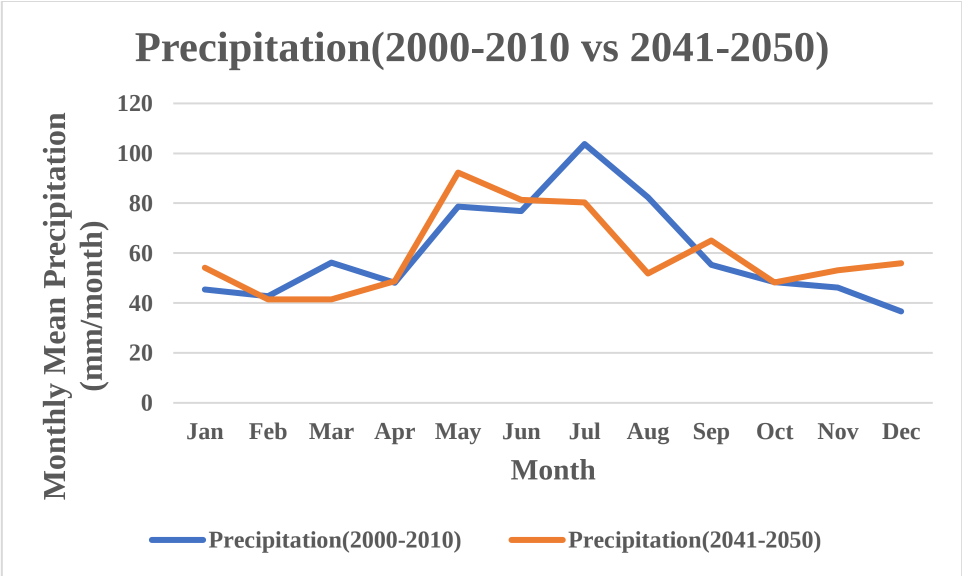

Figure 9 Monthly mean precipitation plot between base model and forecasted model.

Figure 9 shows the monthly mean precipitation over the years. The data was extracted from the panoply software and compared with base model to understand the trend between base model and forecasted model. We can interpret that trend over the years has displayed a relatively declining rate of precipitation when compared to precipitation which is seen in 2000-2010. Although there is a large rise in the month of May, the precipitation drops dramatically in the months of July and august.

A combination of consistently increasing temperature and slightly to moderately decreasing precipitation (depending on the period and RCP) results in decreases of the annual river discharge. Changes in long-term mean monthly discharge indicate an increase during the winter months and a little decline during the April-May months. This might be due to a rise in temperature, which causes early snowmelt and a shift in the date of the spring flood (Didovets et al. 2020).

Forecasted Evapotranspiration

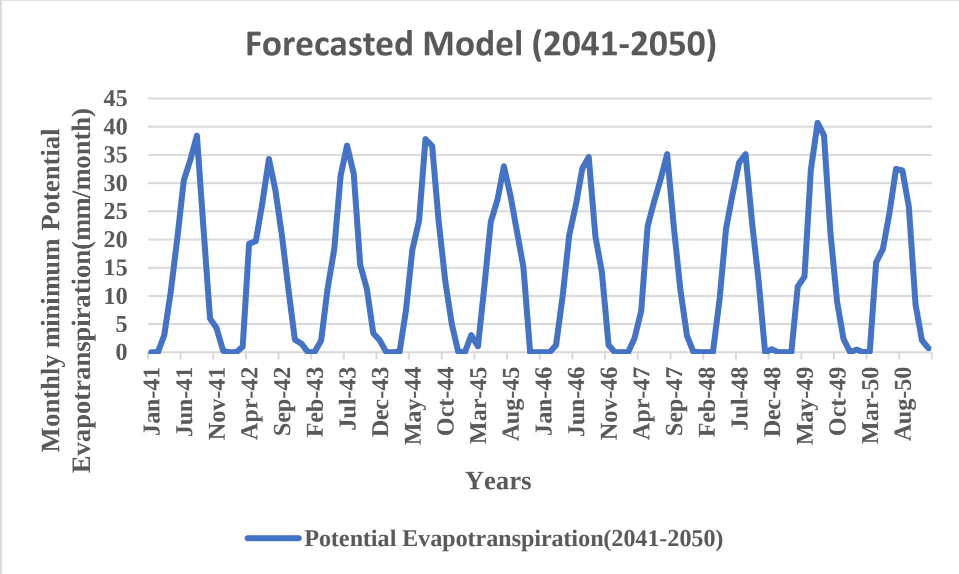

Figure 10 Monthly mean Potential Evapotranspiration from 2041-2050

Figure 10 was obtained by following the Thornthwaite equation, it shows that evapotranspiration has been declining over time from 2041-2050.

A multitude of causes might cause potential evapotranspiration (PET) to decrease over time. Changes in atmospheric circulation patterns, shifts in precipitation systems, and losses in water-holding capacity owing to land use changes such as deforestation or urbanization are all typical reasons of diminishing precipitation. Changes in climate, such as increases in temperature and decreases in relative humidity, can also cause PET to drop over time, increasing evaporation rates and reducing the quantity of water available for plants to transpire. Changes in land use and management methods, such as increased irrigation or conversion of natural areas to agriculture, can also lower PET by affecting an ecosystem's water balance (Teuling et al. 2019).

Forecasted data of evapotranspiration for this model is not too precise because when the temperature is decreasing below zero-degree Celsius potential evapotranspiration is taken as zero as per the Thornthwaite equation. However, a different method could be used to obtain the evapotranspiration which is more accurate for example Penman-Monteith equation or different GCM models to project the data.

Forecasted Water Temperature

Figure 11 shows the water temperature data comparison between the base scenario and the future climate scenario it can be clearly seen from the figure that there is an increase in water temperature in the future scenario as compared to the base scenario, this can be accounted to the increase in air temperature.

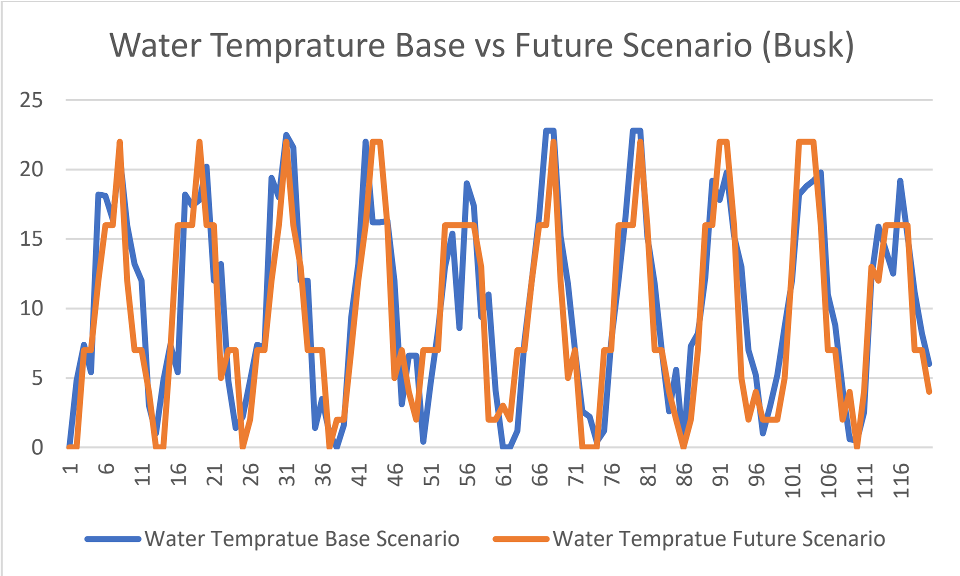

Figure 11 Water Temperature Data Results

Changes in the water temperature of open watercourses are one of the most primary principles of environmental change (Bonacci et al. 2022). Water temperature has a considerable impact on many physical features as well as chemical and metabolic reactions in the river system. It has a particularly large impact on water quality and, as a result, biological processes (Webb et al. 1993; Ducharne et al. 2008).

4.2 Population Data Forecasted

The results obtained from WEAP, for predicted population in the future scenario are mentioned in the Table 8 below.

Area	Population (2041)	Population (2050)
Lviv Village	16,498	15,195
Lviv City	672,426	654,143
Busk City	8725	8770
Busk Village	91,427	84,206

Table 8 Forecasted Population Data

In case of the Busk, catchment there can be seen a substantial decrease in the overall population from the year 1989 to 2050 as evident from Figure 12.Whereas in case of village there is an overall forecasted decrease of Population by 42.7% from the year 1989 to 2050. However, in case of the city population an increasing trend can be seen, where the population increased by 2.8%.

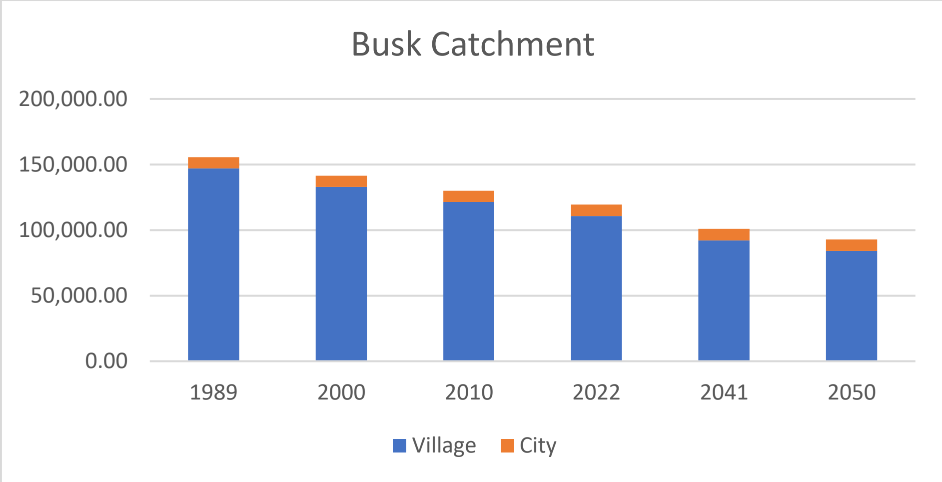

Figure 12 Forecasted Population Data Busk Catchment

In case of Lviv according to Figure 13, The city's population is expected to decrease by 14% between 1989 and 2050. A similar decreasing trend can be seen in the village population, which has decreased by 42.7%

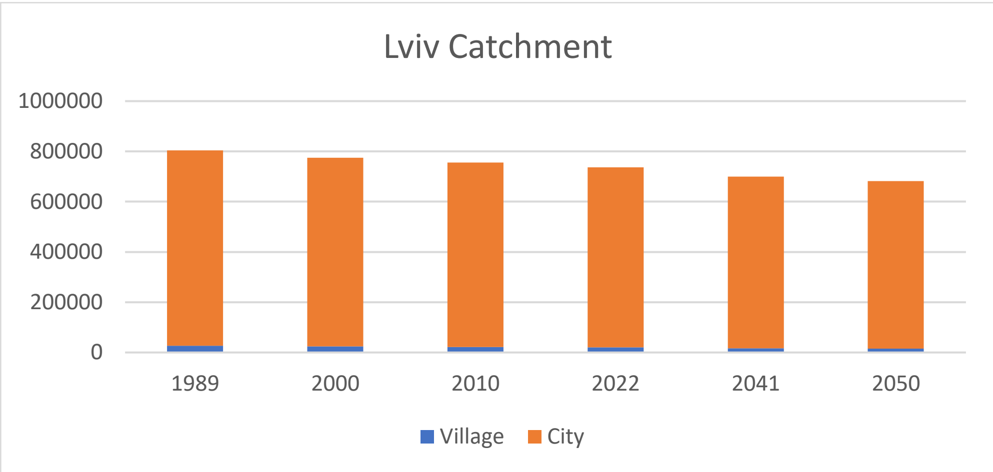

Figure 13 Forecasted Population Data Lviv Catchment

The key reasons that can be attributed towards the overall decrease in population in Ukraine are due to the fact that, Ukraine has one of the lowest birth rate in Europe (Perelli-Harris, 2005) and has high mortality rate especially in working age men due to factors such as unhealthy lifestyles, alcohol and drug abuse, and poor access to healthcare (Ukraine’s Demographic Reality, 2014).

Major factors contributing to the decreasing Urban population are migration of Ukrainians to other countries due to economic opportunities and poor health care facilities available. While the Rural population is declining work opportunities and low incomes obtained in the agriculture sector in Ukraine (Short-Term Outlook Report, 2022), which mostly pushes people from rural areas to migrate to the urban areas with hope of more opportunities, higher standard of living and to get access to basic facilities such as healthcare, safe water supply (Water, Sanitation and Hygiene (WASH), n.d.) as well as better education (Ella Libanova & Olena Malynovska, 2012).

To view detailed information about the data used refer to Population Data Forecasted in Appendix 2 : Data Forecasting.

4.3 Land Use Data Forecast

The WEAP results for predicted land cover data in the future scenario are shown in Table 9 below.

Area	Projected Area (2041)	Projected Area (2050)
Catchment Lviv Agriculture	41,232	40.520
Catchment Lviv Others	29,165	29,372
Catchment Busk Agriculture	988,328	971,744
Catchment Busk Others	354,416	356,984

Table 9 Land Cover Data Future Scenario

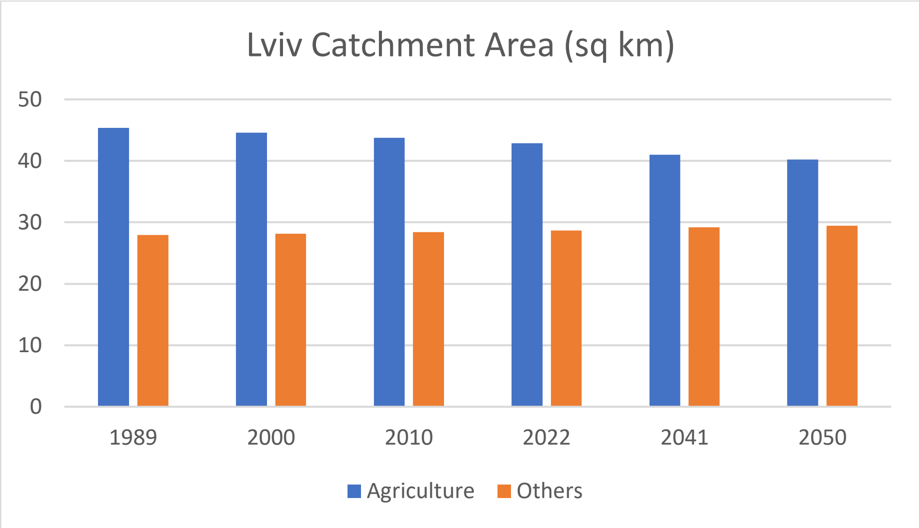

Figure 14 Forecasted Area Lviv Catchment

From the results obtained in case of the Lviv catchment it can be observed that there has been a significant decrease in the Agricultural land from the year 1989 to 2050 where it is forecasted that the agricultural land would shrink by 11.27 %, on the other hand it is also predicted that the urban land or city area would expand by 5.3 %.

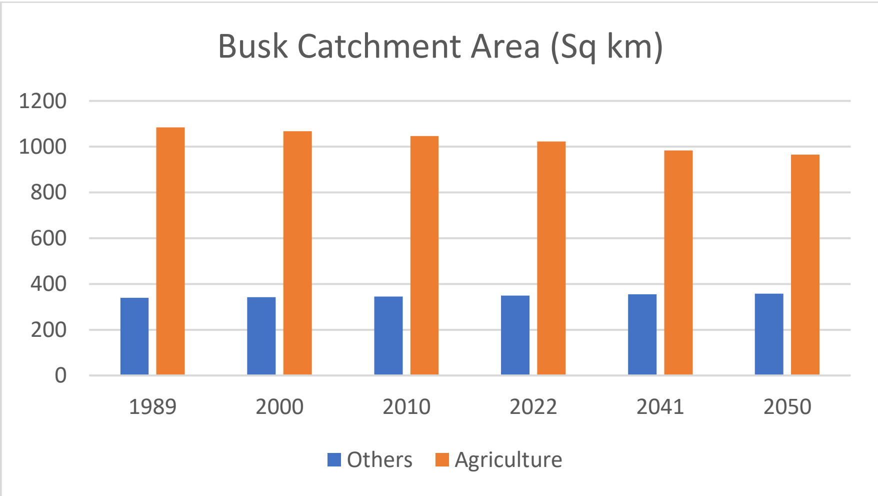

Figure 15 Forecasted Area Busk Catchment

While in case of the busk catchment a similar pattern is observed where the urban area is increasing by 5.45 % and the rural or the agricultural land is decreasing by 10.4%.

The major reason for a projected increasing urban area is due the fact that storyline A was considered for the calculations of the land use data where a more market and industry-oriented scenarios are taken into consideration, thereby an increase in the artificial surface land use type.

Urbanization results in a continuing loss of agricultural land, both directly through land take and indirectly through the use of agricultural land for non-productive rural activities such as leisure, horse keeping, or hobby farming. These urbanization processes put farmers under strain, making farming more difficult due to decreasing agricultural area, negative externalities, and competition for land (Beckers et al. 2020).

To view detailed information about the above data used refer to Land Use Data Forecasted in Appendix 2 : Data Forecasting

4.4 Water Quality constituents' comparison between base scenario and future scenario

BOD Concentration

Based on the Figure 16 and Figure 17 When the BOD values for the outflow into the Busk Wastewater treatment plant are compared, it is clear that the BOD concentration has increased by 0.0365% per month. In the case of Lviv, the BOD concentration for outflow has increased by 6.5% per month. This indicates that as Lviv has become more populated and industrialized, there has been a significant increase in the BOD released directly into the WWTP.

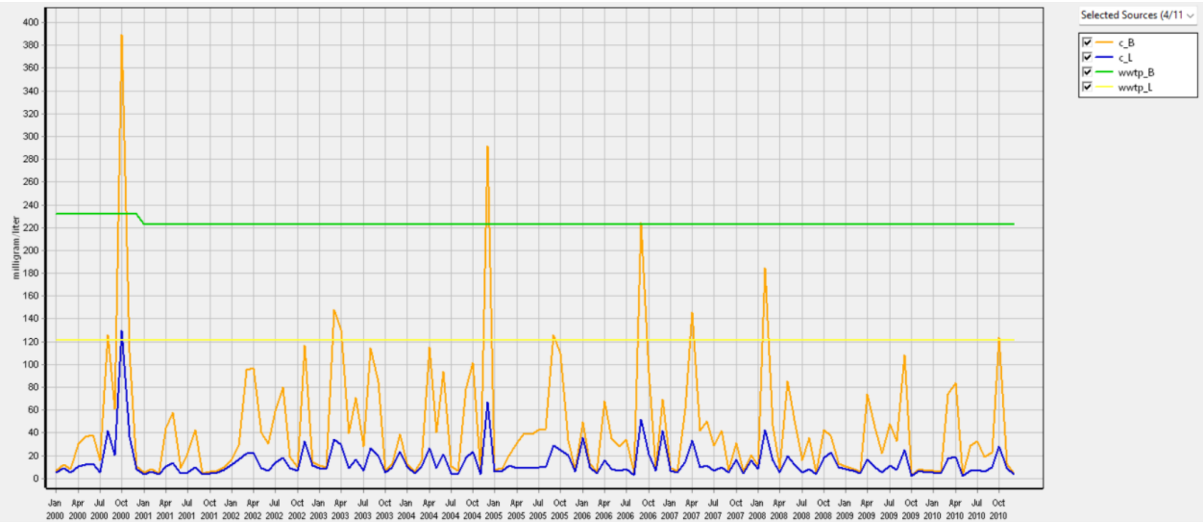

Figure 16 BOD Concentration Outflow 2000-2010

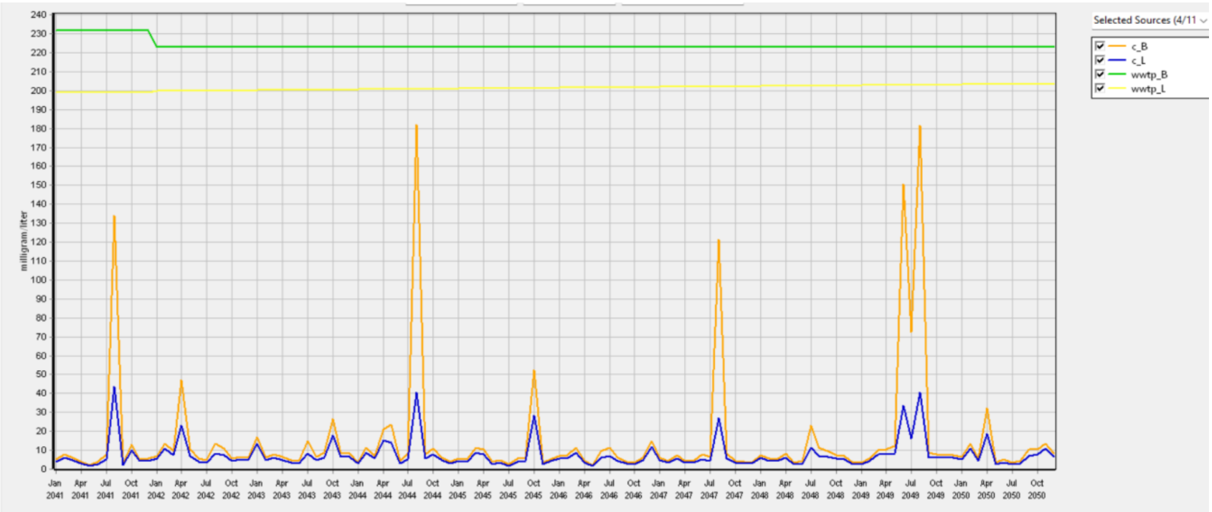

Figure 17 BOD Concentration Outflow 2041-2050

The current BOD removal efficiency of the WWTP is 49% and 9% respectively for Lviv and Busk shown by Figure 18 and Figure 19 according to the base scenario this is visible from the ratio of inflow and outflow BOD concentration. The BOD inflow to the WWTP Busk in the forecasted years are almost same as the base year concentrations, even though there has been a huge decrease in the population as shown by Figure 18. For the WWTP Lviv a considerable increase in inflow concentration can be seen mainly due to the increased water consumption by industries over the years.

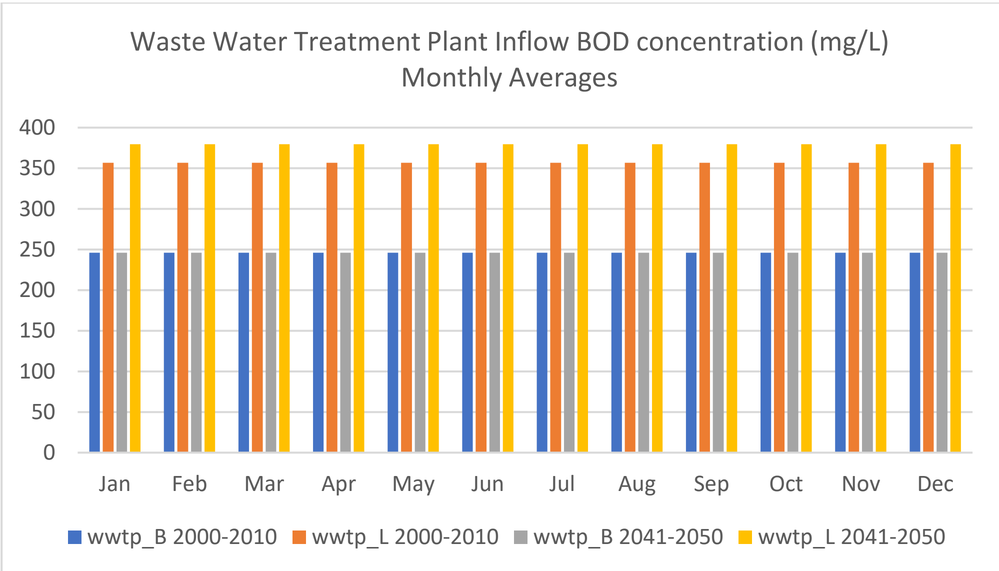

Figure 18 Wastewater Treatment Plant Inflow BOD concentration (mg/L)

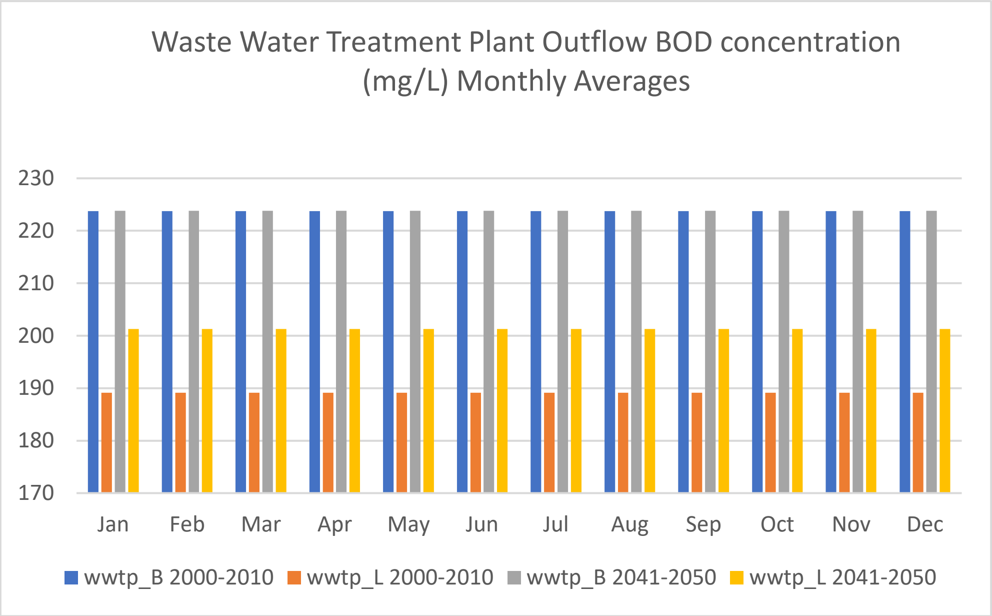

Figure 19 Wastewater Treatment Plant Outflow BOD concentration (mg/L) Monthly Averages

When comparing the Future projections to the Base model for BOD concentration in the Catchment of Lviv and Busk, a significant decrease in concentration is evident, with an average decrease of 10.35 mg/L per month in Lviv and an average decrease of 30.62 mg/L per month in Busk this can be visualized by Figure 20.

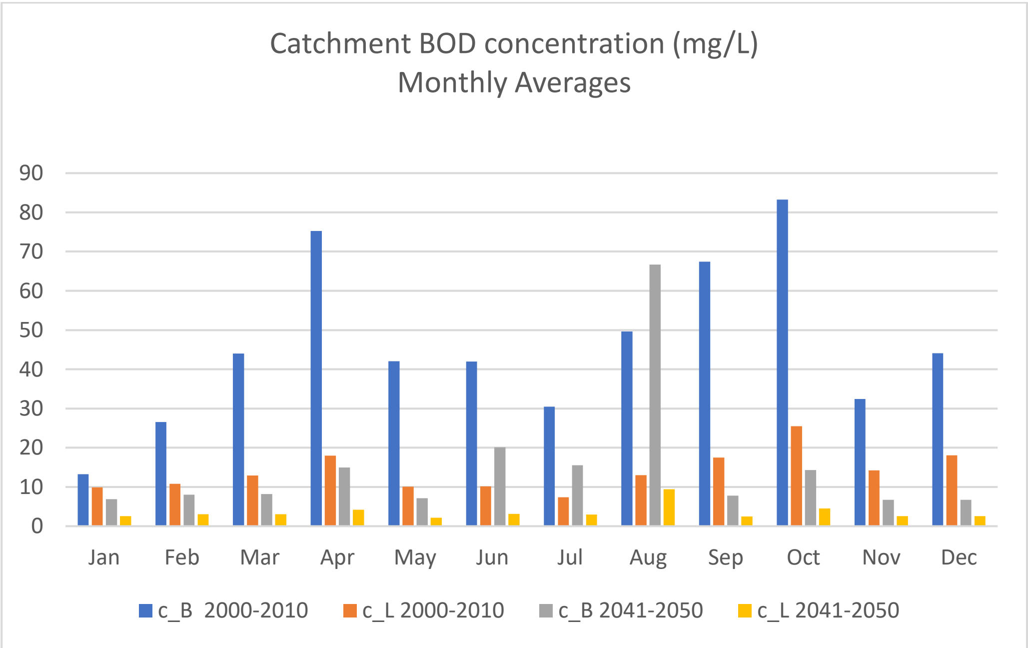

Figure 20 Catchment BOD concentration (mg/L)

In Figure 21 displays a comparison of the river water return flow BOD concentrations from the WWTP between the base scenario and the future scenario, it was found that in case of WWTP in Lviv there has been an increase in BOD concentration by 25% and in case of Busk there has been an increase of 7%.

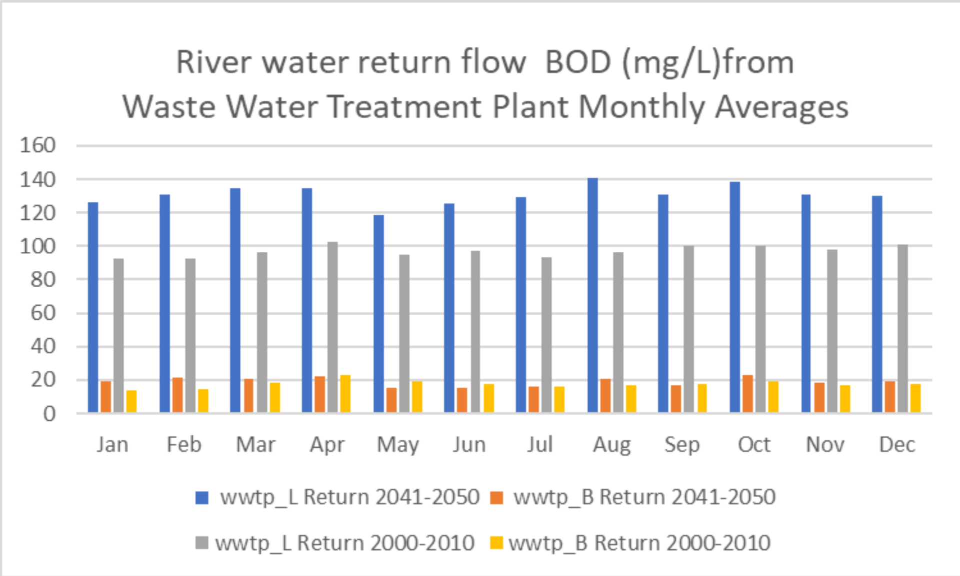

Figure 21 Catchment BOD concentration (mg/L)

BOD levels can be influenced by the many factors. Higher population can result in increased water demand and wastewater outflow, thereby raising BOD. Land use changes, such as urbanization and deforestation, can have an impact on the amount of organic matter in water and BOD levels. Precipitation can dilute organic matter and lower BOD; however, a lack of precipitation can raise BOD. Evapotranspiration, or water loss from the surface, can limit the quantity of water available for breakdown and hence potentially lower BOD. Warmer water promotes bacterial growth and increases BOD, whereas cooler water inhibits decomposer activity and decreases BOD. These elements must be taken into account in water management and water quality monitoring operations.

Nitrogen Concentration

The Nitrogen outflow concentration graphs for the base scenario and future scenario are given below in Figure 22 and Figure 23. From the comparisons it can be seen that, there is an increasing trend in the concentration of N entering the WWTP in Lviv by an average of 0.2mg/L per month, which can be attributed to industry within Lviv putting more strain on the WWTP and thus increasing the outflow N concentration.

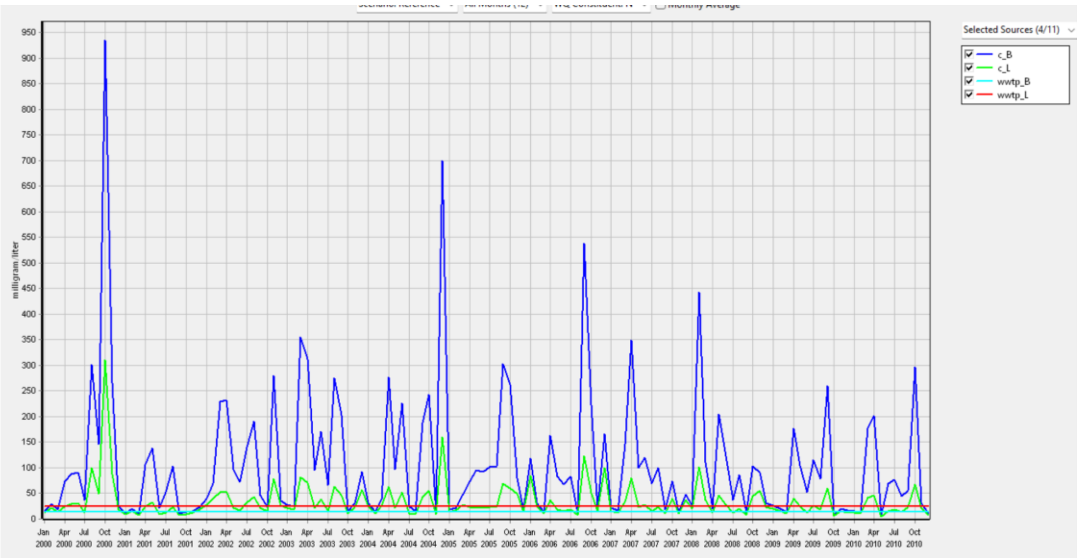

Figure 22 Outflow water quality by source N Concentration 2000-2010

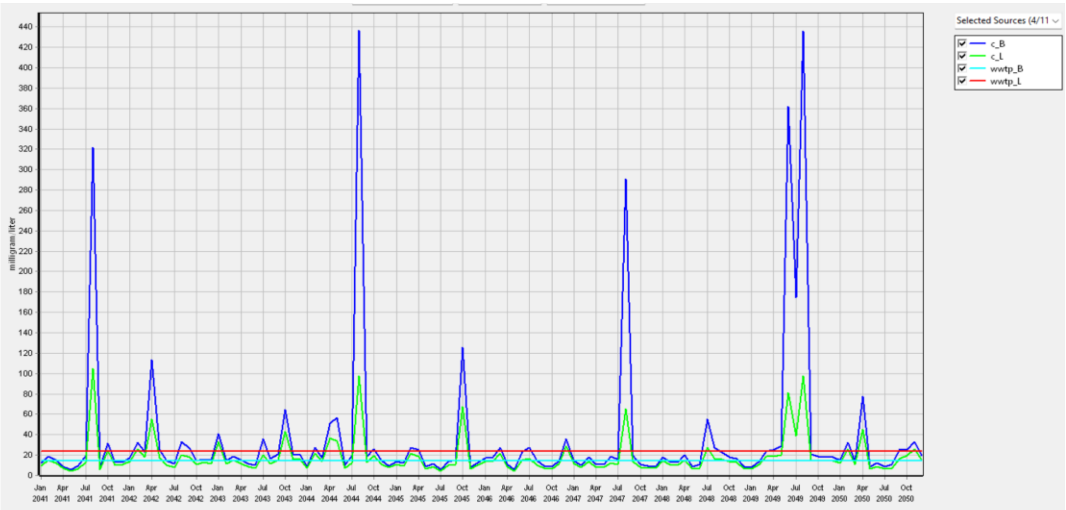

Figure 23 Outflow water quality by source N concentration 2041-2050

The N concentration for Busk Catchment has substantial decrease with an average decrease of 73.5 mg/L per month. Whereas in case of Lviv catchment there has been a decrease in N concentration by 24.95 mg/L per month this can be visualized by the Figure 24. For the Village areas a decrease in N concentration by a value of 38.31 mg/L per month for Busk and 53.81 mg/L in the case of Lviv can be observed.

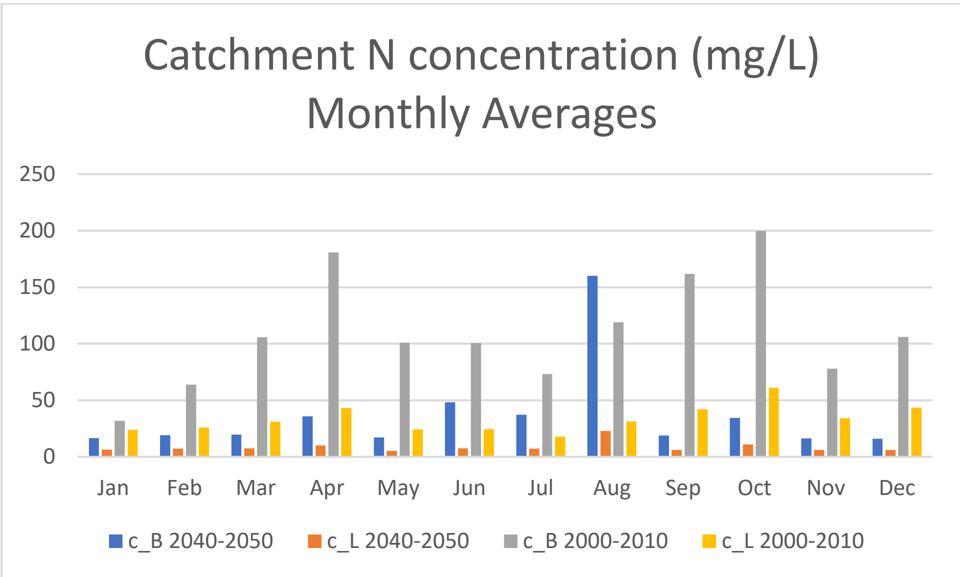

Figure 24 Concentration of N Monthly Avg. for Catchments

Figure 25 and Figure 26 shows a comparison of the N concentrations can be seen side to side for the base scenario and the future scenario for the WWTP's, from this we can find out that the waste water treatment efficiency for N in WWTP in Lviv and Busk are 45% and 70% respectively. From these graphs another interesting thing which can be seen is that N inflow and outflow values for Busk in both base and future scenarios are the same, therefore pointing out that there is not much significant change in the N load in WWTP Busk.

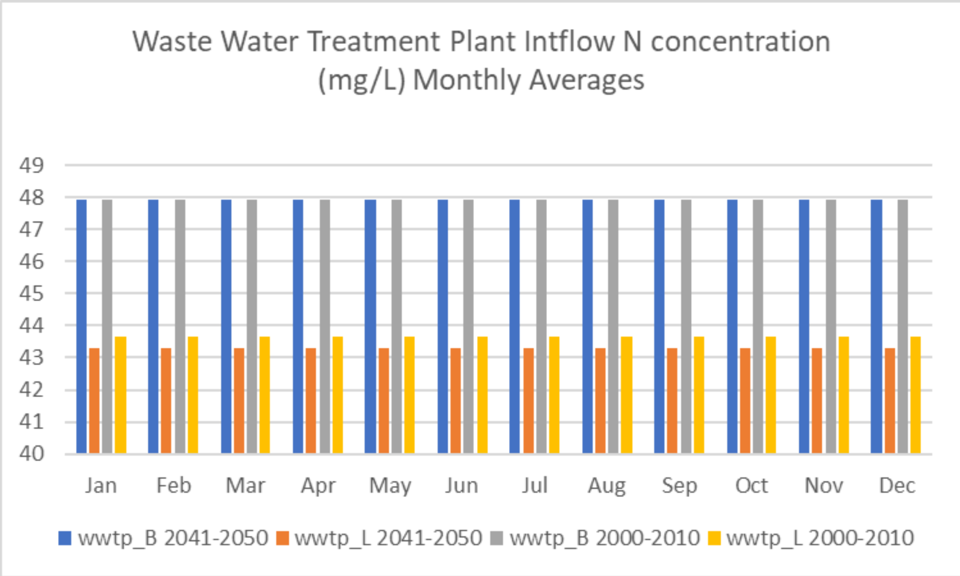

Figure 25 N Concentration Waste Water Treatment Plant Inflow (mg/L) Monthly Averages

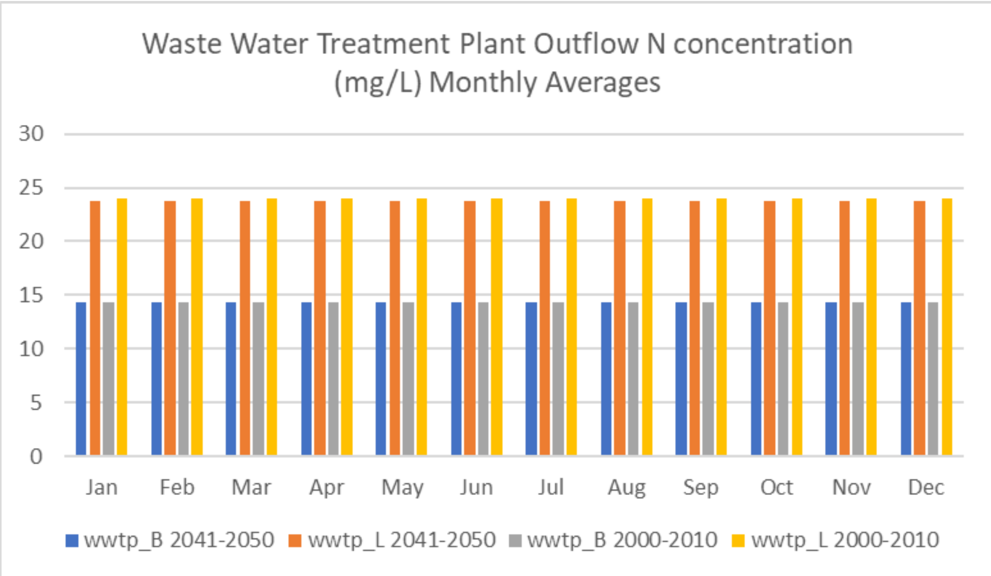

Figure 26 N-Concentration Wastewater Treatment Plant Outflow (mg/L) Monthly Averages

Figure 27 displays a comparison of the river water return flow BOD concentrations from the WWTP between the base scenario and the future scenario, it was found that in case of WWTP in Lviv there has been a decrease in N concentration by 71.8% and in case of Busk there has been a decrease of 22.3%.

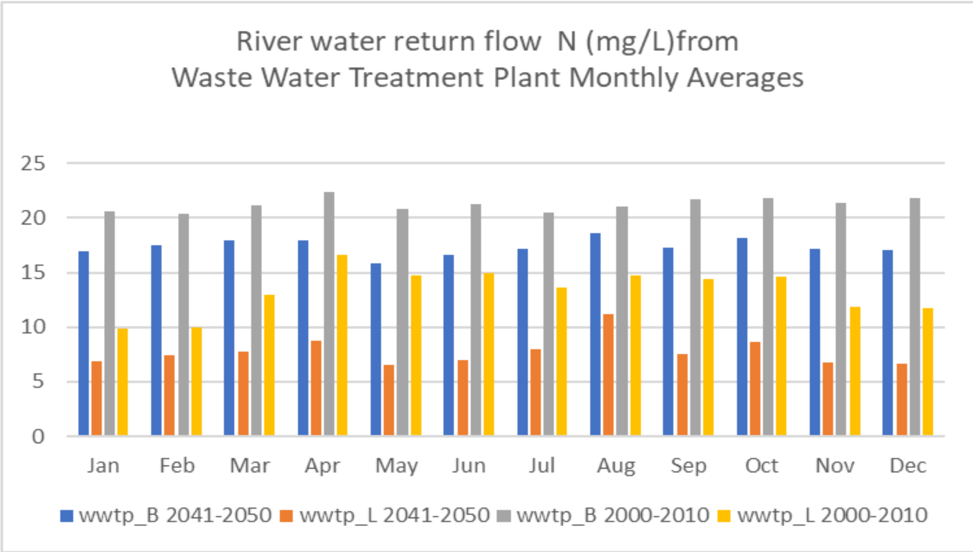

Figure 27 River water return flow N (mg/L)

The amount of nitrogen can be affected by the following factors. Increased population can increase nitrogen inputs from sources such as sewage and fertilizer, resulting in increased nitrogen levels. Changes in land use, such as deforestation and agriculture, can have an influence on nitrogen levels in the soil, water, and air. Precipitation can wash nitrogen into surface and groundwater, increasing nitrogen levels, but a lack of precipitation can limit nitrogen imports and lower levels. Evapotranspiration, or the loss of water from the surface, can reduce the amount of water available for nitrogen cycling and hence lower nitrogen levels. Warmer water can stimulate denitrification, resulting in nitrogen loss, whereas cooler water can limit denitrification and boost nitrogen levels.

In case of both BOD and N outflow concentrations a common increasing trend has been observed, during the months of July and August, one of the possible reasons for this can be due to the increase in precipitation during these months due to which the pollutants present on the surface get carried to the river water due to which there is a sudden increase in concentrations.

Pollutant Generation Load

Figure 28 displays the BOD pollutant generated load for the different regions of the Poltva sub catchment for the year 2050 as it can be seen from the figure most of the BOD pollutant load is generated by the Lviv city, followed closely by Industry in Lviv and agricultural areas in Lviv and Busk respectively.

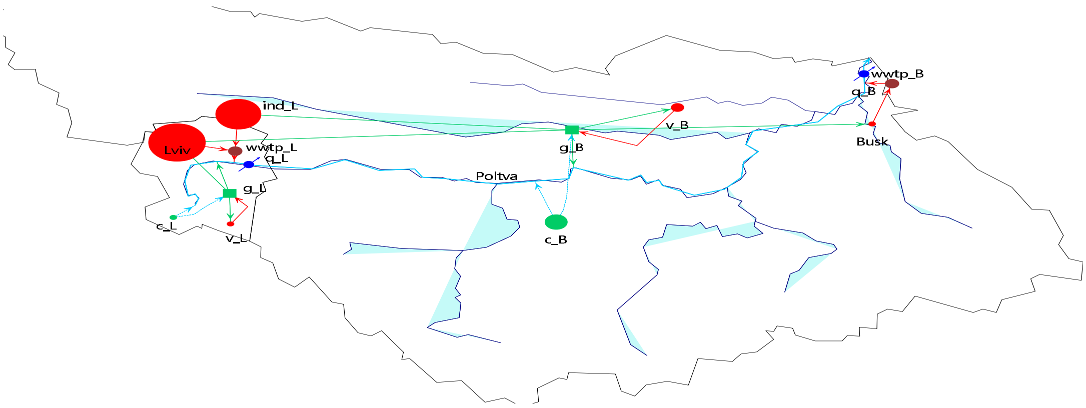

Figure 28 Poltva Basin by Pollutant Load Generation (BOD)

The following data can be visualized by a simple graph as shown below in Figure 29, Figure 30 can be used to compare the forecasted model pollutant generation with the base model pollutant generation.

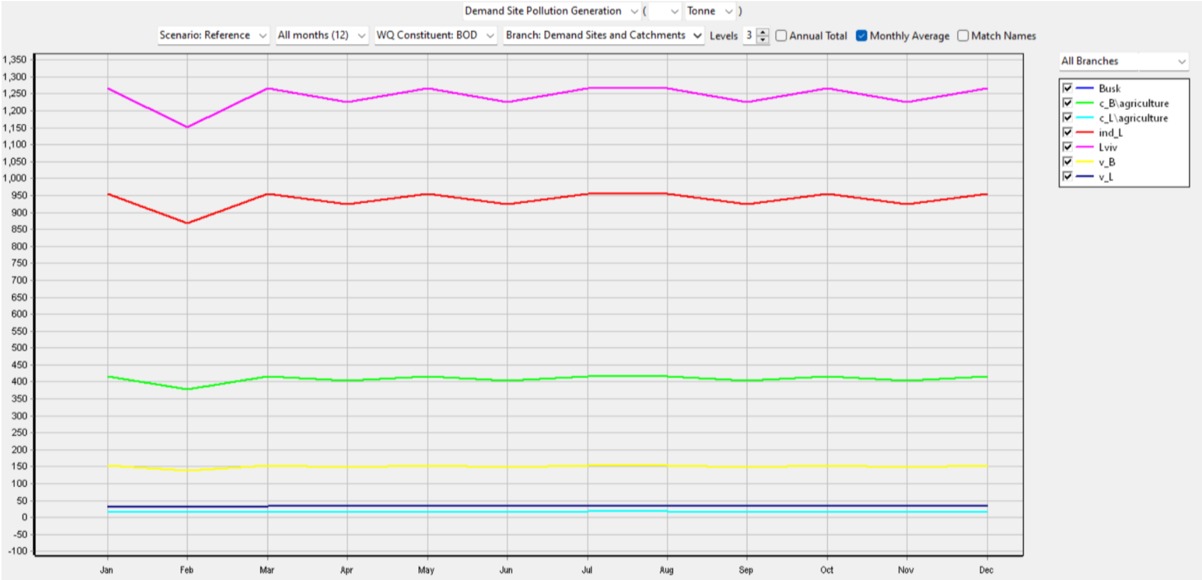

Figure 29 Pollutant Load Generation (BOD) 2040-2050 monthly average

From Figure 30 it can be seen that in case of Cities and Villages the pollutant load is slightly decreasing for the future scenarios in case of agricultural areas there has been approximately 9% decrease in the pollutant load whereas in case of villages the pollutant load being generated has drastically shot down accounting which is accounted to the lowering of the population in the rural areas.

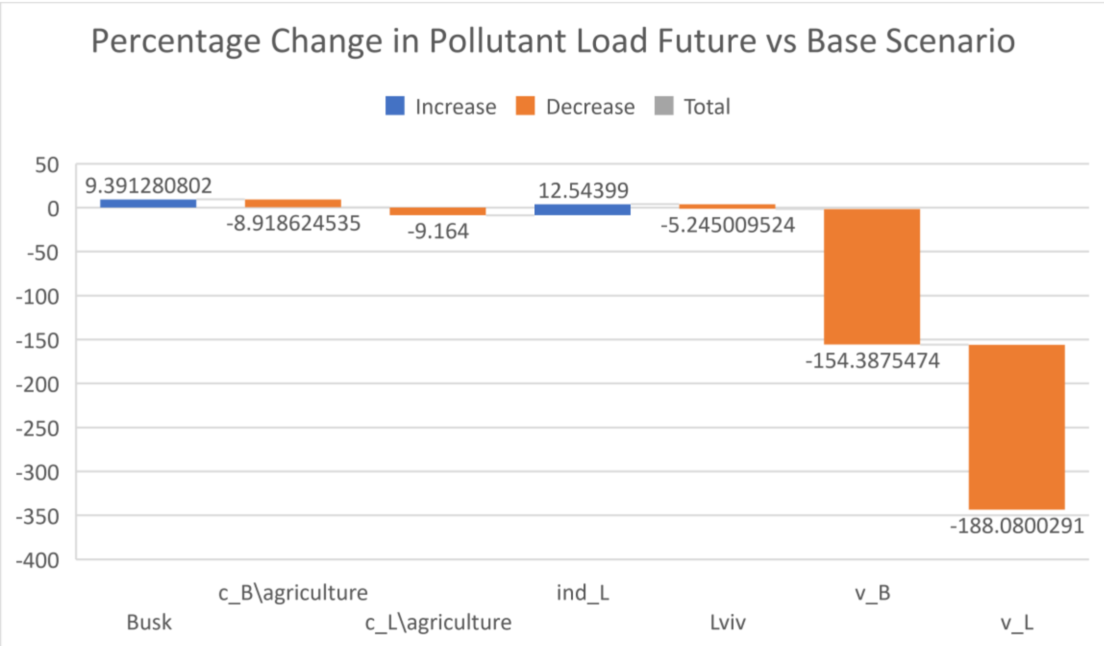

Figure 30 Pollutant Load BOD yearly sum percentage change (tones)

Figure 31 depicts the N pollutant generated load for the various regions of the Poltva sub catchment in 2050. As can be seen, the Busk Catchment generates the majority of the N pollutant load, followed closely by Lviv City. When N loads are generated, it is observed that the majority of the load is generated in agricultural areas in Lviv and Busk, indicating a, rather than in Lviv's industry. The same can be visualized by Figure 32.

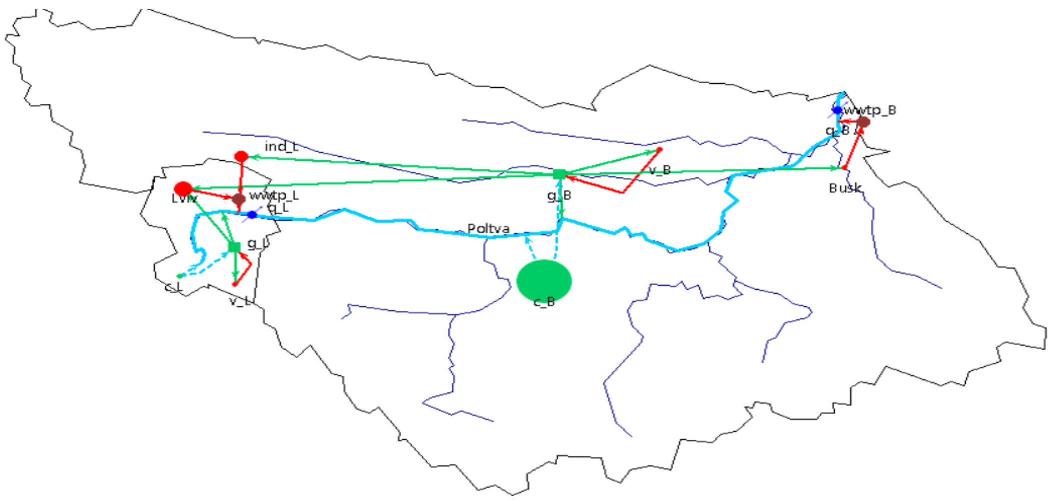

Figure 31 Poltva Basin by Pollutant Load Generation (N)

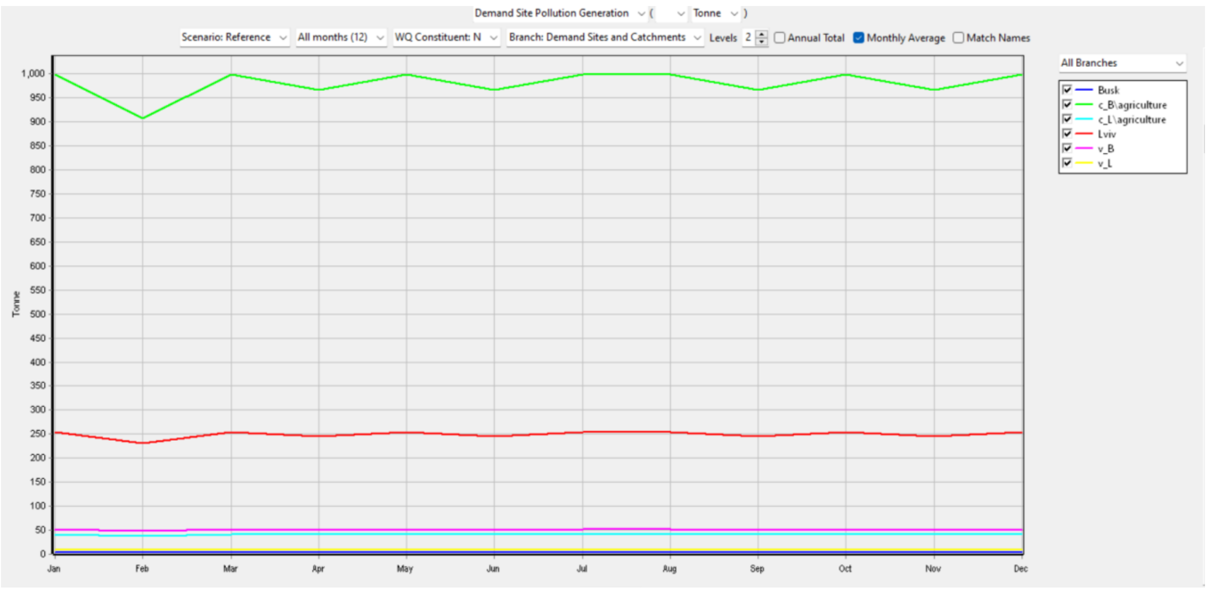

Figure 32 Pollutant Load Generation (N) 2040-2050 monthly average

From Figure 33 It can be seen that the N pollutant load in Busk City is increasing by nearly 10% in the future scenario, which can be attributed to the growing population in the urban area, whereas in villages there has been a decreasing trend of approximately 34%, which can be believed to be due to the decreasing village population. In the case of catchments, a decrease in pollutant load can be seen due to the projected decrease in the catchment area, which leads to less agricultural growth and less N being generated.

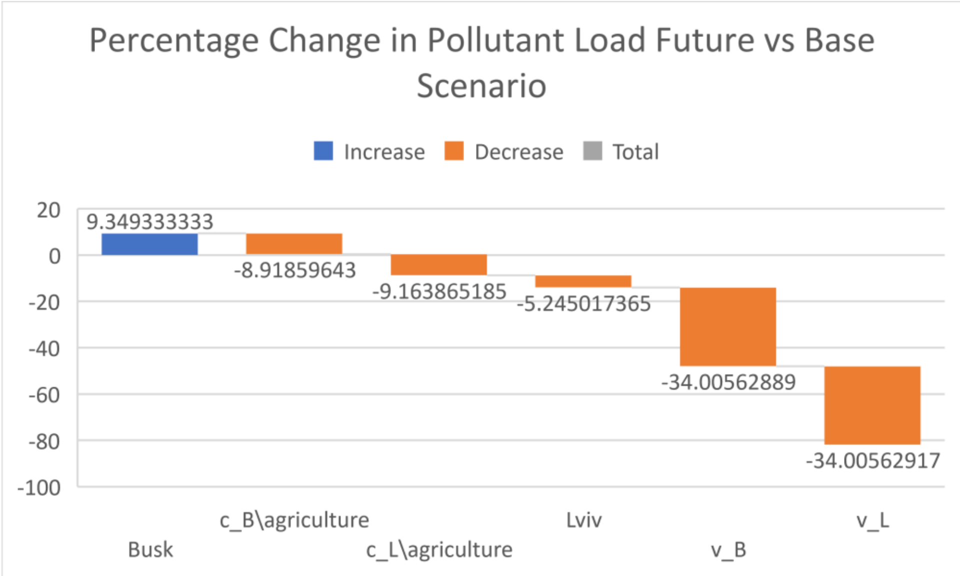

Figure 33 Pollutant Load N yearly sum percentage change (tonnes)

Increased levels of Biochemical Oxygen Demand (BOD) and Nitrogen (N) can harm water quality and aquatic life.

Increased BOD levels indicate an increase in organic pollutants, which results in lower oxygen levels in the water. Increased nitrogen levels can also cause eutrophication, excessive development of algae and other aquatic plants, and disruption of nutrient cycles. Eutrophication can destroy aquatic life, promote the growth of hazardous algal blooms, and have an influence on human health. Changes in acidity can also make survival difficult for some aquatic animals. It is critical to monitor and regulate BOD and nitrogen levels in order to ensure high water quality and a healthy aquatic habitat.

Day to day there is increase in Lviv's pollution and industrial growth. This could be due to several factors, including economic opportunities, infrastructure development, location, education and cultural scene, and favorable government policies. An increase in job growth and industries can boost the local economy. The development of transportation and communication networks and the presence of resources make Lviv more accessible and attractive to people and businesses. A strong education and cultural scene can also attract residents and businesses. These factors influence in increasing the BOD & decreasing N concentrations in the Inflow & Outflow of the WWTP of Lviv. Although the concentration of BOD is decreasing in the catchment of Lviv & Busk due to decrease in Population & land usage for agricultural practices.

Further investigation of the sources of pollution in the entire catchment and analysis of each source one by one revealed that the Busk Ground Water Reservoir is primarily polluted by the Busk catchment. Pollutant loads for BOD in the groundwater reservoirs of Busk and Lviv are reduced by 1.21 and 2.04 tons per month, respectively, compared to the baseline scenario.

BOD & N Concentration with increased Removal Efficiency of WWTP

The removal efficiency of the WWTP's were increased to check the concentrations of BOD and Nitrogen in the Outflow of the WWTP and see if they fall under the EU standards. The standards of the WWTP were improved according to the European commission Urban Waste Water Treatment Directive 2019 (EUROPEAN COMMISSION, 2019). According to the directive, the removal efficiency must be 96% and 80% for BOD and N which has been therefore implemented in the model. The results obtained from new WWTP efficiency are as follows:

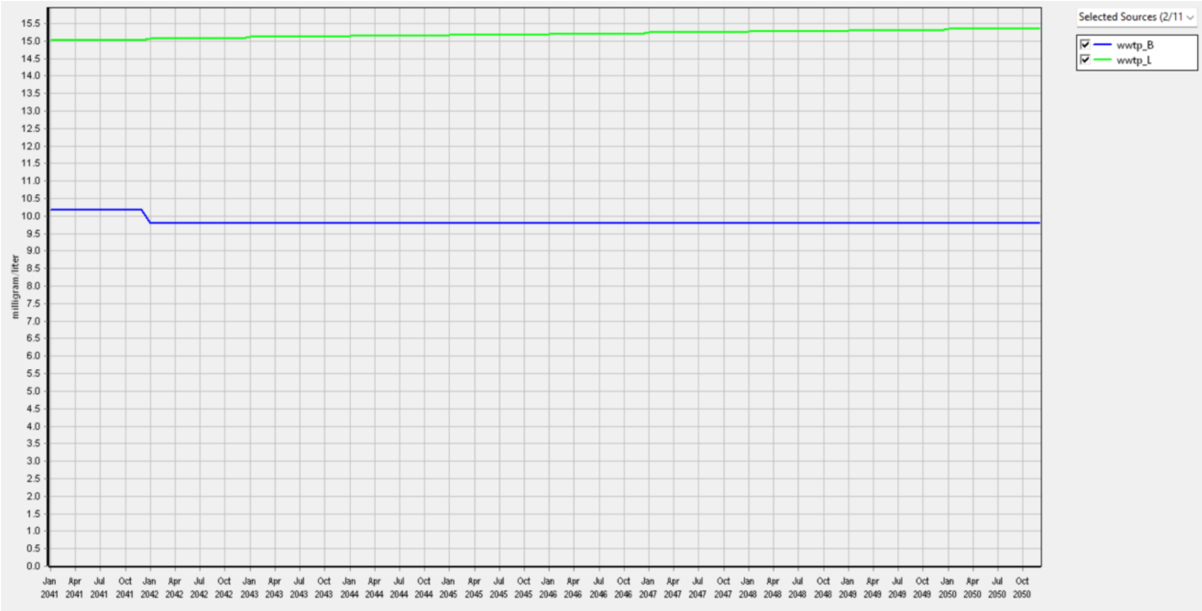

Figure 34 Outflow water quality BOD concentration

The outflow water quality BOD concentration reduced from 225mg/L to 15mg/L in the Busk WWTP and from 201mg/L to 9.5mg/L in Lviv WWTP as shown by Figure 34. Therefore, the BOD Concentrations are bought down to the permissible limits.

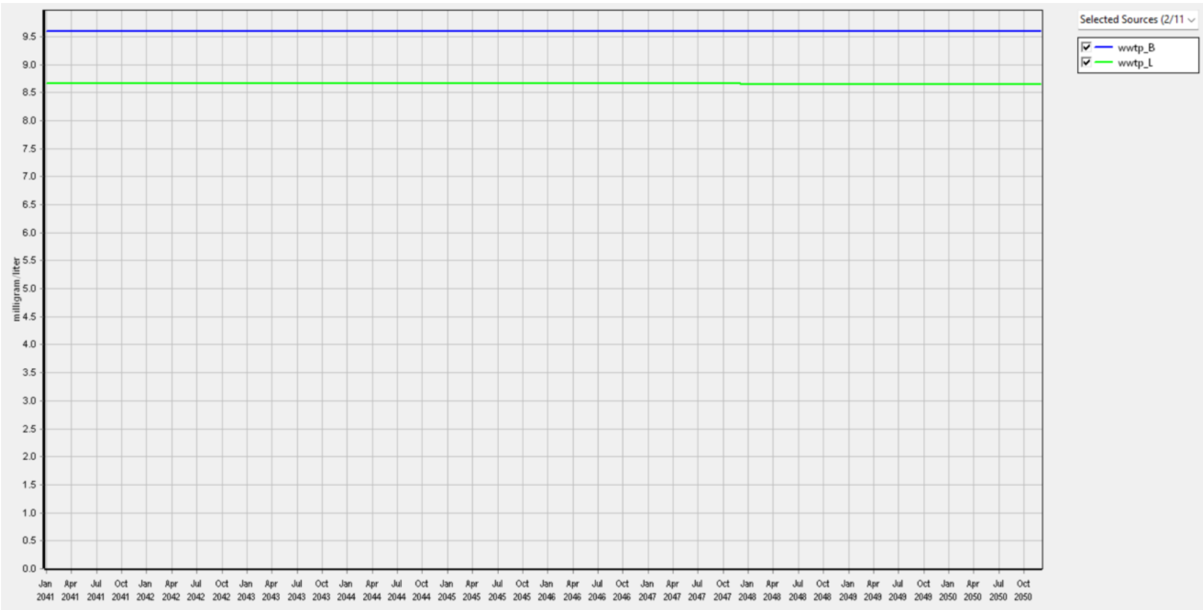

Figure 35 Outflow water quality N concentration

Likewise, from Figure 35 it is evident that the N concentrations are also substantially decreased.

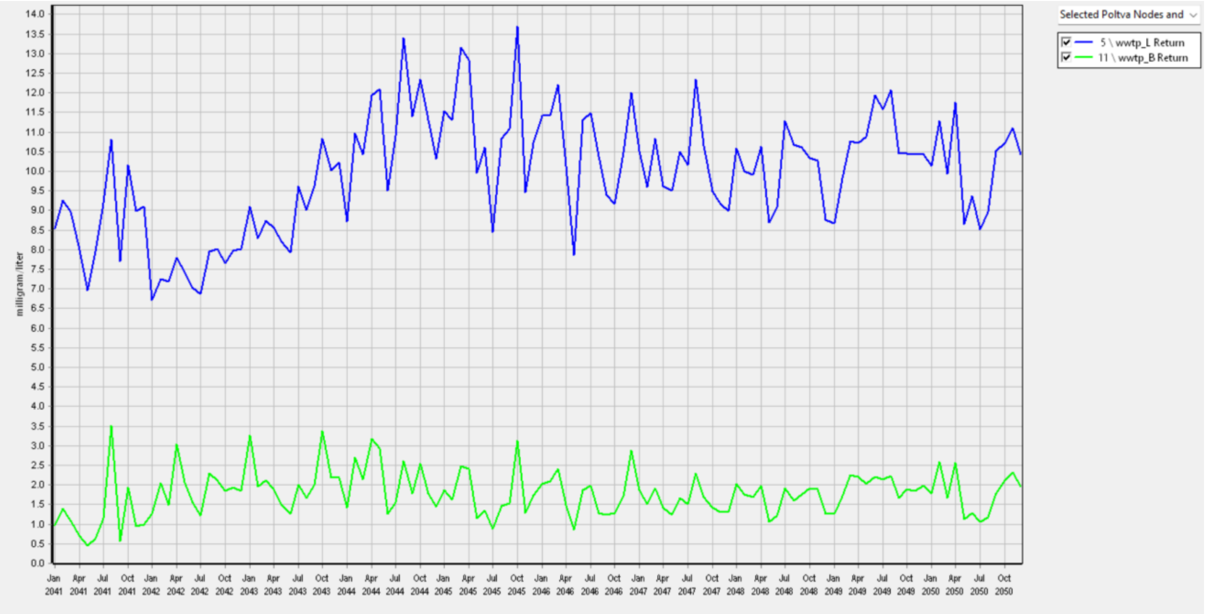

Figure 36 Return Flow BOD Concentration

Figure 36 shows the return flow concentration of BOD is reduced by 92.40% for Lviv treatment plant and by 90.06% for the Busk treatment plant.

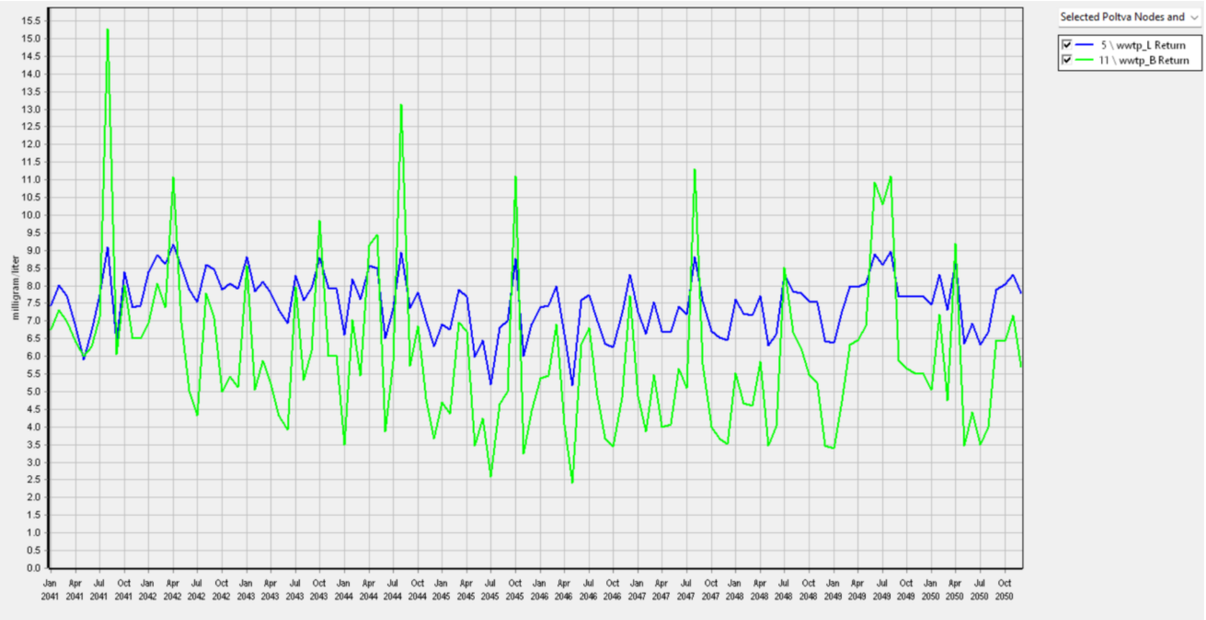

Figure 37 Return Flow N Concentration

On the other hand, the return flow nitrogen concentrations are reduced by 22.6% and 56.7% for Lviv and Busk treatment plants respectively which are shown by Figure 37.

As per the model it is evident that the load due to the presence of pollutants in the waste water treatment plant has increased significantly, therefore it is necessary to improve the efficiency of WWTP in order to incorporate and process the pollutants. It can be quite costly when water treatment plants are not running efficiently. The combination of inefficient and inefficient pumping and process equipment, along with obsolete water management procedures, can result in greater operating costs and lesser revenue generated, significantly impacting the bottom line of a treatment plant. (5 ways to improve water treatment plant efficiency, 08-2017, Retrieved February 8, 2023)

Technologies to improve Wastewater Treatment Plant efficiency in removing BOD and N

Addition of a tertiary wastewater treatment unit

The main treatment can be followed by an additional wastewater treatment to achieve better wastewater treatment results, according to Mažeikienė, 2019 a tertiary waste water treatment unit consisting of sorbing media and sand can improve the efficiency of BOD removal by 53% and N removal by 60 % on average. An example of such a tertiary treatment plant is shown in the Figure 38. The wastewater treatment plant shown is designed according to the European Standard EN12566-3 and can improve the overall efficiency of treatment by 1m^3/day, water is transferred from the Main unit to the tertiary unit without using any electricity and therefore low operating costs are associated with it and since no chemical reagents are used it is environmentally friendly.

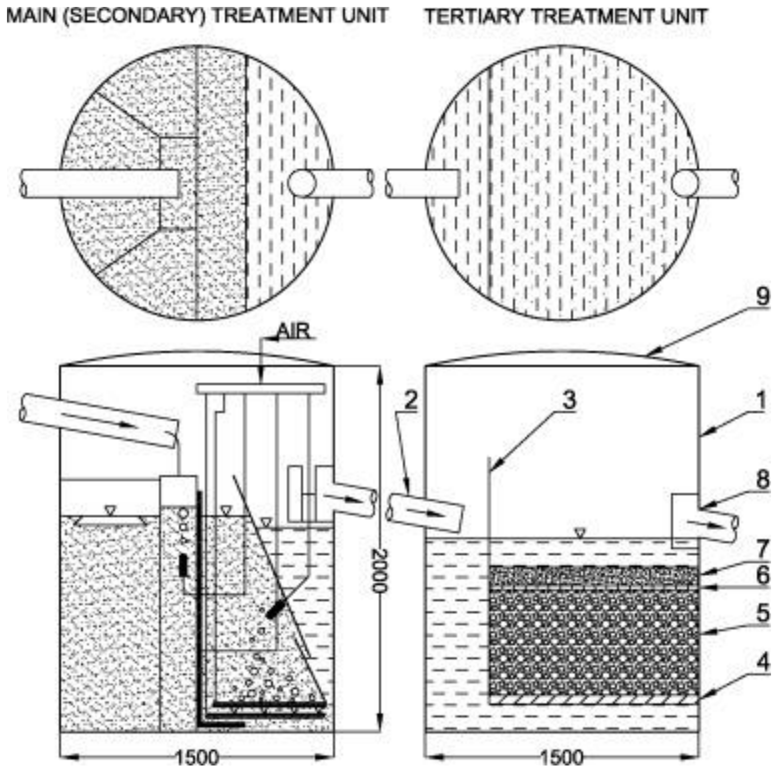

Figure 38 Tertiary Waste water treatment unit cross section with following components (Mažeikienė, 2019) 1 – radial carcass; 2 – inflow pipe; 3 – partition wall of the tank; 4 – grid to support sorbing media from the bottom; 5 – sorbing media; 6 – grid to support sorbing media from the top 7–8-cm supporting layer of quartz sand; 8 – three-way pipe; and 9 – tank lid.

Using Coagulants and artificial Neural network to determine the dosage of coagulant

Excessive coagulant dosage in the wastewater treatment process can cause a repulsion effect due to electronegativity, reducing treatment efficiency. Less coagulants, on the other hand, can have a negative impact on water treatment, so the optimal coagulant dosage must be chosen(Takić et al., 2019). To determine the optimal coagulant dosage, appropriate data about the effluents entering the plant must be obtained, for which an artificial neural network can be used to predict the values of waste water parameters in advance based on previous data from industry and other areas (Rustam et al., 2022), thus using the optimal coagulant dosage a significant drop in the BOD values can be seen thereby improving the waste water treatment plant efficiency.

Improving BOD removal efficiency by using WWTP with optimized trickling filter

Using a Biological trickling filter is really common in modern WWTP's to reduce the BOD and N, in these filters there are microorganisms attached to a medium to remove organic matter and hence reduce the BOD of the water, typically the enzymes used by these microorganisms are really sensitive and their effectiveness depends upon the pollutant loading in the water and pH. Hence selection of optimal kind of material for the trickling filter and appropriate microbes can improve the efficiency of the WWTP (Naz et al., 2015) .

Apart from these major measures suggested the following measures can be incorporated to make the WWTP more sustainable:

Upgrading equipment: Installing newer, more efficient equipment can help reduce energy and chemical consumption while also improving overall plant performance.

Implementing energy-saving measures: Energy-saving measures such as reducing aeration time or using more energy-efficient blowers can help reduce energy consumption and improve plant efficiency. (Jian Liu et al , 2019)

Implementing better management practices: better management practices, such as the use of real-time monitoring and control systems, can help improve the plant's efficiency and effectiveness.

Implementing a preventive maintenance program: A preventive maintenance program can help ensure that equipment is performing optimally and minimize downtime.

5. Conclusion

WEAP is a simplified hydrological model that is adequate to forecast water quality change over the years. BOD & N concentration for the years 2041 till 2050 was successfully forecasted using the model by inputting various parameters such as land cover change, demographic changes and change in water use.

The average yearly BOD & N has decreased over time even though there is decrease in precipitation due to a decrease in population growth, increase in city areas. The population of rural areas are decreasing and trend of decrease in agricultural area is also seen from this it can be inferred that people are relocating to urban areas.

There has been a significant increase in the Pollutant Load in the Water treatment plants in the cities especially in Lviv, due the presence of major industries in this area of the catchment.

As a consequence, the modeled findings appear to support the premise that climate change will have a detrimental influence on the ecological integrity of the river Poltva as water quality declines over time.

Water quality in the Poltva river can be attributable to the low efficiency of the wastewater treatment plants in cities. This study exemplifies the need for Eastern Europe to implement changes in water management to meet the challenges posed by climate change and meet the European Water Framework Directive.

Allocating funds to improve the efficiency of water treatment plants in Ukraine is critical for improving water quality, reducing environmental impact, and saving money in the long run. Efficient operations can also ensure a steady supply of clean water to homes and businesses, even during peak demand or emergencies. As a result, Ukraine must prioritize funding for improving the efficiency of its water treatment plants.

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Appendix

Appendix 1: Input data

Settings				EZG		Tabelle (ProblemDescription WesternBugStudyCase)
				L`viv	Busk	
Catchment	Land Use		c_B / c_L	no data entered at this level		Tab.2
		Area (km^2)	others	28	340	
			agriculture	45	1076	
		Crop Coefficient (Kc)	others	0.7	0.94	
			agriculture	MonthlyValues(Jan, 0.6, Feb, 0.6, Mar, 0.7, Apr, 0.9, May, 1.05, Jun, 1.2, Jul, 1.05, Aug, 0.95, Sep, 0.95, Oct, 0.8, Nov, 0.6, Dec, 0.6)		
		effective Precep.(%)		60	90	
	Climate	Precepitation (mm/mon.)		ReadFromFile(Prec.CSV)		
		Etref. (mm)		ReadFromFile(ETP.CSV)		
	Water Quality	BOD Intensity (kg/(km^2*a))	agriculture	5000		
		N Intensity (kg/(km^2*a))	agriculture	12000		
	Advanced			Rainfall Runoff (FAO)		
Demand Site	Water Use	Annual Activity level (cap.)	urban	700,000	8,000	Tab. 2
			rural	24,000	133,000	
			Industry [m^3/a]	3,300,000		
		Annual Water Use Rate (m^3/(cap*a	urban	100		
			rural	40		
		Consumption (%)		0		
	Water Quality	BOD Intensity (kg/person)	City	21.4		
			Village	20.3		
			Industry [t/a]	10000		
		N Intensity (kg/person)	City	4.3		
			Village	3.8		
	Advanced			Specific yearly demand and monthly variation		
Groundwater	Physical	Storage Capacity (m^3*1mio)		750	15000	Tab. 3
		Initial Storage (m^3*1mio)		375	7500	
		Hydraulic Conductivity (m/day)		3.3	3.3	
		Specific Yield		0.35	0.35	
		Horizontal Distance (m)		2000	5000	
		Wetted Depth (m)		5	2	
		Storage at River Level (m^3*1mio)		150	3000	
		Method		Model GW-SW flows		
River	Inflows And Outflows	Reach		Below G_L Inflow	Below G_B Inflow	Tab. 4
		Reach Length (GW) (m)	Poltva	3,000	53,000	
	Physical	Distance Marker (km) (Tailflowpoint)	Poltva	56		
		Flow stage width	Poltva	FlowStageWidthCurve(0, 0, 10; 1.5, 0.6, 10; 6, 1.5, 10; 15, 2.7, 10; 30, 4.2, 12; 45, 5.1, 15; 60, 6, 18) FlowStageWidthCurve(0, 0, 0, 1.5, 0.6, 10, 6, 1.5, 10, 15, 2.7, 12, 30, 4.2, 12, 45, 5.1, 15, 60, 6, 18)		
	Water Quality	Water Temperature		ReadFromFile("xxx")		
			°C	"WT.csv,2"	"WT.csv,1"	
Streamflow Gauges	Inflows And Outflows			ReadFromFile("xxx")		
		Discharge	m^3s^{-1}	"Q.csv,2"	"Q.csv,1"	
	Water Quality	BOD	mg/l	"BOD.csv,2"	"BOD.csv,1"	
		N	mg/l	"N.csv,2"	"N.csv,1"	
WWTP	Treatment	BOD Removal (%)		80	50	Tab. 5
		N Removal (%)		65	30	
Transmission Links		Loss to groundwater (%)		15		Tab. 7
		to Groundwater		G_L	G_B	
Runoff and Infiltration		Runoff Fraction (%)	to GW	30	65	Tab. 8
			to River	70	35	
Pollutant Decrease In Returnflow	from Agriculture	BOD Decrease (%)	to GW	95		Tab. 9
			to River	90		
		N Decrease (%)	to GW	85		
			to River	70		
	from Villages	BOD Decrease (%)	to GW	100		
		N Decrease (%)	to GW	50		
General	Years and Timesteps	Current Acconts Year		2000		
		Last Year of Scenarios		2010		
		Time Steps Per Year		12		
		Water Year Start		January		
	Water Quality Constituents			calculate by: Decay Rate Per Day	Note	Tab. 9
		Temperature		Temperature (Data)	data input for each reach	
		BOD (kg; mg/l)		BOD-Model	biochemical oxygen demand	
		N (kg; mg/l)		First-Order Decay = 0.2	(= NH4N + NO3N + NO2N)	

Appendix 1: Calibrated Data for base model

Instance	Variable/Parameter	Calibrated Value
Settlement	Annual activity level	
	v_L	24000
	Lviv	700000
	v_B	133000
	Busk	8000
	ind_L	0
	Consumption	
	v_L	1.706
	Lviv	1.5
	v_B	0.14
	Busk	6.126
	ind_L	1
Watershed	Kcf	
	c_L	
	Agriculture	Monthly values*0.79
	Others	0.61
	c_B	
	Agriculture	Monthly values*0.95
	Others	0.95
	Effective precipitation	
	c_L	
	Agriculture	64
	Others	62.5
	c_B	
	Agriculture	85
	Others	85
	ETref	Scaling factor of 1.11
	Precipitation	Scaling factor of 0.9
Groundwater	Storage Capacity	
	g_L	1000
	g-B	21000
	Initial Storage	
	g_L	500
	g-B	4500
	Hydraulic Conductivity	
	g_L	20
	g-B	14
	Specific Yield	
	g_L	0.2
	g-B	0.3
	Horizontal Distance	
	g_L	2000
	g-B	5000
	Wetted Depth	
	g_L	5.1
	g-B	2.8
	Storage at River Level	

	g_L	195
	g-B	2500
Run off and Infiltration	Run of fraction to GW	
	from c_L	
	to g_L	50
	to c_L Runoff	50
	from c_B	
	to g_B	60
	to c_B Runoff	40

BOD	N	Q	TOTAL SCORE
6.458	4.481	5.353	16.292

Calibrated parameters Total Score

Appendix 2 : Data Forecasting

Population Forecasting Functions

Area	Syntax Used for Projection
Village Lviv	GrowthFrom(-0.91%,2000,24000)
City Lviv	LinForecast(1989,790908, 2001,732818, 2014,729038, 2022,717273)
Village Busk	GrowthFrom(-0.91%,2000,133000)
City Busk	LinForecast(1989,8404, 2001,8673, 2014,8484, 2022,8662)

Land Use Forecasting Functions

Area	Syntax Used for Projection
Catchment Lviv Agriculture	LinForecast(1989,45, 2000,45, 2010,43.65, 2025,42.36)
Catchment Lviv Others	LinForecast(1989,28.075, 2000,28, 2010,28.56, 2025,28.8)
Catchment Busk Agriculture	LinForecast(1989,1076, 2000,1076, 2010,1044.79, 2025,1014.49)
Catchment Busk Others	LinForecast(1989,340.92, 2000,340, 2010,346.9, 2025,349.91)

Land Use Data Forecasted

Lviv Catchment		
Year	Agriculture	Others
1989	45.348	27.967
2000	44.615	28.178
2010	43.739	28.434

2022	42.863	28.691
2041	41.024	29.203
2050	40.236	29.46

Busk Catchment		
Year	Others	Agriculture
1989	339.583	1,084.15
2000	342.193	1,067.10
2010	345.369	1,046.70
2022	349.18	1,022.22
2041	355.215	983.461
2050	358.074	965.102

Population Data Forecasted

Lviv Catchment		
Year	Village	City
1989	26538	778058
2000	24000	750191
2010	21903	733430
2022	19989	716668
2041	16649	683145
2050	15195	666383

Busk Catchment		
Year	Village	City
1989	147,069.81	8,469.51
2000	133,000.00	8,551.87
2010	121,380.78	8,583.04
2022	110,776.65	8,614.21
2041	92,266.66	8,676.55
2050	84,206.01	8,707.72