Application of the WEAP model in evaluating the future water demand and its impact on water quality in the Poltva river basin

Scientific Report - MWW-27 Integrated Water Resources Management

Group-7

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IV. Acronyms and Abbreviations

a	Annual
bcm	Billion cubic meter
BOD	Biochemical oxygen demand
cap	Capita
eq	Equation
EU	European Union
EECCA	Eastern Europe, Caucasus and Central Asia
GW-	Ground Water
SW	Surface Water
Kc	crop coefficient Kc
km	kilometer
m	Meter
N	Nitrogen
NH_4	ammonium
R^2	coefficient of determination
RMAE	root mean square error
SDGs	Sustainable Development Goals
SEI	Stockholm Environment Institute
WEAP	Water Evaluation and Planning system
WWT	Wastewater Treatment
WWTP	Wastewater Treatment Plant

Abstract

Global challenges like water quality and scarcity are getting more and more serious, particularly in Ukraine. One of the cities in Ukraine where there is a serious water quality problem is Lviv, which affects social and economic development as well as the ecosystem. This city is located on the banks of river Poltva, one of the most polluted rivers in Ukraine. To prepare for the future and make informed decisions, it is essential to be able to evaluate the catchment's capacity to meet projected water demands. To evaluate the effects of potential water demands on the water resources of the Poltva catchment in 2060, a scenario analysis technique was employed in conjunction with the Water Evaluation and Planning model. The effects on water resources under the given scenario were compared to a "baseline" for 2010. The Poltva River's resources must be optimized to meet future population demands. In this study, the future water demand of the Poltva river basin is estimated mainly due to the change in population, agricultural usage and industrial development. The study will also focus on the effect of the change in the river water quality by representing the final BOD (Biochemical oxygen demand) and N (Nitrogen) concentrations.

The study is based on two scenarios, the first one being the current scenario from 2000-2010 and the second being the future scenario from 2010-2060. The current scenario reflects the current state of the Poltva basin while the future scenario tries to find the impact of current conditions on the future state of the region. The data was collected for the future scenario in terms of change in population, agriculture and industrial activity through extensive research and literature review. The obtained data were used to run the model in WEAP to obtain the change which might occur over the years. The results of this study show a significant decrease in population, agricultural productivity and industrial activity in the Poltva basin from 2010 to 2060. As a result, a constant reduction in water demand can be seen till 2060. The second analysis shows the improved condition of the water quality of the region due reduction in overall water consumption but still fails to reach the EU guidelines. It also compares the water quality to EU guidelines and concludes that the current and future water quality is way below European guidelines. To improve this situation, the study proposes to upgrade Lviv WWTP by adding a grease removal unit and decreasing the load on the activated sludge by pretreating the industrial wastewater before it is received by Lviv WWTP. Next, improvement in the treatment performance of Lviv WWTP from 80% to 95% BOD removal and from 65% to 70% N removal should be done. That leads to attenuating the source of contamination in the Poltva river from 90 mg/l to 18 mg/l BOD.

Keywords: Water resources management; Water demand; Water quality; Poltva river basin; Wastewater treatment

1. Introduction

By 2025, it is predicted that about two-thirds of all countries would be under water stress (UNEP, 2012). The fundamental issue may not be the average per capita lack of water, but rather the high expense of ensuring the availability of water where it is needed when it is needed, and in the required quality. Therefore, one of the top priorities of the Sustainable Development Goals (SDGs) of the United Nations is to ensure that everyone has access to good quality water and that water is managed sustainably by the year 2030 (Bos et al., 2016). Water resources are anticipated to become more vulnerable in terms of their quantity and quality whenever there is intense agricultural and industrial activity (Goharian, Burian Steven, Bardsley, & Strong, 2016).

The situation is made worse by the fragile institutional capacity of the important organizations working in the water policies sector in developing nations, and as a result, the quality of freshwater resources continues to degrade globally (Zimmerman, Mihelcic, Smith, & James, 2008). From the point of view of human usage, this often has the effect of raising the cost of water treatment and decreasing the supply of usable water. The contamination of freshwater resources is also attributed to rising population and economic development, although it is expected that future climate change will worsen water quality issues (WWAP, 2015). Therefore, future growth and its impact on water quality should be taken into consideration when developing management and adaptive methods for controlling and enhancing water quality.

1.1 Problem statement

Recent challenges like excessive groundwater exploitation, skewed water supply, demand due to population change, and the negative effects of climate change are making the situation of water security in the most populous and rapidly developing regions, particularly the cities of Ukraine, worse (T. I. Adamenko, 2016). Water demand in Ukraine's Poltva basin will change as a result of future economic and demographic development. Along with the change in demand, the quality of water in the river will also be affected. Currently, the most significant water quality issues in the Poltva River basin in the north-western region of Ukraine are due to mining, improper agricultural practices, developing urban areas, and the discharge of industrial effluent (Ertel et al., 2012; Odnorih, Manko, Malovanyy, & Soloviy, 2020). Water quality is anticipated to continue to change in the future as a result of change in population growth, agricultural productivity & industrial activity, and the effects of climate change. The treatment methods of the Waste Water Treatment Plant (WWTP), as well as BOD kinetics, will both be impacted by the altered water demand in the region.

1.2 Model Analysis

The ambiguity around the outcomes of anticipated future scenarios is enhanced by questions regarding data, models, and the effects of economic and social issues (Hughes, Kapangaziwiri, Mallory, Wagener, & Smithers, 2011). To support adaptive planning, uncertainty must be integrated into water resource planning. The interdisciplinary examination of numerous potential causes of water quality degradation and related solutions is necessary for the creation of water quality management strategies. For plausible wastewater production and treatment scenarios, mathematical models are frequently employed to simulate the contamination of aquatic bodies (Deksissa, Meirlaen, Ashton, & Vanrolleghem, 2004; Radwan, Willems, El-Sadek, & Berlamont, 2003). These models could be based on empirical research, condensed conceptual models, or physical facts.

Any model of water quality that is used in nations with low financial resources must not be overly dependent on data or difficult to use. Data accessibility, computation speed, and anticipated output variables with a policy-setting interface all play a role in the choice of a water quality model. The Stockholm Environmental Institute's Water Evaluation and Planning (WEAP) model, a decision support system, is frequently used for integrated water resource planning and management. It simulates water quality based on several scenario formulations.

1.3 Poltva basin

A tributary of the Bug, the Poltva is a river in the Lviv Oblast in western Ukraine. The Podilian Plateau and Roztichia are separated by the Poltva valley (Kubiĭovych, 1963). Lviv, the administrative centre of the Lviv Oblast, is situated on the river, with the river running underneath Lviv's main boulevard (Kubijowicz & Struk, 1984). The river used to have serious pollution issues (Nalecz, 2012). As a result, starting in 1839, the river was buried and integrated into Lviv's subterranean sewage system (Areta, 2018).

Along the banks of the Poltva, a small but important river in western Ukraine, the city of Lviv was born. Despite being only 60 kilometres long, the Poltva drains more than 200 creeks and streams before flowing into the western Bug River (Wilkinson, 2018). The river served as a vital conduit for trade, commerce, and security but soon because of excessive pollution, its muddy waterways turned into a pestilence breeding ground. An intolerable odour is frequently accompanied by swarms of flies and mosquitoes (Wilkinson, 2018).

Officials concluded that something needed to be done with the Poltva as the city started to modernize. It had long been a contributor to issues with public health like malaria outbreaks. The Poltva was therefore determined to be enclosed and covered, with the river being sent through the city's sewage system (Figure 1).

Figure 1: River being covered under the Svobody square, Lviv (Wilkinson, 2018)

1.4 Lviv WWTP

Facilities and equipment that treat Lviv's wastewater before being discharged to the Poltva have been operating without replacement for more than half a century (Tvoemisto, 2023). A loan for the upgrading of sewage treatment plants is now being negotiated by Lviv with the National Fund for Environmental Protection and Water Management of Poland (Tvoemisto, 2023). Experts estimate that Lviv will require at least 200 million euros to fully update current sewage treatment plants and construct new ones where they are deficient (Tvoemisto, 2023). Before entering the river, the Poltva's bank is where the effluent from eight hundred thousand residents is treated. Three hundred thousand cubic meters of wastewater are treated on the left bank each day, compared to around 100,000 on the right. In short, the facilities need massive improvements because urbanization, agriculture, and industrial activities keep changing on the daily basis.

Almost 25% of wastewater comes from industrial facilities (Tvoemisto, 2023). The treatment process consists of two stages – physical and biological – as seen in Figure 2. In the physical treatment stage, there are screens, sand trips, grit removals, and then settling tanks. On the other hand, the biological stage consists mainly of activated sludge.

When excessively concentrated wastewater enters biological reactors, activated sludge can die. Then the biological cleaning stops. The water becomes bright red and smelly. The culprits are industrial enterprises that do not have treatment facilities and discharge chemically contaminated wastewater into the sewers (Tvoemisto, 2023).

Figure 2: Satellite image of Lviv wastewater treatment plant

Most research indicates an increasing threat along the Poltva River produced by an overloaded WWTP of Lviv equipped with degrading treatment technology as the primary point source of contamination of the Western Bug River (Ertel et al., 2012; HELCOM, 2005). Figure 3 illustrates how the Poltva river suffers from excessive pollution. Excluding the nitrate, none of the water quality parameters satisfies current Ukrainian and European water quality standards, obstructing the formation of a normal aquatic ecological balance and increasing the health threat for local rural inhabitants living near the river. They depend on private wells to extract water from rivers or groundwater aquifers for drinking water, agriculture, and livestock farming.

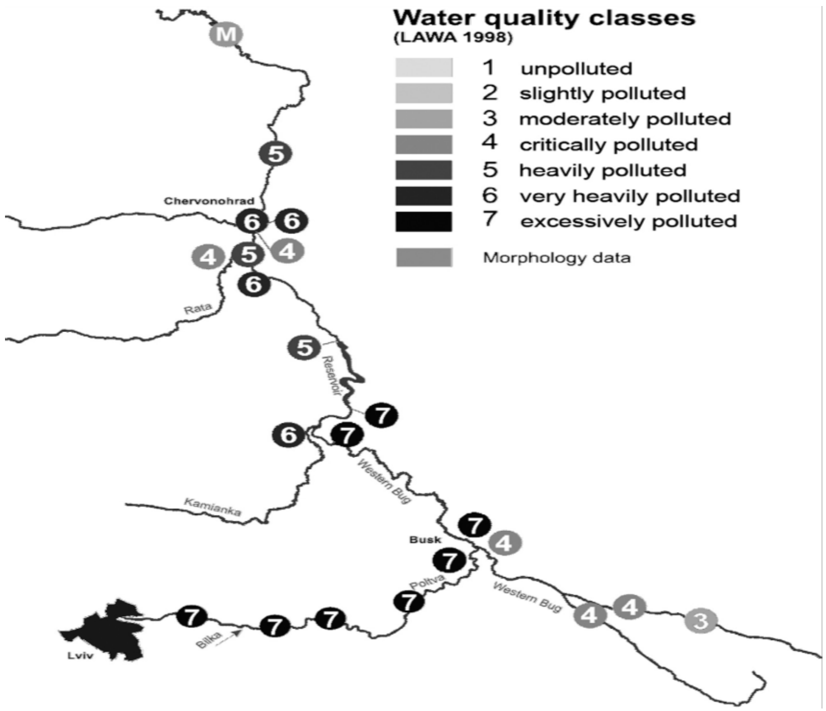


Figure 3: Water pollution in the Western Bug River (Hagemann et al., 2014)

1.5 Objectives

The objective of this study is to analyze how the river Poltva's hydrological conditions are evolving in light of projected changes in population, agriculture practices, and industrial development, with regard to a future reference scenario (2010–2060). This study will use the Water Evaluation and Planning (WEAP) mathematical model to estimate the future water demand of the Poltva basin. The main objectives of the study are summarized as: -

1. Estimate the water demand for the future scenario (2010-2060) of the Poltva basin based on changes in population, agricultural practices, and industrial usage using the Water Evaluation and Planning (WEAP) model.

2. Compute the changes in water quality of the river and aquifer, BOD and N in particular, for the future scenario (2010-2060).

3. Propose changes in the water management system to sustain the supply of targeted water quality with respect to the forecasted water demand.

2. Materials and methods

2.1 Modelling Software

In this study, the software WEAP is used for modelling and performing simulations for several scenarios. WEAP is a simulation tool for integrated water resource planning that examines water supply systems in the context of ecosystem protection and preservation, water quality, and water consumption demand. It is developed by the Stockholm Environment Institute (SEI), a non-profit worldwide scientific research organization that has spent more than 20 years researching environmental and development challenges at the local, national, regional, and global policy levels (WEAP, NA).

2.2 Model Setup

As the first stage of simulation, A preliminary conceptual model of the research area was made using WEAP software (Figure 4). As shown, two catchment areas were taken into account which are Lviv and Busk. For each catchment, two demand sites (urban and rural) and one groundwater were added. Lviv catchment also has industry water demands. The data in Table 1 were employed as starting points to build a basic model of the study region. Next, the sensitivity analysis was carried out to find the most sensitive parameters in the model. Then the model was calibrated for stream flow in two gauges placed at the exit of each catchment in the study area.

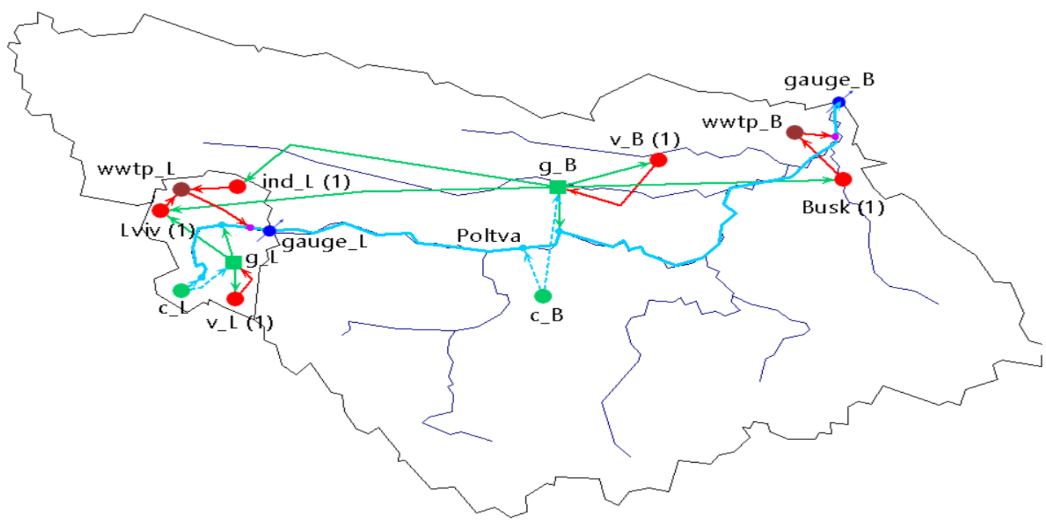


Figure 4: The preliminary conceptual model of the research area was made using WEAP

2.3 Catchment

Several parameters were taken into consideration in modelling the catchment. For instance, land use and climate parameters were simulated in the initial model. We employ crop coefficient (Kc) and effective precipitation both in terms of agriculture and others for the land use part. while precipitation and evapotranspiration were used for Lviv, and Busk catchments located upstream and downstream respectively.

Also, different physical groundwater parameters were simulated by using the recommended GW-SW coefficient method to estimate the specific yearly demand and monthly variation for the two catchments.

2.4 Calibration

The model was run using several input data for both surface and groundwater. The results from the model run were exported to excel files and later compared to the original evaluation sheet using specific target functions. The target functions used include root mean square error (RMAE), and coefficient of determination (R^2) were used to observe the total, annual, seasonal, and monthly variation for Lviv and Busk respectively. A similar simulation was done for the sensitivity analysis using several parameters at different intervals with results compared to the original sensitivity sheet to find out which parameter is more sensitive to the model to perform the model calibration.

To calibrate the model, sensitivity analyses were performed for all 14 hydrology-related parameters taking into consideration the recommended ranges by Helm and Rojas (2021). It was concluded that the most sensitive parameters are initial storage, runoff fraction, precipitation, reference evapotranspiration, crop coefficient, effective precipitation, and consumption. Playing within the recommended ranges of these parameters, the model was calibrated.

Table 1: Parameter values before and after calibration

Parameter	Catchment	Class	Pre-calibration value	Post-calibration value
Runoff fraction (%)	Lviv	To GW	30	32.9[1]
		To River	70	67.1[1]
	Busk	To GW	65	64.8[1]
		To River	35	35.2[1]
Precipitation (mm/month)	Lviv	-	1[2]	1.3[2]
	Busk	-	1[2]	1.3[2]
ET (mm/month)	Lviv	-	1[2]	0.7[2]
	Busk	-	1[2]	1[2]
Kcf	Lviv	Others	0.7	0.5
		Agriculture	1	0.5
	Busk	Others	0.94	1
		Agriculture	1	1
Eff. Precipitation (%)	Lviv	-	60	50
	Busk	-	90	60

1. Setted with monthly variation to substitute the snow accumulating and melting.
2. Multiplying the given monthly variation data of precipitation, evapotranspiration, and crop coefficient by the factor value.

Table 1 illustrates the assigned values of the sensitive parameters to calibrate the model. However, there was an issue in the calibration process which is a lack of matching between the seasonal observation measurements and model data because of the phenomenon of snow accumulation and melting. That leads to receiving water from rainfall in the model which is not active because it accumulates on the surface, with no infiltration nor runoff. Unfortunately, the snow behaviour cannot be simulated in WEAP, so this issue was solved by changing the value of the runoff fraction monthly to obtain an acceptable matching in the seasonal measurements.

Wastewater Treatment plants were added to both catchments, as illustrated in (Figure 4), to simulate water quality. For the elements of water quality, specifically BOD and nitrogen, sensitivity analysis and calibration were carried out using the water quality parameters presented in the table as input.

Table 2: BOD and Nitrogen removal rate of wastewater treatment plant after calibration

Lviv	BOD Removal %	MonthlyValues(Jan, 56, Feb, 50, Mar, 38, Apr, 61, May, 85, Jun, 53.5, Jul, 00, Aug, 56.5, Sep, 72, Oct, 56, Nov, 66, Dec, 80)
	N Removal %	MonthlyValues(Jan, 56.5, Feb, 61, Mar, 61, Apr, 64, May, 59, Jun, 61.5, Jul, 59, Aug, 59, Sep, 60, Oct, 60, Nov, 60, Dec, 58)
Busk	BOD Removal %	MonthlyValues(Jan, 50, Feb, 55, Mar, 10, Apr, 60, May, 10, Jun, 15, Jul, 10, Aug, 15, Sep, 10, Oct, 15, Nov, 10, Dec, 55)
	N Removal %	MonthlyValues(Jan, 20, Feb, 25, Mar, 35, Apr, 35, May, 25, Jun, 25, Jul, 25, Aug, 35, Sep, 30, Oct, 32, Nov, 32, Dec, 35)

For the further calibration of the model, pollutant decrease while flowing through the link in Busk catchment has also changed as follows:

Table 3: Pollutant decrease through the link in Busk

BOD Decrease %	To GW	MonthlyValues(Jan, 30, Feb, 50, Mar, 12, Apr, 0, May, 92, Jun, 60, Jul, 40, Aug, 35, Sep, 90, Oct, 55, Nov, 38, Dec, 5)
	To Runoff	MonthlyValues(Jan, 80, Feb, 80, Mar, 88, Apr, 100, May, 8, Jun, 40, Jul, 60, Aug, 65, Sep, 0, Oct, 45, Nov, 62, Dec, 100)
N Decrease %	To GW	85
	To Runoff	MonthlyValues(Jan, 0, Feb, 05, Mar, 100, Apr, 100, May, 30, Jun, 33, Jul, 00, Aug, 100, Sep, 68, Oct, 77, Nov, 85, Dec, 100)

The values obtained after the final calibration are shown in Table 4:

Table 4: Total score values of the final calibrated model

Name	Streamflow (Q)	BOD	Nitrogen	Total
Calibrated value	3.235	4.643	2.730	10.608

2.5 Scenarios

Based on the objective of this project, a scenario is considered to forecast future water demands and water quality, and the data obtained is used as input to the calibrated model. It is based on the assumption that the recent population, land use and change in industrial activities are presumed to continue till 2060 (Impact of current ongoing Russia-Ukraine war is not considered in this study). To keep the focus on the effect of population change on water demand, the scenario assumes that the water consumption rate will remain the same as the current scenario for the years 2000-2010.

2.5.1 Current Scenario (2000 – 2010)

The study area is 2500 km², of which 70% is the agricultural area (1750.0 km²) (Helm & Rojas, 2021). Table 5 shows the data for population, agricultural, and industrial water demands for this scenario.

Table 5: Population, water consumption, and land use in each sector per year

Class	Use	Lviv	Busk
Annual Activity level (cap.)	urban	700,000	8,000
	rural	24,000	133,000
Industry [m³/a]	Industry	3,300,000	-
Annual Water Use Rate (m³/(cap*a))	urban	100	100
	rural	40	40
Area (km²)	Others (non - agriculture)	28	340
	agriculture	45	1076

2.5.2 Future scenario (2010-2060)

2.5.2.1 Population

In this scenario, the population is projected for the year 2060. Based on Kummu, Taka, and Guillaume (2018), the urban population of Lviv and Busk is projected to be 673,787 and 5,074, respectively. The rural area population is assumed to remain the same as for the given future scenario since we couldn't find any literature specifically regarding the rural population. Finally, we interpolated the population with linear regression between 2010 and 2060 (Figure 5).

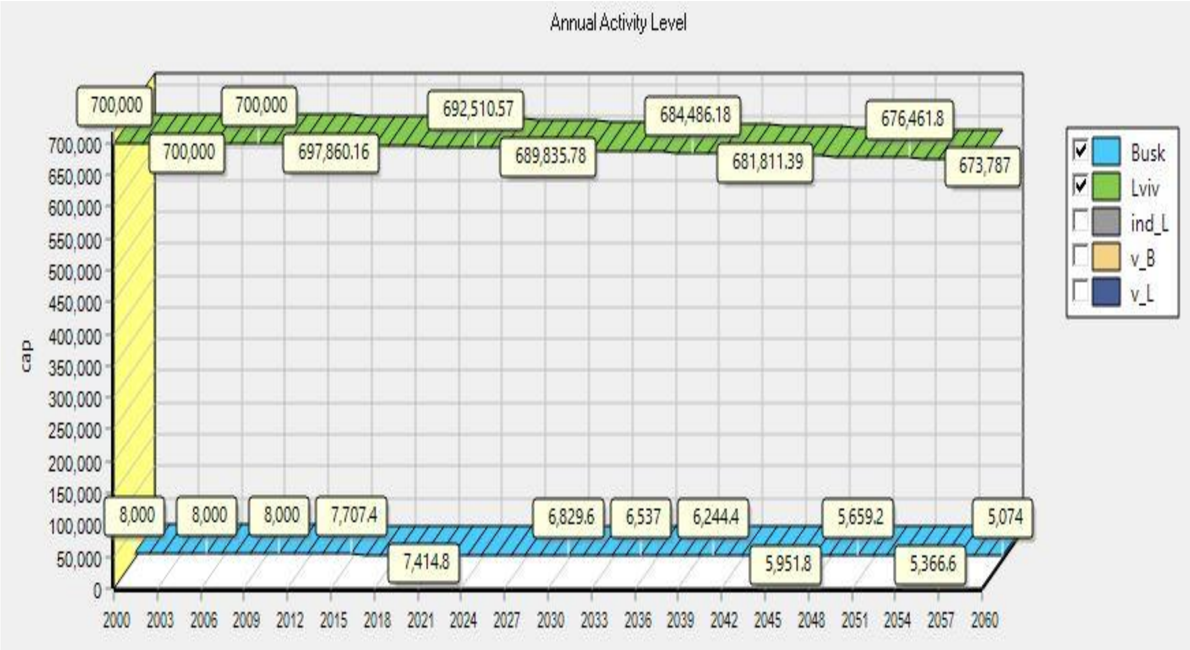


Figure 5: The changes in population from 2000 to 2060.

2.5.2.2 Industrial water use

The average industrial production rate decreases at a rate of -0.1% (Knoema, 1995-2012). Hence, we expect the industrial water requirement to decrease in our future scenario. As there were no data specifically for Lviv's industrial water withdrawal trend, we assume Lviv's industrial water withdrawal trend to be the same as the pattern of Ukraine's. In Figure 6, we can see Ukraine's agricultural and industrial water withdrawal in the years 1992, 2000, 2005, 2010, and 2016. Considering Ukraine as a closed system in terms of water consumption, the water withdrawal equals water consumed (water demand).

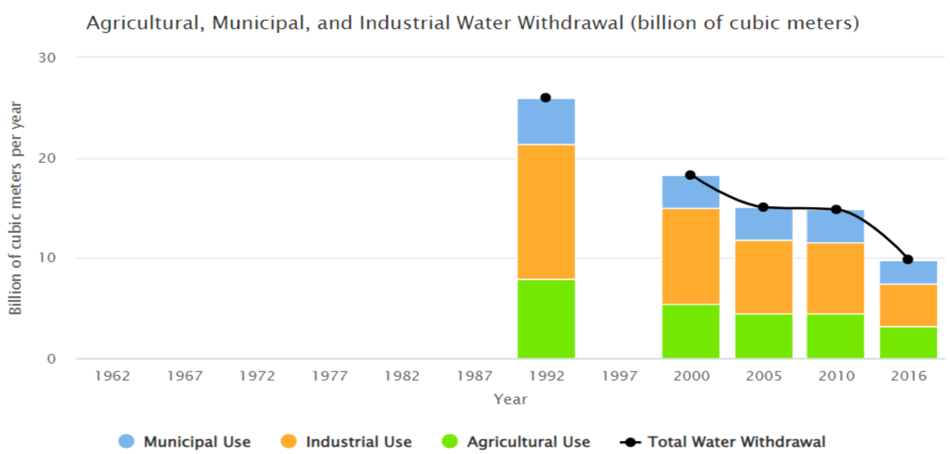


Figure 6: Water withdrawal from each section and trend in Ukraine (Worldometer, 1992-2016)

From 2010 to 2060, the share of industrial water uses in Ukraine reduced from 9.486 bcm (Billion cubic meters) to 7.126 bcm (Billion cubic meters). We calculated the reduction rate with the help of eq.1 and used this rate as the input of the "Growth" function in the WEAP software to extrapolate the industrial water use in 2060.

$$rate = 1 - \left(\frac{Value_{in\ 2010}}{Value_{in\ 2000}}\right)^{0.1} \qquad eq.1$$

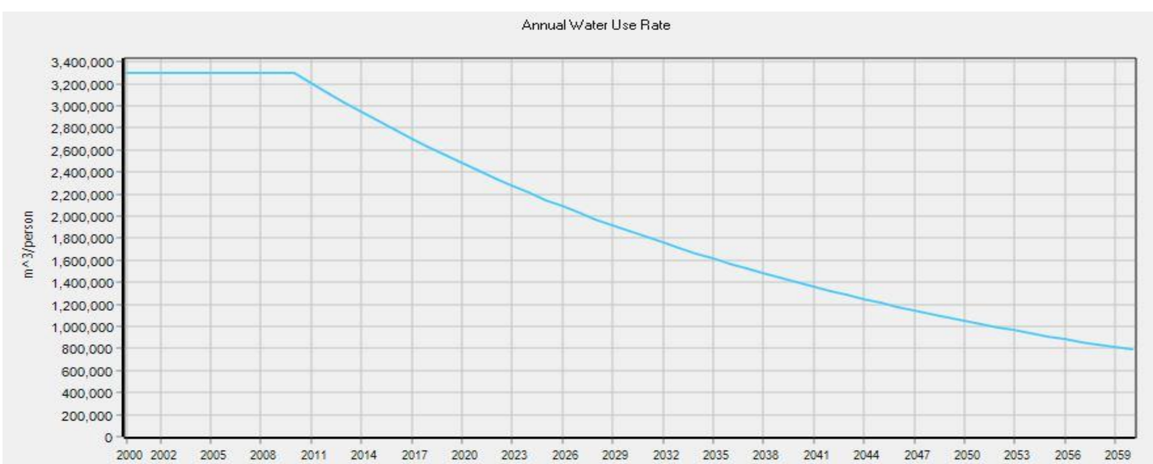


Figure 7: The annual water uses of industry in Lviv from 2010 to 2060

The rate of industrial water use for the region is represented in the graph (Figure 7) from 2000 to 2060 which shows a drop in total consumption from 2010 to 2060.

2.5.2.3 Agricultural land use

Burmeister and Schanze (2016) analysis shows a significant grassland-arable land exchange and mixing of different forest types. We focused mainly on arable land in our study as it is used for agriculture, with a reduced rate of 2.9% per 10 years (Table 6). With eq.1, the rate for each year was calculated as 0.6421%. Therefore, we can estimate the land changes in Lviv and Busk up to 2060. Figure 8 shows the changes in agricultural and other (non-agricultural) areas in Busk.

Table 6: Results of land-cover change between 2000 and 2010 in percentage (Burmeister & Schanze, 2016)

Land cover classes		Artificial surface	Arable land	Broad-leaved forest	Coniferous forest	Natural grassland	Water bodies
∑	2000	11.3	47.2	17	4.3	19.9	0.3
	2010	13.3	44.3	13.9	4.8	23.5	0.3
2000 - 2010	Persistence	10.7	36	12.5	3.1	11.3	0.2
	gross gain	2.5	8.3	1.4	1.7	12.1	0.1
	gross loss	0.6	11.2	4.5	1.2	8.6	0.1
	net change	1.9	2.9	3.2	0.6	3.6	0
	total change	3.1	19.5	5.9	2.9	20.7	0.2
	swap	1.2	16.6	2.7	2.3	17.1	0.2

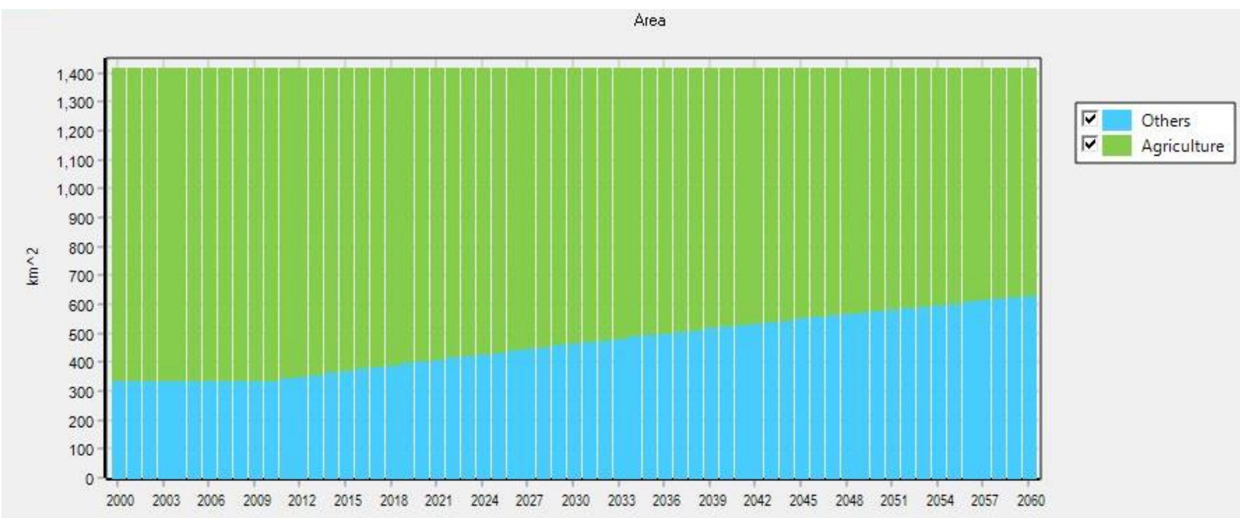


Figure 8: The Busk area changes from 2000 to 2060.

The summary of the calculation outputs for the year 2060 is shown in Table 7. We use these values for our input data in the WEAP model to estimate the future water demand and respective BOD and N concentration.

Table 7: Estimated population, water consumption, and land use in each sector per year in 2060

Class	Use	Lviv	Busk
Annual Activity level (cap.)	urban	673,787	5,074
	rural	24,000	133,000
	Industry [m³/a]	789,512	-
Annual Water Use Rate (m³/(cap*a))	urban	100	100
	rural	40	40
Area (km²)	others	40	632
	agriculture	33	784

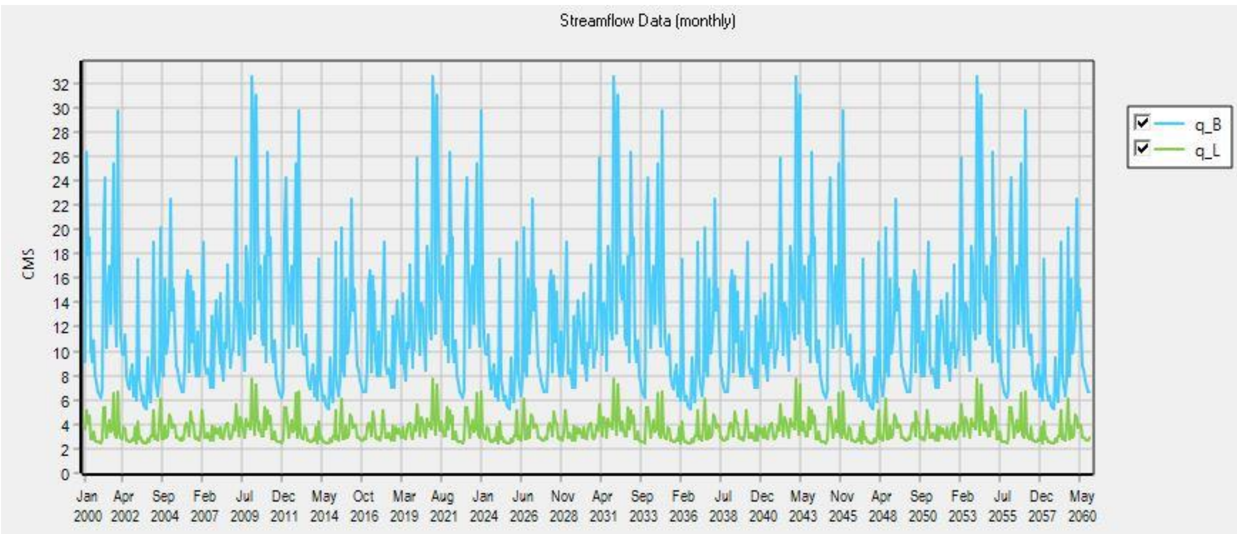


Figure 9: Cyclic variation of streamflow in Busk and Lviv

The above graph (Figure 9) shows how the stream flow for the future scenario period has been observed in the model. There is a special function In WEAP software called cycle. Using this function, the data has been replicated 5 times to take the stream flow till 2060. "Streamflow will be repeated" per 10 years was assumed. The same assumption was made for the following values and taken as cyclic values till 2060 for the future scenario.

1. Water quality data BOD for Busk and Lviv
2. Water quality data N for Busk and Lviv
3. Water temperature Poltva
4. Monthly precipitation
5. Monthly evapotranspiration

As the main focus of the study is to only analyze the change in water demand due change in population, agriculture and industrial activities. Hence, change in climatic factors were assumed to vary in a cyclic manner based on observed data for 10 years already calculated for the current scenario (2000-2010)

2.6 Water Quality

To compute the water quality of the Poltva river basin, BOD (Biochemical Oxygen Demand) and N (Nitrogen) loads were analyzed. Several other studies have suggested that there is a lack of sufficient wastewater treatment plants in both Lviv and Busk (Halyna, Marta, Natalia, & Stepan, 2019) and that there are more BOD and N loads introduced into the Poltva basin which largely deteriorates water quality and this trend may continue unless improvements are made. Correlation between population growth and pollutants loads, for our case BOD and N loads in both surface and groundwater will be direct base on the existing trend. Meaning, as already discussed above, the population of the Poltva basin is changing, which might affect water quality.

Most parts of Lviv and Busk have since moved towards the production stage, and several industries have been built along the Poltva river basin (Odnorih, Manko, Malovanyy, & Soloviy, 2020). The industrial effluents released into the river negatively impact the water quality as depicted by our current scenario. However, since industrial water demand is projected to reduce, the water quality might not be significantly affected in our future scenario (2010-2060).

Regarding agriculture, excessive fertilizers (e.g., N from ammonium) used in crop production are also introduced into the basin which could deteriorate the water quality (Mateo-Sagasta, Zadeh, Turral, & Burke, 2017). This has several impacts both on humans and living organisms in the water body. Given that Ukraine's towns are mainly dependent on agriculture, the use of fertilizers for agricultural food production will probably increase. Nevertheless, the arable agricultural area is projected to decline in the future scenario (2010-2060). It is almost certain that their future agricultural water demands will change along with an increase or decrease in the concentration of contaminants.

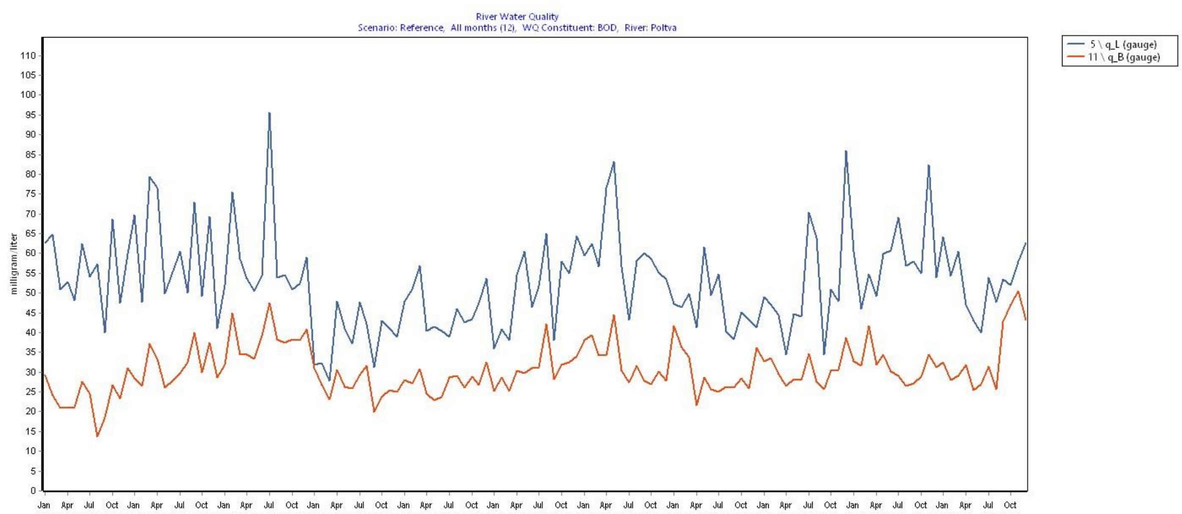


Figure 10: BOD concentration in the current scenario (2000-2010)

Figure 10 indicates BOD concentration for the gauge at Lviv is on average 63mg/L and that of Busk is about 30mg/L in the current scenario (2000-2010). This present concentration is far above the minimum BOD concentration from EECCA (Eastern Europe, Caucasus and Central Asia) guidelines (Ukraine is a member of EECCA) which implements allowable concentration in rivers.

The EECCA guideline states that the mean concentration of BOD for wastewater discharged into the river should be 25 mg/L (Dombrowsky, Hagemann, & Houdret, 2014). This guideline is the same as that of EU (European Union) set standard for BOD limit into rivers of European rivers.

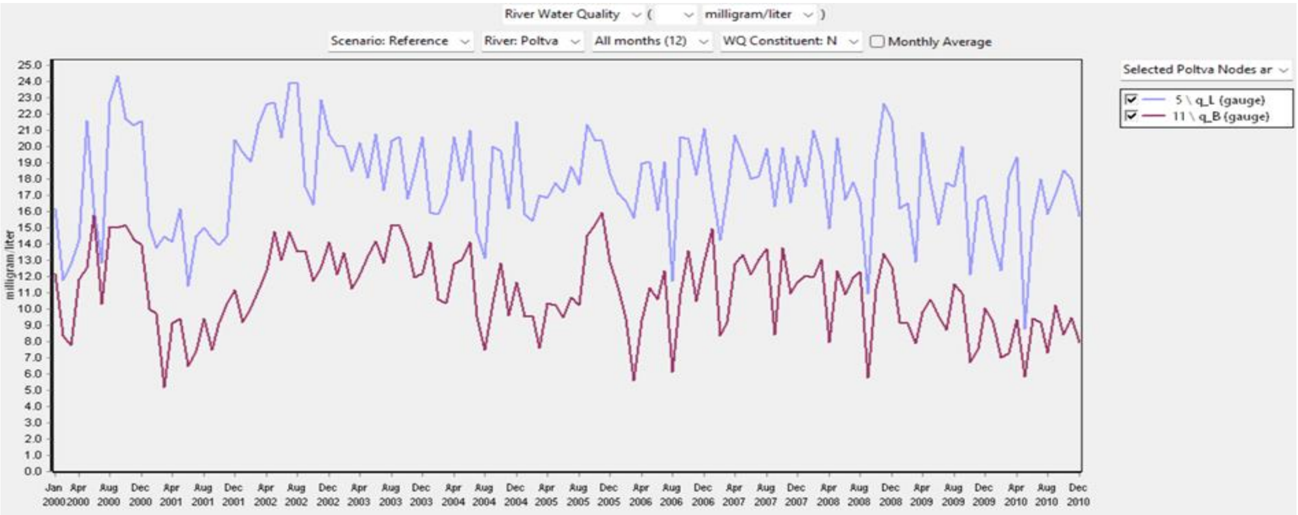


Figure 11: N concentration in the current scenario (2000 - 2010)

In the current scenario, Figure 11 shows that the N concentration for the gauge at Lviv is around 16 mg/L and that of Busk is approximately 12 mg/L. This amount is also slightly above the EECCA thresholds for permissible N content in rivers. According to EECCA guidelines, the mean concentration of nitrogen (N) for wastewater discharged into the river should range from 10-15 mg/L (Dombrowsky et al., 2014). Again, this threshold is similar to that of EU standard. Hence, improvement in wastewater treatment technologies is required to lower both the both the BOD and N concentration in future scenario.

3. Results

3.1 Future scenario with the existing condition

3.1.1 Streamflow

The graph in figure 12 shows how the BOD of future runoff to Poltva varies. The fluctuation is directly affected by the calibration and the repeated cyclic behaviour of the precipitation and BOD inputs. Though the overall values have a declining trend for BOD, Lviv is comparatively higher than Busk. But the average value of BOD for both catchments is above the allowable EECCA, and EU limit guidelines as explained in the water quality chapter. Because of this reason, the existing treatment plant needs upgrade or introducing a new treatment plant is essential for both catchments.

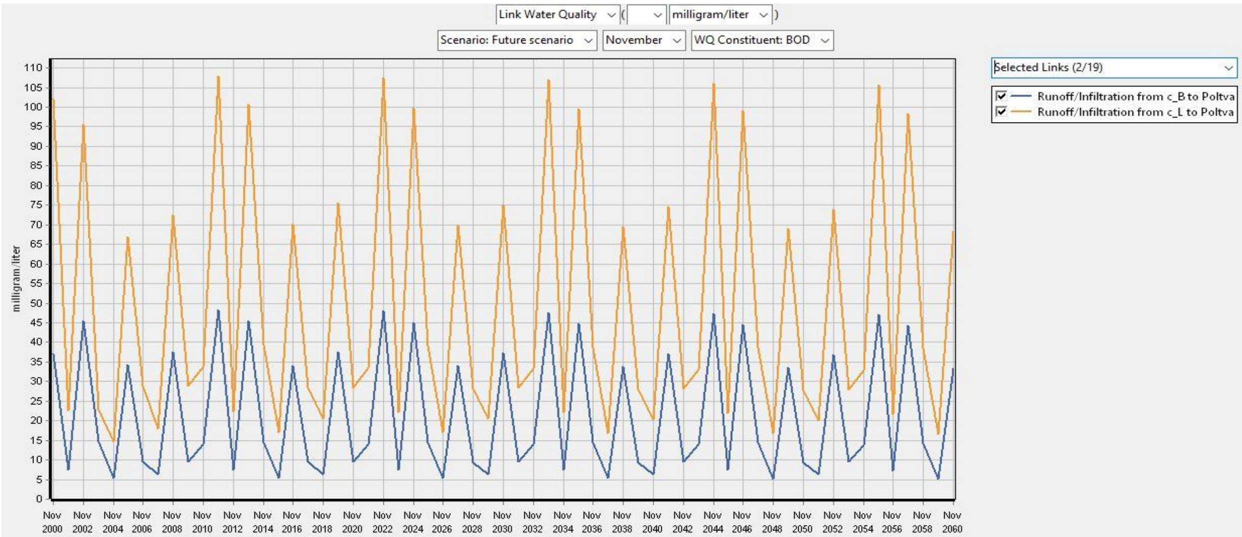


Figure 12:Change in the Water quality received by Poltva

3.1.2 Water demand

After adding all the data in the model regarding the change in population, industrial usage and agricultural productivity for our future scenario (2010-2060), a graph of water demand was plotted for the entire Poltva basin represented in figure 13. As it can be seen at first water demand remains constant for our current scenario from 2000 to 2010 which was our initial assumption.

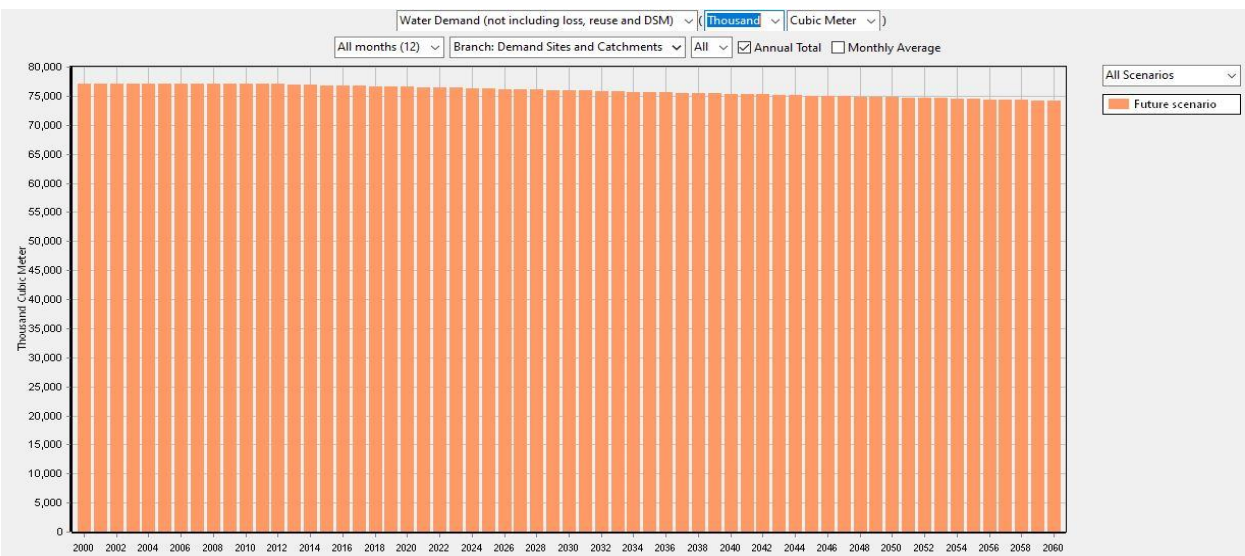


Figure 13: Water demand for the entire catchment (2000-2060)

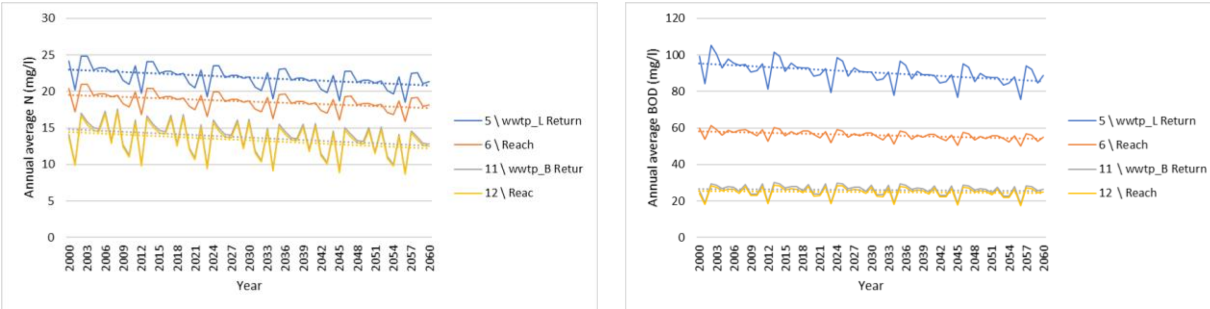
Then a constant decrease in demand can be seen from 77,000 thousand (77 million) m^3 in 2010 to 74,166.10 thousand (74.17 million) m^3 in 2060. The major cause of this decrease in demand over time is the fact that the population in our catchment is decreasing along with a fall in industrial water consumption. Also, we have already seen that the agricultural area and productivity are also decreasing. A combined effect of all this leads to a decrease in water demand by 2060.

Figure 14: water demand shown separately in each catchment area of the Poltava basin.

In the graph (figure 14) shown above, water demand of each catchment in Poltva basin is represented individually where a common trend of reduction in water demand for each component can be seen. For Lviv, the water demand falls from 70,000 thousand (70 million) m^3 in 2010 to 67,380 thousand (67.38 million) m^3 in 2060 mainly because there is a drop of over 26 thousand people in the total population of the entire city which reduces the consumption. A similar trend is seen in Busk where the demand decreases to 507.4 thousand (0.5 million) m^3 by 2060. In Busk, it is mainly due to the decrease in the agricultural area from 1076 km^2 to 784 km^2 by 2060. While in villages of both Lviv and Busk, the demand remains more or less constant as in this study we assumed the population of villages to be constant.

3.1.3 River Water Quality

The water quality of the river is very poor and does not meet the EECCA (Eastern Europe, Caucasus and Central Asia) and EU (European Union) standards (BOD 25 mg/l and N 15 mg/l) as mentioned in sections 1.4 and 2.6. As illustrated in Figure 15, the WWT that is dumped into the river from Lviv WWTP carries on average BOD of 90 mg/l and N of 22 mg/l which is the major source of pollution of the river. That results in poor quality in the river as seen 6 / Reach (just after the WWTP). On the other hand, the river water quality in Busk has a slight difference compared with the EECCA and EU standards. This is attributed to the dilution process due to the runoff received in the river before the Busk WWTP effluent. Generally, the water quality of the Poltva river will slightly improve over the next 60 years of simulation because of the decrease in water demand in the domestic, industrial, and agricultural sectors.

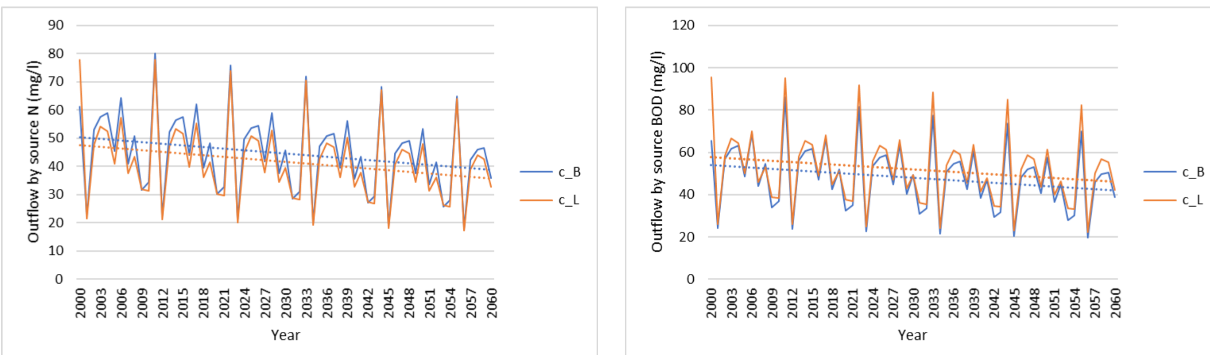


(a) (b)

Figure 15: River water quality, annual average (a) nitrogen (mg/l) and (b) BOD (mg/l)

3.1.3.1 Outflow water quality

The catchment areas of Lviv and Busk consist of two types of categories: others and agriculture. The other category produces much less pollution compared with agriculture in both catchments. Additionally, since Busk has much more area than Lviv, 1416 and 73 km^2 relatively, more pollution load is produced from Busk than from Lviv (Figure 16).



(a) (b)

Figure 16: Water quality of outflow by source, average annual (a) N (mg/l) and BOD (mg/l)

3.2 Future scenario with increased WWT capacity

The wastewater treatment in Lviv had been deteriorating for a long time severely polluting the Poltva river which is upstream of the Western Bug River as discussed in Section 1.4. WWTP is suffering from technical and operational problems as well as overloading. These problems need to be tackled to attenuate the pollution in the Poltva river to meet European and Ukrainian standards.

First, the WWTP does not have a grease removal unit (Tvoemisto, 2023) which negatively affects the efficiency of the biological treatment (activated sludge) (Kommalapati & Johnson, 2001). Also, there is a considerable flow that comes from the industrial sector without treatment carrying a huge load of chemical and organic contaminants, especially in BOD (25 thousand tonnes) as seen in Figure 18 while the N is relatively minor (almost zero) as shown in Figure 17. Also, the capacity of the activated sludge needs to be increased.

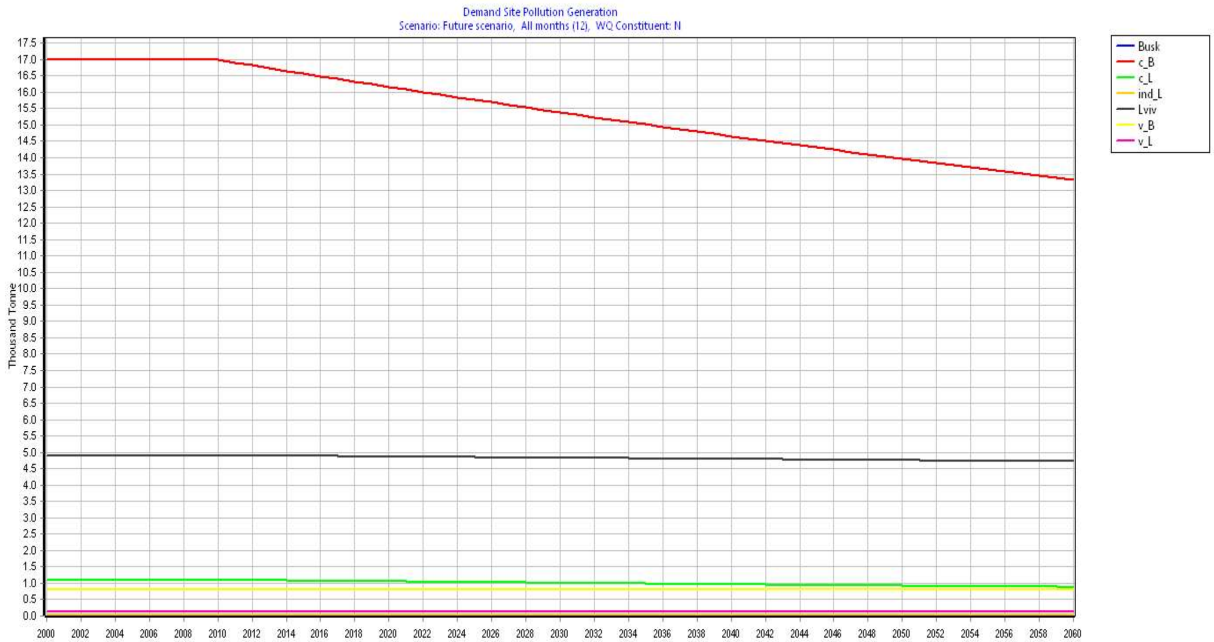


Figure 17: Demand site pollution generation, N (tonne)

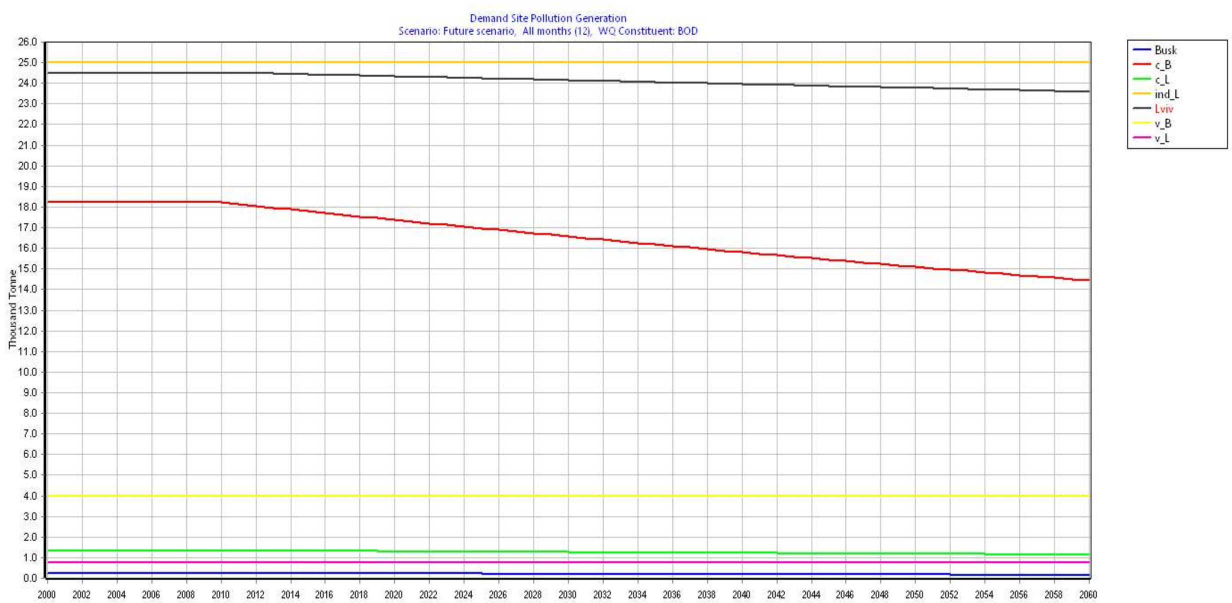


Figure 18: Demand site pollution generation, BOD (tonnes)

In this scenario, a WWTP was added to treat the industrial wastewater before sending it to the main WWTP (Figure 19). The function of the industrial WWTP is to decrease the pollution load in the industrial effluent, which is the highest source of BOD as seen in Figure 18, resulting in improving performance of Lviv WWTP. Also, the efficiency of the Lviv WWTP increased to 95% BOD removal and 75% N removal assuming this enhancement is due to tackling the above-mentioned issues. Figure 20 shows the water quality at the river and the effluent of the WWTPs. There is a significant improvement in the water quality as a result of Lviv WWTP upgrading and the addition of WWTP for industrial effluent (Figure 20). After implementing the proposed procedures in this scenario, a good meeting with the EECCA and EU standards is expected according to the simulation.

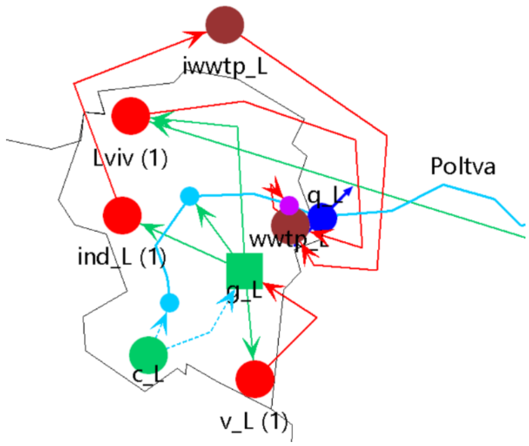
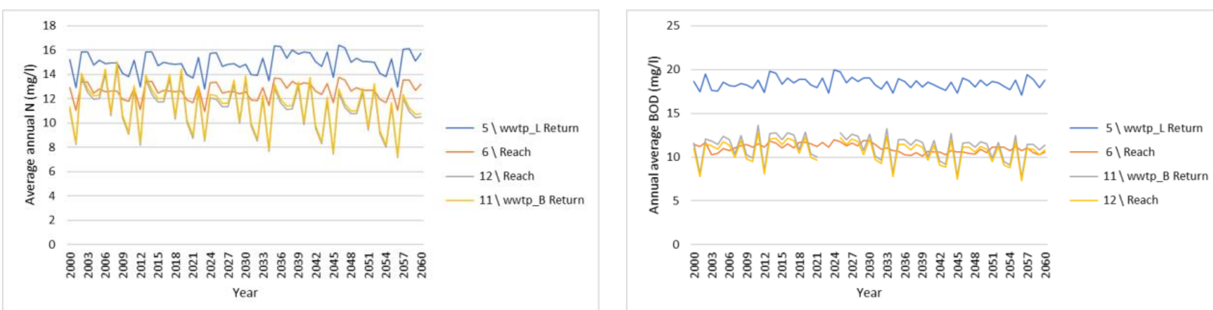


Figure 19:The addition of WWTP downstream of the industrial effluent



(a) (b)

Figure 20:River water quality after upgrading, annual average (a) N (mg/l) and (b) BOD (mg/l)

4 Discussion and Conclusions

The study estimates the future water demand for the Poltva basin using different management scenarios in WEAP. The two scenarios focused on in this study are the current scenario (2000-2010) and the future scenario (2010-2060). The results show a gradual decrease in water demand in the entire catchment. The fall in demand can be explained by the fact that the population, agricultural productivity and industrial usage are all decreasing till 2060. The decrease in population and agricultural productivity can be due to Poor health conditions and improper use of alcohol and drugs (Temnycky, 2020). The coronavirus pandemic has only aggravated these issues which have led to Ukraine being one of the countries with the highest death rates in the world. Secondly, the overall fertility rate has also declined mainly due to the economic hardships faced by the people. Finally, the emigration rate has considerably increased as people are looking for financial stability by moving to a new country. This situation might only be intensified if we add the current war situation into the mix. Therefore, all these effects have led to a fall in industrial development and agricultural productivity and eventually reduction in water demand.

The effect of this decrease in demand can be seen on the quality of water in the region. As the overall demand is decreasing the water quality of Poltva is improving over the course of next 50 years till 2060. So, instead of having a downside due to a decrease in the population of the area which is a reduction in industrial development and agricultural productivity. Still, there is an upside which is the improvement of the water quality of the basin. But having said that, the water quality still remains below the current EECA (Eastern Europe, Caucasus and Central Asia) as well as EU (European Union) guidelines in terms of both BOD and N concentration. Hence, to improve the situation further the WWTP can be upgraded to improve the BOD and N removal efficiency. So, the research suggests upgrading Lviv WWTP by installing a grease removal unit and reducing the load on activated sludge by pretreating the industrial wastewater before receiving it at Lviv WWTP. Following that, Lviv WWTP's treatment performance improved from 80% to 95% BOD removal and from 65% to 70% N removal. As a result, the source of pollution in the Poltva river can be reduced from 90 mg/l to 18 mg/l BOD.

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