ESTIMATION OF POLLUTANT LOAD IN DRINKING WATER PROTECTION AREAS OF SPRINGS SV. IVAN, BULAŽ, AND GRADOLE

Professional paper / Stručni rad

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Abstract: In this paper, the estimation of pollutant load within the drinking water protection areas (DWPA) of springs Sv. Ivan, Bulaž, and Gradole in Northern Istria (Croatia) is presented. To estimate the pollution load, the spreadsheet tool for estimating pollutant load (STEPL) model was used. STEPL calculates loads of organic pollutants, nutrients, and suspended solids. For each analyzed spring total, specific and pollutant loads by each analyzed category are calculated. The results show that the greatest loads are caused by human activities. In addition, for the purpose of the analysis, two additional future scenarios are introduced; one describes the situation after the implementation of the first phase of the Istrian water protection system project, and the other that describes a possible future state where each agglomeration of over 100 inhabitants within the protected areas has an adequate wastewater treatment plant (WWTP).

Keywords: springs Sv. Ivan, Bulaž, Gradole, pollutant load estimation, STEPL, drinking water protected areas

PROCJENA TERETA ONEČIŠĆENJA U ZONAMA SANITARNE ZAŠTITE IZVORIŠTA SV. IVAN, BULAŽ I GRADOLE

Sažetak: U radu je prikazana procjena tereta onečišćenja unutar zona sanitarne zaštite izvora Sv. Ivan, Bulaž i Gradole, koji se nalaze na sjevernom dijelu Istre (Hrvatska). U svrhu procjene tereta onečišćenja primijenjen je STEPL model koji izračunava opterećenja organskim zagađivačima, hranjivim te suspendiranim tvarima. Za svaki analizirani izvor izračunani su ukupni, specifični te tereti onečišćenja po pojedinim kategorijama, iz kojih se može vidjeti da su najveća opterećenja uzrokovana ljudskim aktivnostima. Također, za potrebe analize izrađena su i dva dodatna scenarija, prvi koji opisuje stanje nakon realizacije prve faze projekta istarskog vodozaštitnog sustava, te drugi scenarij koji opisuje moguće buduće stanje da se za svako naselje iznad 100 stanovnika unutar zona sanitarne zaštite izvede odgovarajući uređaj za pročišćavanje otpadnih voda.

Ključne riječi: izvor Sv. Ivan, izvor Bulaž, izvor Gradole, procjena tereta onečišćenja, STEPL, sanitarna zaštita izvorišta

1 INTRODUCTION

Water protection and improvements to the quality of water resources on the Istrian peninsula is very important for the future development of the Istrian region. Deterioration of water resource quality in the past was the result of urbanization of the central parts of the peninsula without adequate wastewater collection and treatment infrastructure; the extensive development of agriculture; the increased uncontrolled exploitation of groundwater aquifers in the coastal areas; and the impact of the changed amount, intensity, and frequency of rainfall. These changes in the composition and concentration of contaminants in water resources are primarily caused by human activities in the catchment areas [1].

Diffuse sources of pollution, such as nutrients from agriculture, are difficult to control, whereas the control of nutrients (i.e., nitrogen and phosphorus) in to wastewater treatment plants (WWTPs), point sources, can be an easier and more effective solution. For this reason, it is necessary to increase the control of nutrients discharged from sewerage systems. One of the strategic development and environmental projects of Istrian County is the construction of public sewerage systems and wastewater treatment plants in central Istria according to the highest standards to protect water resources used for drinking, as well as the implementation of other measures i.e., the promotion of ecological and organic farming [1].

Estimating pollutant loads is essential in watershed management. Proper management of watersheds, such as introducing adequate wastewater treatment, or other pollutant management measures can reduce the pollutant loads in water resources. An example of watershed management in Croatia is presented in [2], which gives an example of improving watershed management in a small watershed in the River Danube basin in Northern Croatia. Three topics are investigated: 1. Protection against floods, 2. River restoration, and 3. River-water quality management. Without knowing the sources of pollutants, the watershed cannot be effectively controlled, restored, and protected. The analysis of pollutant loads provides a more specific numerical estimate of loads from the various sources in the watershed. It also helps to plan restoration strategies, target load reduction efforts, and estimate future loads under new conditions. In Croatia, watershed management is presented in “River Basin management plan 2016-2021 (Plan upravljanja vodnim područjima 2016-2021),” which has two main parts, 1) Water quality management and 2) Flood risk management [3].

This paper shows the estimated pollution loads within drinking water protection areas for springs Sv. Ivan, Bulaž, and Gradole. Previous research made in the observed study area refers only to the nutrient load for the whole catchment area of the Mirna River [4, 5] on which the analyzed water sources are situated. Other existing studies are related mainly to the water quality of springs Sv. Ivan, Bulaž, and Gradole and not on pollution load estimation from the inflow area [6-8].

For the assessment of pollution loads, a model called spreadsheet tool for estimating pollutant load (STEPL) was used. STEPL is a simple watershed and landscape model that requires minimal data preparation and no calibration. It is good for long averaging periods and it can be tested or validated. STEPL is an application supported by United States environmental protection agency (USEPA) and is mainly used in the United States of America [9-14].However, with a few adjustments, it can be used elsewhere.

Pollution loads in the analyzed areas of springs Sv. Ivan, Bulaž, and Gradole have been estimated for the pollution from the population due to the discharge of wastewater into the environment, agriculture, and livestock data.

Pollutant loads were estimated and analyzed for the present state (Present state) (year 2012). In addition, two different future scenarios depending on the status of construction of sewerage systems and WWTPs were analyzed: one describes the situation after the implementation of the first phase of the Istrian water protection system project (Scenario 1); the other describes a possible future state where each agglomeration of over 100 inhabitants within the protected areas has adequate wastewater treatment plants (Scenario 2). Agriculture and livestock pollution are assumed equal in all three analyses.

The purpose of this paper is to use springs in Northern Istria as a case study to show a simple and effective method to estimate pollutant loads in watersheds if minimal input data are available.

2 MODEL DESCRIPTION

STEPL [15] employs simple algorithms to calculate nutrient and sediment loads from different land uses and the load reductions that would result from the implementation of various best management practices (BMPs). STEPL computes watershed surface runoff, nutrient loads (nitrogen-N and phosphorus-P), 5-day biological oxygen demand (BOD_5), and sediment delivery based on various land uses and management practices. For each watershed, the annual nutrient load is calculated based on the runoff volume and the pollutant concentrations in the runoff water, as influenced by factors such as the land use distribution and management practices. The annual sediment load is calculated based on the Universal Soil Loss Equation (USLE) [16] and the sediment delivery ratio. The sediment and pollutant load reductions that result from the implementation of BMPs are computed using the known BMP efficiencies.

3 CASE STUDY AREAS AND DATA DESCRIPTION

3.1 Study areas description

The largest part of the Istrian peninsula is permeable karst. Due to the high permeability of the cover layer, the underground is extremely sensitive to contamination from the surface. Because of this, approximately 70% of the area is under the drinking water protection regime [17]. Sv. Ivan, Bulaž, and Gradole springs are located in Northern Istria inside the Mirna River catchment area (Figure 1). Average annual rainfall in the area is approximately 1238 mm and the average annual temperature is 11.3 °C [18]. All three springs are used for water supply within the water utility of Istria system with water from Butoniga reservoir [19].

Sv. Ivan spring (Figure 1) is located at the upstream part of the river Mirna Valley, approximately 1 km southeast of Buzet, and approximately 200 m from the Mirna riverbed, at an altitude of 49 m. Flow of the spring typically ranges from 0.2 to 2 m^3/s, and the minimum is approximately 0.09 m^3/s [19]. Bulaž spring (Figure 1) is located at the beginning of the wide valley of the Mirna River middle flow, near the thermal water source of Istarske toplice. Mean annual flow is somewhat larger than 2 m^3/s, while the minimum recorded overflow is 0.042 m^3/s and the maximum is approximately 38 m^3/s [19]. Gradole spring (Figure 1) is located on the left bank of the Mirna River valley, approximately 9.5 km upstream of its estuary [1, 20].

Comparing available information from previous research on watershed areas for each spring [21-23] and delineated drinking water protection areas [24], based on expert evaluation of the authors, it was concluded to estimate the pollution loads within the first three protected zones for Sv. Ivan spring (103 km^2) and Gradole spring (163 km^2), and for all four protected zones in for Bulaž spring (108 km^2).

Figure 1 Location of the study area (Sv. Ivan, Bulaž, and Gradole springs)

3.2 Water quality of observed springs

Water quality at the observed springs is monitored by the Public Health Institute of Istrian County once a month or 12 times per year according to the program of the Croatian Waters.

All observed springs are well saturated with oxygen, owing to the well-developed underground relief. The content of substances that can be oxidized and decomposed by microorganisms (BOD_5) or by using a strong oxidant (COD permanganate index) is very low (Figure 2) [25].

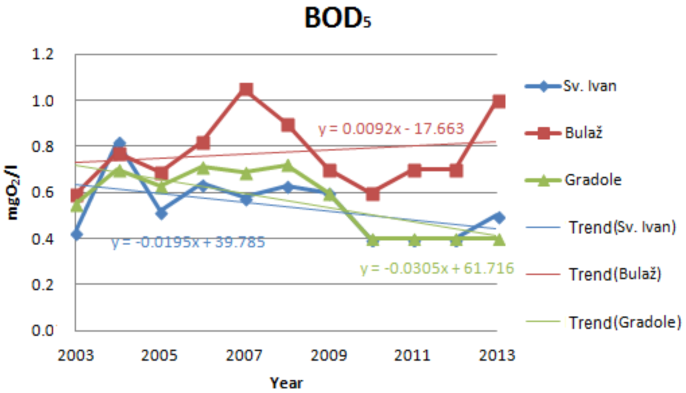


Figure 2 Mean annual values for BOD_5 at observed springs [25]

The nutrient content, which is indicated by the content of nitrates (Figure 4) and total phosphorus (Figure 3) decreases with time. The values of total nitrogen are several times lower than the maximum allowable concentration (MAC) for drinking water (for nitrate the content is 50 mg/l (NO_3-) or 11.3 mgN/l). The largest contribution to the total nitrogen is the inorganic content of nitrogen due to the nitrate content. Generally, the content of the inorganic nitrogen is almost entirely composed of nitrates, which means that the content of ammonium and nitrite as indicators of current fresh contamination is very low and very rarely appears in detectable concentrations. The nitrate content at the springs that drain water from Ćićarija Mountain ant the northern part of the Istrian peninsula (Sv. Ivan and Bulaž) is low. Owing to the more developed agricultural activities in the catchment of Gradole spring, which drains water from the interior of the Istrian peninsula, the nitrate content is higher. However, all springs have had a decreasing trend in recent years, although up to the year 2007 there was an increasing trend for total nitrogen and nitrates. Phosphates and total phosphorus are also very low for all springs [25].

Microbiological contamination is present at all springs, and is associated with the hydrological conditions in the watersheds. High values are associated with the occurrence of torrential waters, and increased amounts of silt entering the aquifers. In addition, higher concentrations of total number of microorganisms and microorganisms of fecal origin were observed at all springs (at least occasionally) [25].

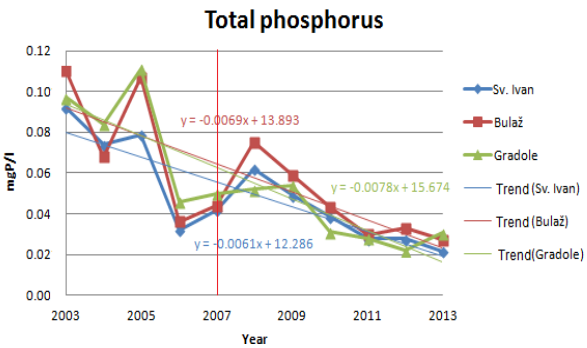


Figure 3 Mean annual values for total phosphorus in test areas from 2003-2013 [25]

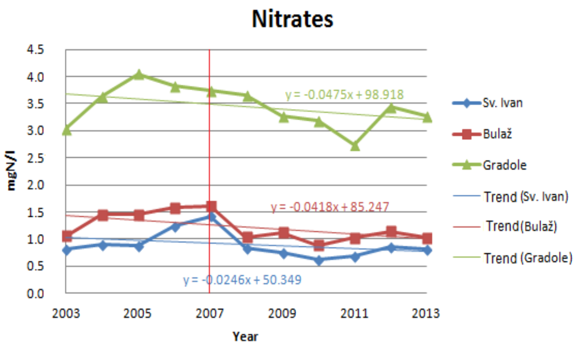


Figure 4 Mean annual values for nitrates in test areas from 2003-2013 [25]

From the analysis of the water quality of springs Sv. Ivan, Bulaž, and Gradole, it is concluded that the values of nearly all indicators are decreasing, and the quality of the water in the springs is improving [25].

3.3 Data set description

3.2.1 Population and WWTP data

Population data within the study areas are given according to the population censuses from 2001 and 2011 [26], and are shown in Table 1. Tourist data are also included in the population data.

Table 1 Population data within the study area

Spring	2001	2011
Sv. Ivan (Croatia)	1554	1458
Bulaž (Croatia)	825	789
Bulaž (Slovenia)	394	
Gradole (Croatia)	6116	6121

For agglomerations located in Slovenia (part of study area related to Bulaž spring), population data were adopted from the 2002 population census. Data on WWTPs, their location, and the number of inhabitants connected to a specific plant are shown in Table 2.

Table 2 Data on WWTPs and water protection zones [27]

Agglomeration (WWTP) / In operation since year	Location	No. of PE	Level of WWT	Type of WWTP	Drinking water protection zone
Existing WWTPs (Present state)					
Roč - Stanica Roč / 2012	Sv. Ivan	500	98%	MBR	III
Višnjan / 1983	Gradole	375	95%	BIO-DISC	III
WWTPs planned in the first phase (Scenario 1)					
Roč - Stanica Roč with Ročko Polje	Sv. Ivan	2 x 500	98%	MBR	III
Brajkovići-Trviž	Gradole	2 x 500	98%	MBR	III
Crklada-Ferenci	Gradole	2 x 200	98%	MBR	II
Ritošin Brig	Gradole	150	95%	SBR	III
Rapavel	Gradole	2 x 100	95%	BIO-TYPE	III
Marušići	Bulaž	200	95%	Unknown	III/IV

3.2.2 Land use/cover data

To determine the land use in the study areas, the CORINE land cover (CLC) from 2012 was used [28].

3.2.3 Livestock data

Data on the number of livestock was given by the Croatian Agricultural Agency and Veterinary Administration [29]. Data on livestock refers to the number of cattle, pigs, sheep, goats, horses, donkeys, rabbits, and chickens. Livestock data in the part of study area of the Bulaž spring which is in Slovenia were not known. Thus, the number of livestock was multiplied by 1.21, which represents the correction factor based on the surface area ratio (total study area of the Bulaž spring/study area of the Bulaž spring in Croatia).

3.2.4 Hydro-meteorological data

Average annual rainfall and temperature data used for calculations were obtained from the Meteorological and Hydrological Service of Croatia [30] and they refer to the Pazin meteorological station.

3.2.5 Topographic and soil data

An elevation layer with a spatial resolution of 0.5 × 0.5 km was used to calculate the land slope-related data for use within STEPL for calculating parameters in the USLE equation. Soil maps were used to obtain information pertaining to various soil-related properties important for calculating the nutrient wash-off. The soil data were obtained from the European Soil Portal [31].

4 MODELLING EXPERIMENT AND MODEL SETUP

Estimation of pollution load was carried out using the computer program STEPL [15] which uses USLE equation for calculating soil erosion [16]:

$$A = R \times K \times LS \times C \times P \quad (1)$$

where:

A = the average amount of soil erosion in t / ha / year;
R = factor of rainfall erosivity - an indicator of the intensity of the rain is calculated on the basis of the kinetic energy of the rain that causes the surface runoff;
K = soil erodibility factor - soil characteristics;
LS = indication of the topography where: L = length of the slope (m), S = slope steepness (%);
C = vegetation and land management factor;
P = factor for supporting practices.

USLE predicts the long-term average annual rate of erosion on a field slope based on rainfall pattern, soil type, topography, crop system, and management practices. USLE only predicts the soil loss that results from sheet or rill erosion on a single slope and does not account for additional soil losses that might occur from gully, wind, or tillage erosion. This type of erosion model was created for use in selected cropping and management systems, but is also applicable to non-agricultural conditions, such as construction sites [16].

Applicability of USLE in Karst areas in Croatia is shown in a paper by Kisić et al., [32] where it is used for the estimation of erosion risk in soils of the Vinodol valley.

The parameters used in the USLE equation were determined by authors from digital elevation and soil layers, rainfall, and temperature data, as well as CLC data.

The average load generated by one population equivalent (PE) for one day was adopted as 60 g for BOD_5, 11 g for N, and 2.5 g for P. In the calculation, it is assumed that 1 inhabitant = 1 PE. The efficiency of the plants was adopted as 98% for MBR (membrane bioreactor) systems and 95% for BIO-TYPE and SBR (sequencing batch reactor) plants. The efficiency of a bio-disc plant in Višnjan was adopted as follows: 30% for BOD_5 and 10% for N and P.

Concentrations of nutrients in the water that drains from agricultural land, pastures, and forests were the only data adopted from STEPL owing to a lack of measured data, and are shown in Table 3.

Table 3 Nutrient concentration in runoff (mg/l) [15]

Land use	Total N	Total P	BOD	With manure	Total N	Total P	BOD
1. L-Cropland	1.9	0.3	4	1a. w / manure	8.1	2	12.3
2. M-Cropland	2.9	0.4	6.1	2a. w / manure	12.2	3	18.5
3. H-Cropland	4.4	0.5	9.2	3a. w / manure	12.2	3	18.5
4. Pastureland	4	0.3	13				
5. Forest	0.2	0.1	0.5				

Pollutant loads were estimated and analyzed for Present state (year 2012). In addition, two different future scenarios depending on the status of construction of sewerage systems and WWTPs were analyzed:

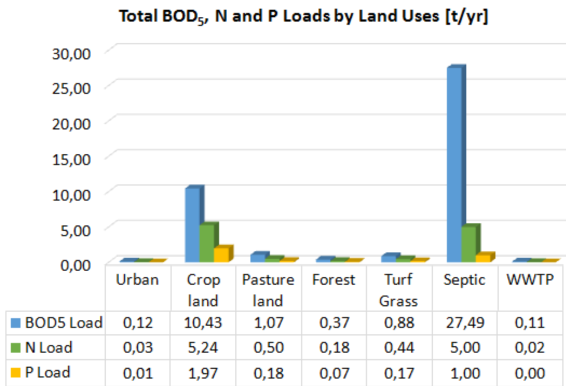
- Scenario 1: future state after the construction of WWTPs for small agglomerations from the first phase of the program of the Istrian water protection system [1].
- Scenario 2: a possible future state (a presumption is adopted that each agglomeration within the drinking water protected area, which according to the population census from 2011 had 100 or more inhabitants, has an adequate WWTP).

Agriculture and livestock input data and results are assumed equal for all three analyses.

5 RESULTS AND DISCUSSION

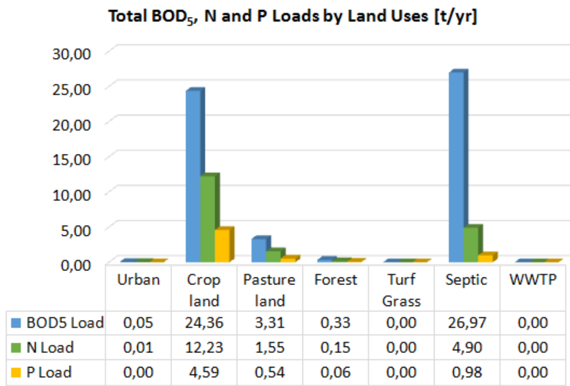
Present state situation is given for the year 2012. In Present state, the agglomerations that are not connected to public sewerage systems are treated as if they are completely untreated and their wastewater is discharged directly into the ground. The only agglomerations in Present state that are connected to a WWTP are Višnjan in the Gradole, and Roč with its surrounding smaller agglomerations (within the study area of Sv. Ivan spring).

The results of estimation of pollution load for Present state obtained by the calculation performed using the STEPL model are shown in the diagrams and associated tables for each category of land use (urban land, cropland, pastures, forests, grasslands, septic systems or direct discharge of wastewater into the ground, and WWTPs). Figures 5, 6, and 7 show the obtained values of BOD_5, total N, and total P for each study area and by each land use category. Figures 8, 9, and 10 show the results for suspended solids for the same areas and categories. Figures 11 (BOD_5, total N, and total P) and 12 (suspended solids) show the total pollution load generated within each study area.



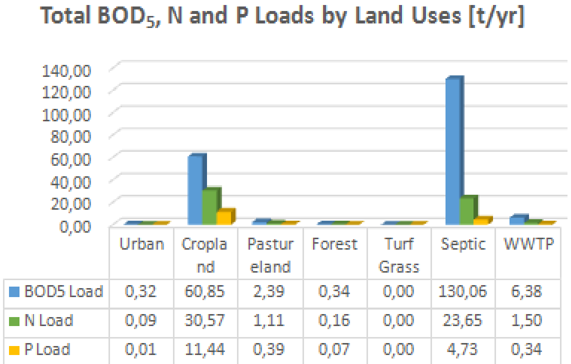
	Urban	Crop land	Pasture land	Forest	Turf Grass	Septic	WWTP
BOD5 Load	0,12	10,43	1,07	0,37	0,88	27,49	0,11
N Load	0,03	5,24	0,50	0,18	0,44	5,00	0,02
P Load	0,01	1,97	0,18	0,07	0,17	1,00	0,00

Figure 5 Results for total BOD_5, N, and P loads by land use for the study area of Sv. Ivan spring



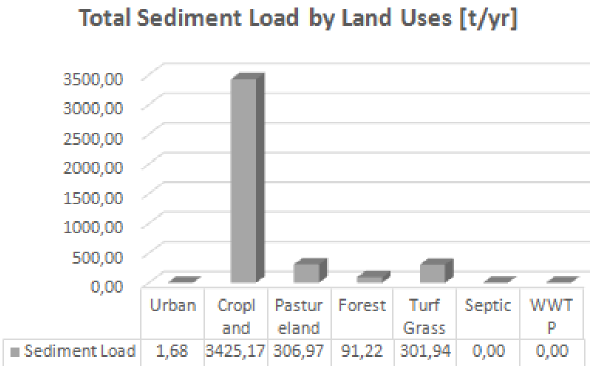
	Urban	Crop land	Pasture land	Forest	Turf Grass	Septic	WWTP
BOD5 Load	0,05	24,36	3,31	0,33	0,00	26,97	0,00
N Load	0,01	12,23	1,55	0,15	0,00	4,90	0,00
P Load	0,00	4,59	0,54	0,06	0,00	0,98	0,00

Figure 6 Results for total BOD_5, N, and P loads by land use for the study area of Bulaž spring



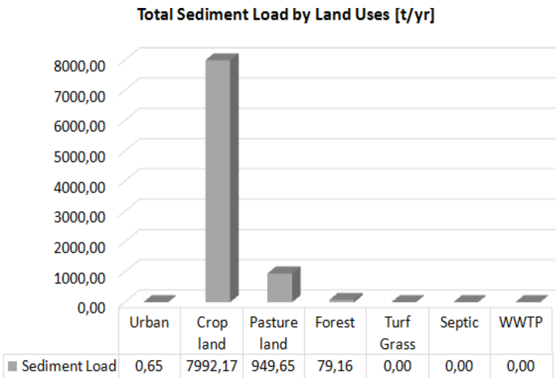
	Urban	Cropland	Pastureland	Forest	Turf Grass	Septic	WWTP
BOD5 Load	0,32	60,85	2,39	0,34	0,00	130,06	6,38
N Load	0,09	30,57	1,11	0,16	0,00	23,65	1,50
P Load	0,01	11,44	0,39	0,07	0,00	4,73	0,34

Figure 7 Results for total BOD_5, N, and P loads by land use for the study area of Gradole spring



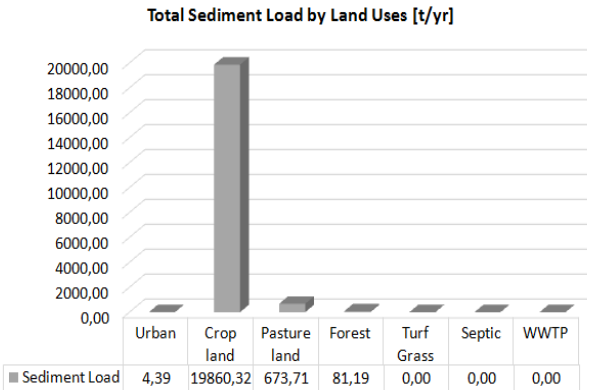
	Urban	Cropland	Pastureland	Forest	Turf Grass	Septic	WWTP
Sediment Load	1,68	3425,17	306,97	91,22	301,94	0,00	0,00

Figure 8 Results for total sediment load by land use for the study area of Sv. Ivan spring



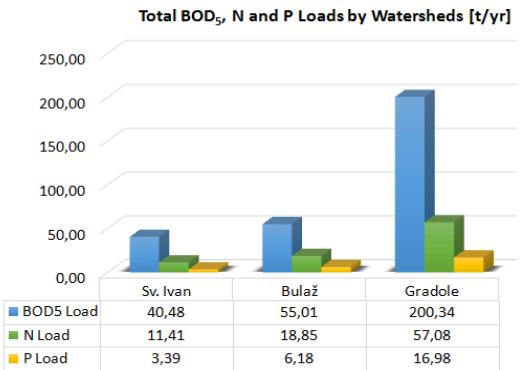
	Urban	Crop land	Pasture land	Forest	Turf Grass	Septic	WWTP
Sediment Load	0,65	7992,17	949,65	79,16	0,00	0,00	0,00

Figure 9 Results for total sediment load by land use for the study area of Bulaž spring



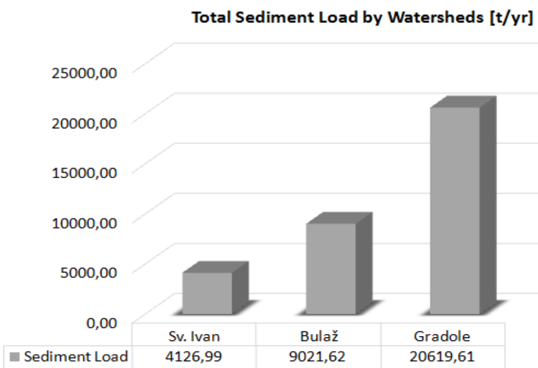
	Urban	Crop land	Pasture land	Forest	Turf Grass	Septic	WWTP
Sediment Load	4,39	19860,32	673,71	81,19	0,00	0,00	0,00

Figure 10 Results for total sediment load by land use for the study area of Gradole spring



	Sv. Ivan	Bulaž	Gradole
BOD5 Load	40,48	55,01	200,34
N Load	11,41	18,85	57,08
P Load	3,39	6,18	16,98

Figure 11 Results for total BOD_5, N, and P loads by study area



	Sv. Ivan	Bulaž	Gradole
Sediment Load	4126,99	9021,62	20619,61

Figure 12 Results for total sediment loads by study area

The size of the study area greatly affects the total pollution load. A bigger area usually has a greater pollution load, but this does not mean that smaller catchment areas cannot produce a greater pollution load. For this reason, it is important to determine the specific load (load per km^2).

For the study areas of springs Sv. Ivan, Bulaž and Gradole, a greater area also means a greater pollution load, where the pollution loads in descending order are Gradole, Bulaž, and Sv. Ivan. Pollution loads can be estimated with the analysis of the water quality given in Section 3.2. By dividing the total pollution load by the analyzed area, the specific pollution load is obtained. The largest specific pollution load was obtained for Gradole (according to all indicators of pollution), then for Bulaž, and finally for Sv. Ivan. Total and specific pollution loads for Present state within the study areas are shown in Table 4.

Table 4 Total and specific loads by study area – Present state

Spring	Sv. Ivan	Bulaž	Gradole
Area [km^2]	103	108	163
Total Load [t/yr]			
BOD_5 Load	40.48	55.01	200.34
N Load	11.41	18.85	57.08
P Load	3.39	6.18	16.98
Sediment Load	4126.99	9021.6	20619.61
Specific Load [t/km^2/yr]			
BOD_5 Load	0.39	0.51	1.23
N Load	0.11	0.17	0.35
P Load	0.03	0.06	0.10
Sediment Load	40.07	83.36	126.21

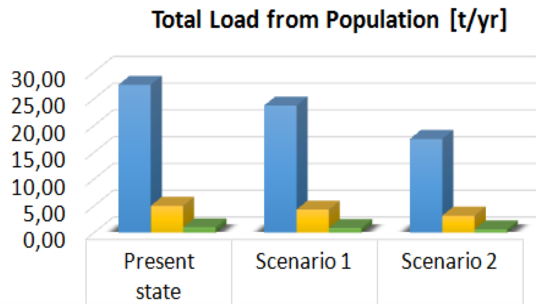
Results by different sources of pollution (population, agriculture, and livestock) are shown in Table 5. The urban areas and forests were not taken into account, and thus these categories are not shown in the table. Loads from the population and the pollution generated by the WWTPs, if they exist, are shown in the first part of the table. The results of the pollution from agriculture and livestock farming are shown in the second part of the table. Agriculture and livestock farming are presented as one category because STEPL does not calculate pollution load from livestock separately, but evenly distributes it over all areas with livestock. Loads from agriculture are composed of loads in Cropland, Pasture Land, and Turf Grass. From Table 5, it can be seen that Gradole spring has the largest impact in terms of agriculture with all pollutant loads (BOD_5, total N, and total P).

Table 5 Total load from population, agriculture, and livestock farming by study area – Present state

Spring	Sv. Ivan	Bulaž	Gradole
Total Load from Population [t/yr]			
BOD_5 Load	27.60	26.97	136.44
N Load	5.02	4.90	25.15
P Load	1.00	0.98	5.07
Total Load from Agriculture and Livestock Farming [t/yr]			
BOD_5 Load	12.38	27.67	63.23
N Load	6.18	13.78	31.68
P Load	2.31	5.14	11.83
Sediment Load	4034.09	8941.81	20534.0

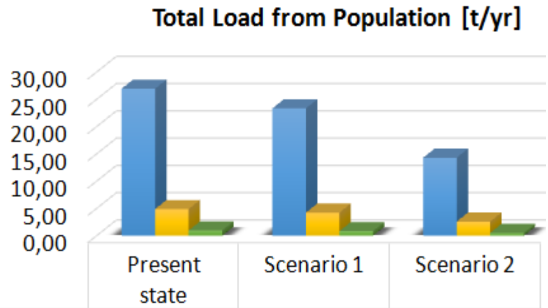
The next part of the paper presents the analysis of two future scenarios. Scenario 1 includes the following WWTPs, for which design documentation exists and which should soon be realized; Brajkovići-Trviž, Crklada-Ferenci, Ritošin Brig, and Rapavel in the Gradole, and WWTP Marušići in the study area of Bulaž spring (see Table 2). In Scenario 2, it is presumed that each agglomeration within the drinking water protection area, which according to the population census from 2011 had 100 or more inhabitants, has an adequate WWTP. Comparisons of these three analyses (Present state, Scenario 1 and Scenario 2) are shown in Figures 13, 14, and 15.

The real impact and benefit of the construction of the WWTPs can be seen in the example of the Gradole spring study area by comparing Present state and Scenario 2, where the annual load of BOD_5 is reduced from 136.44 to 39.48 t/yr.



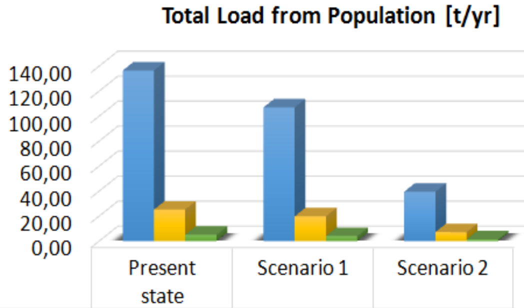
	Present state	Scenario 1	Scenario 2
BOD5 Load	27,60	23,74	17,49
N Load	5,02	4,32	3,18
P Load	1,00	0,86	0,64

Figure 13 Comparison of results of the three analyses in the study area of Sv. Ivan spring



	Present state	Scenario 1	Scenario 2
BOD5 Load	26,97	23,35	14,31
N Load	4,90	4,24	2,60
P Load	0,98	0,85	0,52

Figure 14 Comparison of results of the three analyses in the study area of Bulaž spring



	Present state	Scenario 1	Scenario 2
BOD5 Load	136,44	106,91	39,48
N Load	25,15	19,78	7,18
P Load	5,07	4,00	1,46

Figure 15 Comparison of results of the three analyses in the study area of Gradole spring

Comparison of the water quality analysis of the springs shows that there is a direct link between human activities within the analyzed areas and the water quality. The water quality of Sv. Ivan spring was proved to be the best by all analyzed indicators, which corresponds to the smallest pollution load generated within the analyzed area. Within the analyzed area of the Bulaž spring, which is slightly larger and has more agricultural land, a slightly higher pollution load was obtained. Despite a noticeably higher number of inhabitants in the analyzed area of Sv. Ivan spring, only a slightly higher pollution load was obtained in comparison to the analyzed area of the Bulaž spring. The water quality of the Bulaž spring is slightly worse by all analyzed indicators, but it is still of very good quality. The largest population, number of livestock, and agricultural areas are within the analyzed area of Gradole spring and they contribute to the largest pollution load and therefore the worst water quality by all indicators.

6 CONCLUSIONS

The purpose of this paper is to show a simple and effective model, the STEPL model, to estimate pollutant load in watersheds with minimal data preparation and to estimate pollutant loads in the observed study areas that can be used for management purposes.

In this study, the study areas of Sv. Ivan, Bulaž, and Gradole springs in Northern Istria were analyzed from the aspect of the impact of wastewater, agriculture, and livestock on the total and specific pollution load since the largest sources of groundwater pollution in the study areas are human activities, mainly agriculture.

Through the analysis of pollution load from the population, agriculture, and livestock, an attempt was made to evaluate Present state and the future states (Scenario 1 and Scenario 2) after the construction of sewerage systems with adequate WWTPs. To prevent or reduce contamination of groundwater, it is necessary to hasten the construction of the public sewerage systems with adequate WWTPs. With sewerage systems and WWTPs, it is possible to manage and control a major part of the pollution sources related to population, whereas the pollution sources related to agriculture are more difficult to control owing to the uncontrolled use of fertilizers.

Owing to the variability, non-consistency, and lack of measured data and applied methods, the obtained results can be considered a best estimate at the time of the analysis. Future steps regarding the calibration process of the model should be based on the establishment of a proper measurement system that will provide appropriate data for calculation of pollutant loads on analyzed springs.

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References

[1] Hajduk Černeha, B. 2010: IVS - Istarski vodozaštitni sustav, Sustav javne odvodnje i zaštite voda Istarske županije, Savjetovanje „Istarske vode i more", Udruga za očuvanje hrvatskih voda i mora - Slap i Društvo građevinskih inženjera Poreč, Rabac 8.- 9.4.2010, pp. 139-144 (in Croatian)

[2] Tadić, L.; Tadić. Z. 2005: An Example of Watershed Management in Croatia, River Basin Management III / C.A. Brebbia (ur.). - Southampton: Wessex Institute of Technology, Bologna, Italija, 6-8.09.2005. pp. 111-119.

[3] Hrvatske vode 2015: Plan upravljanja vodnim područjima 2016-2021-Nacrt (in Croatian)

[4] Hrvatske vode 2013: Plan upravljanja vodnim područjima, Dodatak II, Analiza značajki jadranskog vodnog područja (in Croatian)

[5] Volf, G. 2012: Assessment of Proper Wastewater Treatment Level according to Marine Ecosystem State, PhD. thesis, Faculty for Civil Engineering University of Rijeka, Rijeka. (in Croatian)

[6] Kogovšek, J.; Diković, S.; Petrič, M.; Rubinić, J.; Knez, M.; Hrvojić, E.; Slabe, T. 2003: Hydrochemical research of The Mlini springs, Istria, Annales Ser.hist.nat., 13 (1), pp. 91-102.

[7] Mihalić, I.; Kalanj, M.; Rubinić, J.; Nemarnik, M.; Černeha Hajduk, B.; Zorko, 2006: Analiza pojava mutnoća voda izvorišta istarskog vodovoda - podloga za projektiranje i operativan rad uređaja za kondicioniranje pitkih voda, Suvremene tehnologije i uređaji za pročišćavanje pitkih i otpadnih voda, Iskustva u izgradnji, pogonu i održavanju, Linić, A. (ur.). Rijeka: Hrvatska grupacija vodovoda i kanalizacija, pp. 61-69 (in Croatian)

[8] Rubinić, J.; Kogovšek, J.; Diković, S.; Petrič, M.; Hrvojić, E.; Knez, M.; Slabe, T. 2006: Vode gornjeg i srednjeg toka rijeke Mirne, Hrvatske vode. 14 (54), pp. 1-14 (in Croatian)

[9] Deangelo Acord, A. 2015: New applications of stepl watershed modeling of cafo feedlot runoff and implications of surface water impacts, M.S., University of Missouri-Kansas City.

[10] Deer Creek Watershed Management Plan, Appendix 3B: Watershed Management Models.

[11] Shik Park, Y.; Engel, B. A.; Harbor, J. 2014: A Web-Based Model to Estimate the Impact of Best Management Practices, *Water* 2, *6*, pp. 455-471. https://doi.org/10.3390/w6030455

[12] Commonwealth Biomonitoring. 2009: *Little River Watershed Diagnostic Study*; Commonwealth Biomonitoring: Indianapolis, IN, USA.

[13] Florida Department of Environmental Protection. 2009: *State of Florida FY2010 Section 319(h) Grant Work Plan*; FDEP: Tallahassee, FL, USA.

[14] Keegstra, N.; Parks, J.; Linden, L.V. 2012: Whiskey Creek Final Report; Calvin College: Grand Rapids, MI, USA.

[15] Wortman, S. 2013: The Spreadsheet Tool for Estimating Pollutant Loads (STEPL), U.S. EPA, Chicago, IL.

[16] Universal soil loss equation (USLE): http://www.omafra.gov.on.ca/english/engineer/facts/12-051.htm#t1, Accessed 10 April 2014.

[17] Županijska razvojna strategija Istarske županije 2011.-2013., Službene novine Istarske županije 10/2011. (in Croatian)

[18] Horvat, B.; Rubinić, J. 2006: Annual runoff estimation an example of karstic aquifers in the transboundary region of Croatia and Slovenia, Hydrological Sciences Journal, 51 (2), pp. 314-324. https://doi.org/10.1623/hysj.51.2.314
[19] Nežić, M. 2010: „Istarski vodovod" d.o.o., za proizvodnju i distribuciju vode - Buzet, Savjetovanje „Istarske vode i more", Udruga za očuvanje hrvatskih voda i mora - Slap i Društvo građevinskih inženjera Poreč, Rabac 8.- 9.4.2010, pp 97-118 (in Croatian)
[20] Prostorni plan uređenja Grada Buzeta, Knjiga I., Buzet, 2005 (in Croatian)
[21] Bonacci, O.; Magdalenić, A. 1993: The Catchment area of the Sv. Ivan Karst Spring in Istria (Croatia), Ground Water 31 (5), pp. 767-773. https://doi.org/10.1111/j.1745-6584.1993.tb00849.x
[22] Magdalenić, A.; Bonacci, O.; Jurak, V. 1987: Sliv izvora Bulaž u središnjoj Istri, Krš Jugoslavije, 12/1, Zagreb, pp. 1-26 (in Croatian)
[23] Magdalenić, A.; Vazdar, T.; Hlevnjak, B. 1995: Hydrogeology of the Gradole Spring Drainage Area in Central Istria, Geologia Croatica 48/1, Zagreb, pp. 97-106. https://doi.org/10.4154/386
[24] Odluka o zonama sanitarne zaštite izvorišta voda za piće u istarskoj županiji, http://www.istra-istria.hr/, 10.4.2015 (in Croatian)
[25] Report: Kakvoća prirodnih resursa voda uključenih u vodoopskrbu u Istarskoj županiji od 2003-2013. godine, 2014, Zavod za javno zdravstvo Istarske županije (in Croatian)
[26] Data obtained from Croatian Bureau of Statistics.
[27] Hajduk Černeha, B. 2010: IVS – Istarski vodozaštitni sustav, Sustav javne odvodnje i zaštite voda Istarske županije, XIV. Znanstveno-stručni skup: Voda i javna vodoopskrba, Hrvatski zavod za javno zdravstvo i Županijski zavodi za javno zdravstvo, Baška 4.-7.10.2010. (in Croatian)
[28] Data obtained from Croatian Environment Agency.
[29] Data obtained from the Croatian Agriculture Agency.
[30] Data obtained from the Croatian Meteorological and Hydrological Service.
[31] Data obtained from European Soil Data Centre.
[32] Kisić, I., Bašić, F., Mesić, M., Butorac, A. 2000: Estimate of Erosion Risk on Soils in the Vinodol Valley, Agriculturae Conspectus Scientificus, 65 (4), pp. 199-211.