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RESEARCH ARTICLE

Scenario Model for Landuse in Water Springs Conservation Area (Case Study of Umbulan Spring Water)

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ABSTRACT

This study focuses on identifying land cover to create models for hydrological analysis. Data from 2012 and 2019 is used. The Land Change Modeler in TerrSet software is used for modeling scenarios like Business as Usual and Conservation. Hydrological modeling is done using the Soil and Water Analysis Tool integrated with QGIS software. Analyzing the impact of land cover changes on discharge outcomes is done using Geographically Weighted Regression. Results show differences between land cover projections under BAU and Conservation scenarios. Conservation scenario reduces urbanization but benefits nature reserves and protected forests. The Umbulan spring had a simulated output of 4030 liters per second in 2012, with other rivers showing varying annual discharges. The validation test resulted in an r^2 value of 0.89. Typology analysis revealed that conversion of annual crops to residential areas was the main cause of discharge decrease at Umbulan Spring. GWR modeling led to local regression equations for each sub-basin, with an average r^2 value of 54.42 percent. Variables like population density, land cover changes, and household water usage negatively impact Umbulan spring discharge. An optimal scenario aims to promote economic development while ensuring environmental sustainability and protecting protected areas from potential damage. This scenario could potentially reduce Umbulan spring discharge decline by up to 88.32 percent in certain zones.

INTRODUCTION

Water, as a vital component of human life, plays a crucial role in various activities. On the other hand, according to the global Sustainable Development Goals (SDGs), water holds a strategic position with the aim of ensuring universal access to clean water and adequate sanitation (SDG 6) (United Nations, 2024). Access to clean water is not only essential for public health but also for enhancing productivity and overall quality of life. Additionally, SDG 6 includes other important targets such as reducing water pollution, improving water use efficiency across different sectors, and protecting water resources (Triananda, 2024). These points highlight the need for efforts to maintain the sustainability of water resources to guarantee every individual's right to a better quality of life. However, there are currently numerous human interventions, both direct and indirect, that can disrupt the sustainability of water resources in terms of utilization, management, and any factors that threaten their longevity.

Land cover change is a significant human impact on the landscape, evident through various processes such as agricultural expansion, deforestation, and urbanization. In recent decades, rapid land cover changes worldwide have been driven by population growth, leading to environmental degradation. Changes in land use or cover have long been recognized as a global environmental factor (Lambin & Geist, 2008). Several studies over the past decade have aimed to examine the role of land cover change in various environmental aspects, including hydrological responses (Ghaffari et al., 2010), climate change (Xu et al., 2016), biodiversity (Solar et al., 2016), food security (Rutten et al., 2014), energy conservation (Preston & Kim, 2016), and water quality (Giri & Qiu, 2016). A similar situation has been observed in the Umbulan Spring Conservation Area, where since 2010, there has been an increase in cultivated areas like rice fields and eucalyptus plantations, alongside a decrease in agroforestry and forested areas. This shift has led to a reduction in recharge (subsurface flow) and an increase in surface runoff (Tanika et al., 2008). Consequently, this has significantly impacted the water balance of the Umbulan spring, particularly affecting the quantity of its discharge.

Research on the impact of land cover changes on hydrological responses and related factors, such as water quality, is a key focus in water resource studies. However, further exploration is needed to understand the relationship between land cover changes and water resources, as the complexities of land cover change processes and associated hydrological processes are not fully understood. This complexity arises from the diverse types of land cover changes and the driving factors within ecological, socio-economic, and historical-political contexts (Lambin & Geist, 2008). These driving factors interact with one another, making it challenging to assess the relative importance of each factor. Previous studies have indicated variations in driving factors and land cover across different research areas (Birol et al., 2009; Davies et al., 2014; Prishchepov et al., 2012). In the watershed of the Umbulan Spring area, changes in land cover have led to hydrological impacts and several other negative downstream effects (DeFries & Eshleman, 2004; Paul & Meyer, 2001).

The impact of land cover and socio-economic factors is assessed to have an indirect effect on hydrology. The socio-economic conditions of the communities surrounding the Umbulan Spring will also influence water usage patterns and land activities near the source (Prasetyo et al., 2023). The population size that relies on this water source is crucial to consider, particuly regarding the intensity and nature of their usage. Human activities, such as industrial operations that produce waste byproducts (Wahyuni et al., 2023), significantly affect water quality over the long term (Luo & Zuo, 2019). Additionally, activities like sand mining and other surface alterations in the Umbulan Spring area also impact both the physical and non-physical quality of the water source (Dwityaningsih et al., 2018).

Java Island is home to about 60% of Indonesia's 250 million population, with a population density exceeding 900 people per square kilometer. Over the decades, Java has faced constant pressure on land resources and has rapidly transitioned from a predominantly rural area to an urbanized one (Hamidiana et al., 2016; Handayani, 2013; Verburg et al., 1999). This shift has led to a heavier reliance on water resources due to increased water usage and a decline in watershed conditions (Pawitan & Haryani, 2011). Approximately 458 watersheds in Indonesia have been declared critical, highlighting the need for improved watershed management (Fulazzaky, 2014). The Umbulan spring, one of the largest springs in East Java, has also faced over-exploitation since the 1980s due to extensive borewell activities. There are over 460 borewell findings, with estimates reaching up to 600 borewells, ranging in depth from 30 to over 200 meters scattered across the Umbulan area (Toulier et al., 2019). This situation significantly impacts the hydrological cycle balance (Daud, 2022) in the Umbulan Spring area.

The Umbulan Spring has experienced a decline, particularly in terms of quantity. Records indicate that from February 2007 to October 2008, the flow rate of the Umbulan Spring decreased from 4,051 liters per second to 3,278 liters per second. The potential of the Umbulan Water Source is projected to reach between 4,000 and 5,000 liters per second. Previous studies by Rengganis and Kusumawati (2011), Ginting & Rengganis (2010), and Rengganis & Seizarwati (2015) on the hydrological conditions of the Umbulan Spring have highlighted the impact of land cover changes on the spring's output. Additionally, uncontrolled groundwater extraction has been shown to alter the groundwater level and cause a decline in the Umbulan Water Source. Consequently, the effects of land cover changes, along with the inadequate drinking water service coverage which approximately 51.7% for urban residents and 46.5% for rural residents in East Java which is underscore the need for further investigation. This is particularly important given the disruptions caused by human activities in land use and socio-economic activities, which directly affect the sustainability of the Umbulan Spring. Therefore, a spatial approach considering land cover and socio-economic factors is essential to ensure the long-term viability of the Umbulan Spring's benefits and existence.

The Umbulan Spring, recognized as one of the largest water sources in East Java, plays a vital role in the lives of the surrounding communities. Its existence is deemed essential, as a significant portion of the East Java population relies on this spring for their water needs. However, time-series data indicates a decline in the spring's water output, which coincides with changes in land cover and the socio-economic conditions of the local residents. Therefore, the aim of this research is to analyze the spatial changes in land cover within the Umbulan spring conservation area, assess the impact of land cover and socio-economic factors on the spring's water flow, and develop optimal land cover scenarios to manage land use in the Umbulan Spring area, ensuring its sustainability and preservation.

RESEARCH METHOD

This type of research employs a quantitative method. The study focuses on developing a model for managing the utilization of the Umbulan spring through a spatial approach, primarily concentrating on land cover aspects. In the data formulation and analysis techniques, numerical data is utilized along with spatial analysis, including projections of land cover for the next 20 years.

The information utilized consists of both primary and secondary data. Primary data is collected through surveys, field observations, and interviews/questionnaires related to the current conditions of the study area. Secondary data includes demographic and socio-economic information, time-series land cover data and plans, documents from the Regional Spatial Planning, and data on the Umbulan springs. These data sources are obtained from government agencies in Pasuruan Regency and East Java.

Population and sample

The research population consists of all elements or individuals that are the focus of the study and are related to the research topic. In this study, the population emphasizes all activities of the residents around the Umbulan spring conservation area, which is then narrowed down to the research sample. The sample is determined by calculating the total sample size using the Slovin method.

Data collection technique

Data collection aims to support research by gathering a series of necessary information to achieve the research objectives. In this study, the data used is quantitative, obtained through both primary and secondary survey processes.

Secondary data collection methods

Data collection is intended to support research that requires gathering various types of information for its objectives. The data utilized in this study is quantitative, obtained through secondary processes. By collecting secondary data, researchers can access pre-existing information to gain relevant insights without the need to gather raw data from scratch, thereby saving time and costs in the research process.

Data analysis

Land cover analysis and modeling using land change modeler (LCM)

Land Change Modeler (LCM) is a software integrated with IDRISI Selva that allows users to explore Land Use Cover Change (LUCC) by combining CA-Markov and Artificial Neural Network approaches (Adhikari and Southworth, 2012). LCM offers a platform for assessing land cover changes in a spatial, temporal, and dynamic manner. This tool can also enhance land allocation during planning and policy-making processes. Additionally, LCM can be utilized to anticipate changes and predict land cover under various scenarios (Mishra et al., 2014).

Hydrological Modeling Using Soil and Water Assessment Tools (SWAT)

a. Watershed Delineation
b. Formation and Definition of Hydrological Response Units (HRU)
c. Climate Data Development
d. Building Data Inputs
e. SWAT Simulation

Analysis of the effect of land cover and socio-economic activities on umbulan water discharge using geographically weighted regression (GWR)

Geographically Weighted Regression (GWR) is a statistical method used to analyze spatial heterogeneity, where the same independent variable can yield different responses in various locations within a study area. The GWR model analysis provides local parameter estimates at each point or location where the data is examined. In the GWR model, the response variable Y is estimated using predictor variables, with each regression coefficient varying based on the location of the observed data. The weighting in the GWR model plays a crucial role, as the weight values represent the relationship between different observations.

The spatial variables longitude and latitude are used as weighting variables in the formation of the GWR model. Longitude refers to vertical lines connecting the northern and southern sides of the Earth (the poles) and is used to measure the east-west coordinates of a point on the Earth's surface. Meanwhile, latitude represents horizontal lines between the North Pole and the South Pole, connecting the eastern and western sides of the Earth, and serves as a measure for the north-south coordinates of a point on the Earth's surface.

RESULT AND DISCUSSION

Land cover dynamics and projections in the umbulan spring conservation area

Synthesis and comparison between scenarios

Based on predictions from various scenarios, there are notable differences in the results, particularly in the areas generated using the same constraints and driving factors but with different rules. The Business as Usual scenario shows the largest growth in built-up land, primarily spreading in the northern part of the Mata Air Umbulan area, with growth directed towards the urban center of Pasuruan City. Similarly, the urban containment scenario exhibits a comparable growth pattern, although there are some differences in the area sizes. A detailed comparison of the areas produced by each scenario is presented in Table 3.

Table 1: Comparison of BAU and CON scenario land cover projections

Land-use Class	**Area (Ha)**		**% increase/decrease**
	BAU	**CON**	
Annual Crops	21378,8	20933,30	-2%
Agriculture	26093,2	25984,1	0%
Production Forest	17567,7	12009,1	-32%
Conservation Forest	6257,4	9228,03	47%
Nature Reserve Areas	821,4	7030,65	756%
Community Forest	849,5	851,1	0%
Residential Areas	26051,4	23277,8	-11%
Indstrial Areas	82,1	82,5	0%
Water Agency	215,1	215,15	0%
Mining	579,1	284,4	-51%
Total	99896,65	99896,65	

The projections using two different methods, namely Business as Usual (BAU) and Conservation, aim to illustrate the changes in land cover with and without spatial policies or trend-based approaches, as well as conservation efforts. As shown in Table 1, there are significant differences in the areas of residential land, nature reserves, agricultural land, production forests, and mining. Under the BAU scenario, the area of residential land is projected to be 26,051 hectares, while the conservation scenario reduces this to 23,277 hectares. This aligns with the conservation scenario's goal of minimizing the growth of developed land, while ensuring the sustainability of protected areas such as nature reserves and conservation forests.

The SWAT simulation results – years of 2012 and 2019 (Base model)

The SWAT simulation was conducted for the years 2012 and 2019, incorporating various differences in input data such as weather conditions and land cover. This simulation aimed to assess any changes in discharge levels and to examine the influence of several input data factors. The SWAT simulation process took place after completing the previous steps, which included delineating subbasins, identifying HRUs, and inputting climate data. The results of the simulation provided annual discharge data or average monthly figures over the course of one year, from January 1, 2012, to December 31, 2012. Figure 1 illustrates the runoff discharge generated during that one-year period.

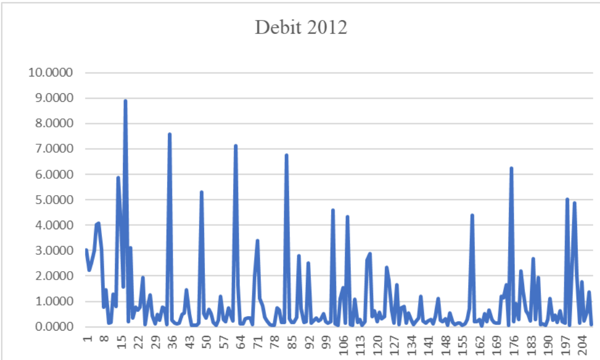

Figure 1: 2012 base model simulation discharge

The simulation results indicate that in 2012, the runoff discharge from the Umbulan Spring was 4030 liters per second. Additionally, other rivers such as Kali Sembayu, Kali Welang, and one river in the Winongan District had annual discharges of 213.2 liters per second, 6363 liters per second, and 200 liters per second, respectively.

In the 2019 hydrological simulation, the discharge was calculated using the same methodology as in 2012. This simulation provided discharge data over a one-year period, from January 1, 2019, to December 31, 2019. The results (see Figure 2) show the runoff discharge generated throughout the year in 2019.

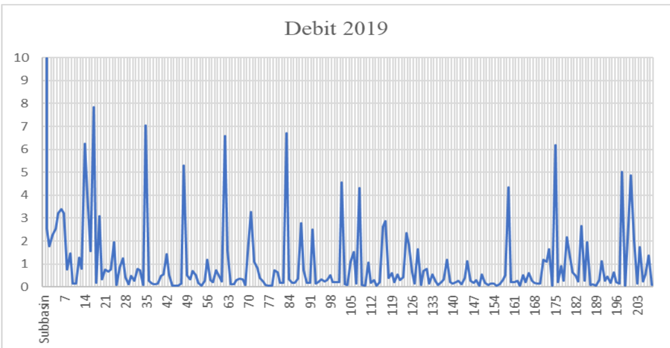

Figure 2: 2019 base model simulation discharge

The simulation results for water flow in 2019 indicate a runoff flow rate of approximately 3,382 liters per second in subbasin 4. This data reveals a significant decrease in flow from 2012 to 2019, particularly at the Umbulan Spring outlet, which is part of the core utilization area. The projected decline in flow is around 600 liters per second. This reduction can be attributed to several influencing factors, likely due to land use changes and residential development, which can impact the infiltration of rainwater into the soil.

1. Model validation test with field data

Validation testing is carried out by comparing the simulated flow rates with the observed flow rates obtained from various secondary sources. Among the numerous data collected, there are several points that can be used for validation testing, which are located within the research study area, as shown in Table 2 below.

Table 2: Observation data of discharge in the umbulan spring area

Watershed/ Spring Area	Year	Discharge lt/sec	Sources
Umbulan	1980	6000	Alix Toulier, researcher from Universite de Monpellier, Perancis (Kartitiani, 2020)
Umbulan	2007	4028	(Rengganis & Seizarwati, 2015)
Umbulan	2008	3900	(Rengganis & Seizarwati, 2015)
Umbulan	2009	3350	(Rengganis & Seizarwati, 2015)
Umbulan	2010	3600	(Rengganis & Seizarwati, 2015)
Umbulan	2011	3900	(Rengganis & Seizarwati, 2015)
Umbulan	2012	4002	(Rengganis & Seizarwati, 2015)
Umbulan	2013	3509	(Rengganis & Seizarwati, 2015)
Umbulan	2018	3278	Jurnal Aplikasi Teknik Sipil, Vol. 20 No. 1 Februari 2022
Umbulan	2020	3302	Pengukuran Debit Umbulan, PUSDA
Winongan	2012	0.115	Jurnal Teknologi dan Rekayasa Sumber Daya Air Vol. 3 No. 2 (2023)
K. Rejoso hulu	2012/2018	0.162	Jurnal Teknologi dan Rekayasa Sumber Daya Air Vol. 3 No. 2 (2023)
K. Rejoso hilir	2012/2018	0.983	Jurnal Teknologi dan Rekayasa Sumber Daya Air Vol. 3 No. 2 (2023)
Kali sembayut	2012	217.5	(Rengganis & Seizarwati, 2015)
banyubiru	2012	386	(Rengganis & Seizarwati, 2015)
watugajah	2012	6.5	(Rengganis & Seizarwati, 2015)
mego	2012	26	(Rengganis & Seizarwati, 2015)
torbayan	2012	22.5	(Rengganis & Seizarwati, 2015)
Kali Petung	2012	4960	Rispam Pasuruan, 2016
Kali gembong	2012	4420	Rispam Pasuruan, 2016
Kali welang	2012	6550	Rispam Pasuruan, 2016
Kali kadaipang	2012	7090	Rispam Pasuruan, 2016

Validation testing involves examining the r^2 value derived from the comparison between simulated and observed flow rates. The calculation yielded an r^2 value of 0.89, indicating that the model is considered good as it approaches 1.

2. SWAT simulation results in 2045 with BAU and CON scenarios

The discharge simulation for the year 2045 is conducted in the same manner as the process used in the base model simulation for 2012 and 2019. The results of the base model are acceptable, with the closer the r^2 value is to 1, the better. The simulation then continues for the year 2045 using land cover data for 2045 under the BAU and CON scenarios.

In the Business as Usual (BAU) scenario, the runoff from the Umbulan Springs shows a decline, reaching as low as 3,090 liters per second. This decrease is notably linked to significant changes in land cover. From 2019 to 2045, under the BAU scenario, there is a considerable drop in runoff, exceeding 1,000 liters per second. This poses a serious threat if urban development continues to expand rapidly without any intervention.

In the Conservation Scenario (CON), the runoff discharge is around 3,286 liters per second, specifically in sub-basin 4. This data suggests that while the CON scenario effectively manages the reduction in recharge, it doesn't do so to the fullest extent. By implementing strict limitations on the expansion of developed areas close to the main utilization zone (sub-basin 4), the conservation scenario helps to lessen the decrease in discharge. At the same time, there are initiatives aimed at maintaining the original state of protective land cover.

3. Calculation of estimated groundwater reserves

Recharge calculations involve several key variables, including the annual recharge volume, the size of the recharge area, and infiltration coefficients. The annual recharge volume is derived from SWAT simulation results, which indicate the potential for water infiltration into the soil over the course of a year. The size of the recharge area is determined from the sub-basin area identified during the initial SWAT modeling phase, measuring 53,333.93 hectares. The infiltration coefficient reflects the percentage of runoff water that can seep into the soil, influenced by the type of soil present.

In the recharge area, the soil conditions are primarily characterized by 80% and 20% coverage of Mollic Andosols, Ochric Andosols, along with smaller amounts of Vitric Andosols and Vertic Andosols, particularly in the northern region. These soil types are typically found in volcanic regions or are products of volcanic activity. The composition of these soils includes sandy clay and clayey gravel, with an infiltration coefficient set at 30%. Detailed infiltration coefficients based on the various soil-forming materials can be found in Table 3.

Table 3: Infiltration data for soil types

No	Material	Infiltration Coefficient (%)
1	Gravel	30
2	Coarse Sand and Sandy Gravel	25
3	Medium Sand	20
4	Fine Sand and Loosely Cemented Sandstone	10
5	Clayey Soil and Clayey Gravel	5
6	Fine-Grained Sedimentary Rock	3-5
7	Limestone, Chalk	2-3

After the three variables were obtained, the analysis for 2012 showed that the total groundwater recharge potential for the Umbulan area over the course of a year was 71,979,793.69 m^3. Meanwhile, in 2019, the total groundwater recharge potential was 70,338,622.36 m^3. These results indicate a 2.27% decrease in groundwater recharge potential. This decline is attributed to several factors, including a reduction in recharge volume from 2012 to 2019. In 2012, the recharge coefficient ranged from 260–590 mm/year, whereas in 2019, it decreased to 250–580 mm/year.

4. Typology analysis

Typology analysis is a method used to assess the extent of increase or decrease in discharge resulting from the conversion of one type of land cover to another. This analysis produces an output that will be utilized to guide optimal land cover in order to sustain the Umbulan Springs from a land cover perspective. The results of the typology analysis are presented in Table 4.

Table 4: Typology analysis of land change on discharge output

Initial LU	Final LU	Average Increase (Ha)	Average decrease in discharge	Impact/Ha (M^3)	Typology
Annual Crops	Residential	5.95	0.12645	0.02124	1
Annual Crops	Mining	4.28	0.05350	0.01250	2
Agriculture	Mining	0.86	0.00510	0.00593	3
Annual Crops	Community Forest	2.36	0.00400	0.00169	4
Annual Crops	Agriculture	6.09	0.00517	0.00085	5
Nature	Residential	8.79	0.00310	0.00035	6

Initial LU	Final LU	Average Increase (Ha)	Average decrease in discharge	Impact/Ha (M^3)	Typology
Reserve					
Nature Reserve	Annual Crops	38.20	0.01082	0.00028	7
Nature Reserve	Agriculture	43.31	0.01023	0.00024	8
Forest	Crop	9.20	0.00138	0.00015	9
Conservation area	Annual				
Nature Reserve	Production Forest	87.26	0.00947	0.00011	10
Conservation Forest	Agriculture	42.48	0.00319	0.00008	11
Conservation Forest	Production Forest	54.80	0.00240	0.00004	12
Annual Crops	Production forest	2.06	0.00002	0.00001	13

Based on the results of the analysis, the change from annual crops to settlements is the largest contributor to the decrease in discharge in the Umbulan Spring Area. The resulting decrease is 21 liters/second from a change of 1 ha of land. While the change of annual crops to mining ranks second with a decrease of 12 liters/second per change of 1 ha of land. The above results are then used in the process of preparing optimal land cover in the form of each typology in order to maintain the sustainability of Umbulan Spring.

Modeling the effect of land cover change and economic activity with GWR

GWR analysis was used to look at the relationship between Umbulan spring discharge (Y) and physical variables and socio-economic activities. The explanatory/independent variables in this model include: land cover change (X1), population density (X2), water use for domestic purposes (X3), water use for agricultural activities (X4), and water use for plantation activities (X5) and water use for industrial purposes (X6) with detailed results of the value of each variable can be seen in table 5.

This analysis was performed to see GWR modeling at the sub-basin level as information on the influence of each independent variable on the discharge variable (dependent). Further, each independent variable in each sub-basin was tested for significance with a t-test at the real level of 0.05 to determine whether each sub-basin had variations in the influential independent variables. For more details can be seen in Table 5.

GWR model in business as usual (BAU) scenario

1. GWR Model Results in the 20% Recharge Zone:

   $Y = 1.48 - 0.106X1 - 0.005X2 - 0.04X3 - 0.003X4 - 0.01X5 - 0.008X6$

2. GWR Model Results in the 80% Recharge Zone

   $Y = 0.89 - 0.05X1 - 0.81X2 - 0.13X3 - 0.009X4 - 0.003X5 - 0.002X6$

3. GWR Model Results in the Core Utilization Zone

   $Y = 3.78 - 1.74X1 - 1.48X2 - 2.82X3 - 0.24X4 - 0.74X5 - 1.84X6$

GWR Model under Conservation Scenario

4. GWR Model Results in the 20% Recharge Zone:

   Y = 1.52 - 0.13X1 - 0.02X2 - 0.03X3 - 0.003X4 - 0.028X5 - 0.01X6

5. GWR Model Results in the 80% Recharge Zone

   Y = 0.88 - 0.11X1 - 0.82X2 - 0.12X3 - 0.01X4 - 0.004X5 - 0.003X6

6. GWR Model Results in the Core Utilization Zone

   Y = 3.58 - 2.22X1 - 1.50X2 - 2.73X3 - 0.16X4 - 0.85X5 - 2.14X6

Description:

X1 : Land cover change
X2 : Population Density
X3 : Household Water Use
X4 : Agricultural Water Use
X5 : Plantation Water Use
X6 : Industrial Water Use

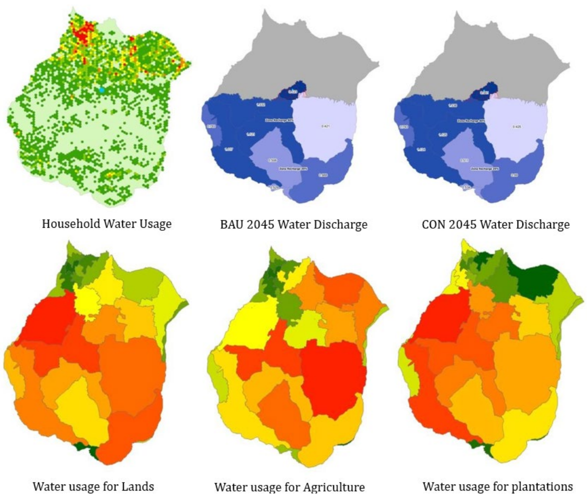

Figure 3: Explanatory/independent variables of GWR model

Table 5: Parameter coefficient values of GWR estimation results

Zone	**Parameter (X1-X6)**	**GWR Parameter Coefficient (BAU Scenario)**	**GWR Parameter Coefficient (CON Scenario)**
Zone of Core Utilization	Intercept	3.787224	3.582614
	Land cover change	-1.749403	-2.226581
	Population density	-1.482514	-1.502342
	Water use for domestic purposes	-2.824421	-2.732721
	Water use for agricultural activities	-0.243842	-0.164871
	Water use for plantation activities	-0.743603	-0.851844
	Water use for industrial activities	-1.845612	-2.145612
80% Recharge Zone	Intercept	0.893404	0.881675
	Land cover change	-0.050834	-0.113842
	Population density	-0.818515	-0.828225
	Water use for domestic purposes	-0.132774	-0.126764
	Water use for agricultural activities	-0.009851	-0.010225

	Water use for plantation activities	-0.003269	-0.004196
	Water use for mining activities	-0.002256	-0.003451
20% Recharge Zone	Intercept	1.48106	1.523912
	Land cover change	-0.106684	-0.137141
	Population density	0.005154	0.0267649
	Water use for domestic purposes	-0.04689	-0.036471
	Water use for agricultural activities	-0.003567	-0.003532
	Water use for plantation activities	-0.018233	-0.028343
	Water use for mining activities	-0.008371	-0.010622

In the significance test with a significance level of 0.05, all parameter coefficients in the GWR model were found to be significant. The results of the GWR model for all independent variables align with the research hypothesis and show variation across each sub-basin in the Umbulan Spring Conservation Area. All variables have negative coefficient values, indicating that the explanatory variables X1-X6 have a negative impact on the discharge of the Umbulan spring. To develop a spatial planning that supports conservation efforts and mitigate the decline in the discharge of the Umbulan spring, it will be necessary to manage all explanatory variables to prevent further increases.

The economic impact on the decline of the Umbulan spring discharge (CON scenario) is reflected in the coefficient of determination (R2), which indicates how well a model fits the data. A higher R2 value signifies a better model. The GWR model produced 208 regression equations corresponding to the number of sub-basins in the Umbulan spring conservation area. This modeling yielded local regression equations for each sub-basin, with an average R^2 value of 0.5442, or 54.42 percent. This R^2 value indicates that the decline in the Umbulan spring discharge can be explained by the variables X1-X6 to the extent of 54.42%. When analyzed spatially and by zoning, the GWR modeling provides several conclusions and characteristics as follows:

1. The Umbulan Spring, one of the largest water sources in East Java, is experiencing a decline in water quantity.
2. Modeling using GWR indicates that all observed variables (population density, household water usage, agricultural and plantation water use, land cover changes, and industrial/mining utilization) negatively impact the flow of Umbulan Spring.
3. Among these, land cover change, household water consumption, industrial activity, and population density are the most significant factors contributing to the reduction in the spring's flow.
4. The core utilization zone shows a notably higher sensitivity to changes in these determining variables compared to the other two zones.

Scenario development optimal scenarios for umbulan spring conservation area

Formulation of Recommendations for Each Zone of Umbulan Spring Conservation

The vulnerability characteristics of each sub-basin to land cover changes and physical activities vary significantly, with diverse spatial distributions. Sub-basins in the core utilization zone are particularly sensitive to changes, especially typology 1, which involves the conversion of perennial crops to residential areas, ultimately increasing water usage for household needs (including small-scale businesses). Typology 5 changes also have a notable impact, particularly on intensive agricultural activities. Sensitivity tests indicate that even small mining areas can have significant effects when considering the impact of land cover changes on water discharge per hectare (typologies 2 and 3). The 80% and 20% recharge zones exhibit a broader vulnerability to decreased discharge due to land cover changes and socio-economic activities, with the most significant impact on discharge reduction stemming from the conversion of protected areas (nature reserves and protected forests) into cultivation zones (residential areas, agriculture, and production forests).

Hydrological modeling results indicate various types of land cover changes and the corresponding decrease in discharge levels caused by these changes. Specifically, shifts towards more intensive land use have a more pronounced impact on discharge reduction. This is further detailed through GWR analysis, which shows that activities related to households, industry, mining, agriculture, and plantations across all zones significantly negatively affect the discharge of Umbulan Spring. The formulation of an optimal scenario aims to minimize land cover changes towards intensive cultivation, taking into account land growth rates and prioritizing changes based on typology levels and the GWR model results. Therefore, based on the hydrological modeling outcomes and the interactions among variables in the GWR modeling, it is essential to establish the foundations for determining the optimal scenario for the conservation of Umbulan Spring as follows:

1) Core utilization zone recommendation

1. The core utilization zone is mostly dominated by changes from perennial crops to settlements and agriculture (Typologies 1 and 5). Therefore, it is necessary to suppress the growth rate of settlements and intensive agriculture.
2. Limiting the growth of residential land must also be accompanied by limiting household use with interests beyond consumption (industrial purposes and micro and small class businesses).
3. Implementation of conservation scenarios by allocating the direction of growth to other zones outside the utilization and recharge areas of the reservoir.
4. Application of a 200m buffer area for direct groundwater utilization around the core utilization zone area and towards the recharge zone.

2) Infiltration zone recommendation

1. The 80% and 20% recharge zones are dominated by changes from protected areas (protected forests and nature reserves) to semi-intensive cultivation (annual crops, wetland agriculture, and mining; Typology 6-13).
2. Restrictions on residential land growth in the core utilization zone should also be applied to the recharge zone.
3. Protected areas (protected forests and nature reserves) must be maintained and cannot be converted as in the provisions of the Regional Spatial Planning
4. Implementation of conservation scenarios by allocating the direction of growth to other zones outside the utilization and recharge areas of the umbulan
5. Existing agricultural areas are maintained through the LSD (Protected Rice Fields) policy and annual crops adjusting to the potential of the local area.

3) Recommendation of release zone

The release zone has an insignificant influence on the decline of Umbulan spring water discharge. Therefore, the spatial planning arrangement in this zone can be carried out by prioritizing the allocation of the growth of built-up land needs in this zone, so that as a whole the Umbulan spring conservation area can also still meet the needs of settlements due to population growth.

These recommendations are also accompanied by the application of rules of transition to the CON (conservation) scenario so as to obtain the best formulation for optimizing Umbulan spring conservation efforts.

Recommendations for proposed optimal scenarios for each umbulan spring conservation spatial planning

The regional spatial planning is a plan for the distribution of regional spatial designations that includes spatial designations for protected functions and regional cultivation functions, formulated with criteria:

a. Based on the regional spatial planning strategy;

b. Considering the allocation of regional space in order to support socio-economic activities and environmental preservation;

c. Considering the carrying capacity and environmental capacity of the region;

d. Refer to the national spatial planning (national RTRW and its detailed plan), the provincial spatial planning (provincial RTRW and its detailed plan), and pay attention to the spatial planning of the bordering district / city;

e. Can be transformed into the preparation of indications of the main five-year medium-term programs for 20 (twenty) years; and

f. Refer to laws and regulations.

In general, the details and distribution of the spatial planning of the Umbulan spring conservation area can be seen in Table 6 .

Table 6: Spatial plan for the umbulan spring conservation area

No	Zone	Spatial Planning	Area (Ha)	Percentage %
1	Core Utilization Zone	Conservation Forest	0	0
2		Production Forest	430.80	30.09
3		Community Forest	8.37	0.58
4		Nature Reserve Area	0	0
5		Residential	202.94	14.17
6		Agriculture	189.05	13.21
7		Annual Crops	587.63	41.04
8		Mining	12.39	0.86
Total			1431.20	
1	80% Recharge Zone	Conservation Forest	6679.48	17.26
2		Production Forest	8016.67	10.71
3		Community Forest	828.55	2.14
4		Nature Reserve Area	106.23	0.27
5		Residential	3969.96	10.26
6		Agriculture	7855.88	20.30
7		Annual Crops	11132.13	28.77
8		Mining	106.51	0.27
Total			38691.28	
1	20% Recharge Zone	Conservation Forest	4103.56	20.11
2		Production Forest	1464.38	7.18
3		Community Forest	12.10	0.06
4		Nature Reserve Area	8300.44	40.67
5		Residential	480.79	2.35
6		Agriculture	4402.94	21.57
7		Annual Crops	1643.34	8.05
8		Mining	0	0
Total			20407.43	

Analysis of the impact of the optimal scenario on changes in the discharge of umbulan springs

The optimal scenario plan for the Umbulan spring conservation area has been developed to assess the extent of its impact on changes in the discharge of the Umbulan springs. This assessment is achieved by comparing the optimal scenario for the year 2045 with the land cover predictions under a no-intervention approach (trend or Business as Usual scenario). Table 7 illustrates a significant difference between the two land cover patterns (optimal scenario and trend-based predictions), indicating that the predictions without spatial control interventions will be largely influenced by substantial changes in land cover, particularly in protected areas and intensive cultivation, which have a considerable impact per hectare on the discharge of the Umbulan springs.

Table 7: Comparison of spatial plan with predicted land cover trends of 2045

No	Zone	Spatial Planning	Area (Optimal Scenario)	Area (BAU)
1	Core Utilization Zone	Conservation Forest	0	0
2		Production Forest	430.80	327.45
3		Community Forest	8.37	14.62
4		Nature Reserve Area	0	0
5		Residential	202.94	302.39
6		Agriculture	189.05	287.97
7		Annual Crops	587.63	498.77
8		Mining	12.39	21.41
Total			1431.20	
1	80% Recharge Zone	Conservation Forest	6679.48	3194.71
2		Production Forest	8016.67	9992.13
3		Community Forest	828.55	979.81
4		Nature Reserve Area	106.23	5.77
5		Residential	3969.96	3461.58
6		Agriculture	7855.88	11218.16
7		Annual Crops	11132.13	9660.90
8		Mining	106.51	178.22
Total			38691.28	
1	20% Recharge Zone	Conservation Forest	4103.56	3038.71
2		Production Forest	1464.38	5447.16
3		Community Forest	12.10	12.30
4		Nature Reserve Area	8300.44	814.45
5		Residential	480.79	909.22
6		Agriculture	4402.94	7254.97
7		Annual Crops	1643.34	2930.62
8		Mining	0	0
Total			20407.43	

Taking into account the effects of land cover changes and socio-economic activities (which are also represented in land cover along with their weighting factors), it can be determined that the formulated optimal scenario plan can reduce the decline of the Umbulan spring discharge by 75.27% in the core utilization zone; 66% in the 80% recharge zone; and 88.32% in the 20% recharge zone, as detailed in Table 8, and spatially, the discharge of the Umbulan spring in the year 2045.

Table 8: Comparison of discharge reduction in spatial plan and bau 2045 prediction

Zone	2019 Discharge	2045 Discharge Spatial Planning	Change in Spatial Planning	c% Change in Spatial Planning	2045 BAU Discharge	BAU Change	% Change in BAU
Core Utilization Zone	2.704	2.666	-0.039	-1.431	2.548	-0.156	-5.784
80% Recharge Zone	1.034	1.024	-0.010	-0.968	1.005	-0.029	-2.848
20% Recharge Zone	0.689	0.683	-0.005	-0.797	0.642	-0.047	-6.828

Based on the proposed optimal scenario, the reduction in output flow can be minimized, although it is still not fully optimal. According to the SWAT analysis results, the suggested land use pattern has an annual recharge quantity of 67,093,762.4 m3. In contrast, the annual recharge in 2019, based on the existing land use pattern at that time, showed a decrease from the previous amount of 70,338,622.3 m^3. Hence, to address the reduction in recharge quantity due to changes in land use planning, it is essential to adapt with supporting infrastructure to maintain the sustainability of the Umbulan Spring.

CONCLUSION

Umbulan Spring is one of the largest springs, serving a wide range of purposes. Located in the village of Umbulan, within the Winongan district of Pasuruan Regency, it stands as one of the major water sources in East Java Province. This spring has significant potential, with an output flow reaching 5,000 liters per second. However, this potential has been declining year after year. Therefore, further research is necessary to investigate the factors contributing to the decrease in flow rate, as discussed below:

1. The dynamics or changes in land cover occurred between 2012 and 2019, marked by a significant increase in development activities, including a 163% rise in residential areas and a 52% decrease in protected lands such as conservation forests and nature reserves. Modeling results indicate that the Conservation Scenario can reduce the growth rate of cultivated areas more effectively than the Business as Usual scenario, particularly emphasizing a reduction of 11% in residential regions.
2. Based on the SWAT simulation results, the simulated discharge of the Umbulan Spring was recorded at 4030 liters per second in 2012, which then decreased to 3382 liters per second. The model's significance test yielded a "Good" result. The decline in spring discharge is negatively correlated with changes in land cover, population density, household water usage, agricultural water use, and plantation water use, all of which affect the recharge capacity of rainwater into the ground. An increase in these activities can lead to a reduction in the discharge of the Umbulan Spring.
3. The Business as Usual (BAU) land cover scenario used for developing land cover plans in spatial planning indicates an overall decrease in projected discharge of 292 liters per second. The Optimal Scenario, which takes into account changes in land cover, hydrological conditions, and socio-economic activities, is estimated to reduce the decline of the Umbulan spring discharge more effectively than the BAU scenario, achieving reductions of 75.27% in the core utilization zone, 66% in the 80% recharge zone, and 88.32% in the 20% recharge zone. This optimal scenario also requires strict guidelines and policies to minimize the risk of converting protected areas into non-protected zones.

The study suggests key improvements for the Umbulan Spring Conservation Area. To address declining spring flow, it recommends implementing both artificial and natural groundwater recharge infrastructure, alongside stricter industry regulations. For the core utilization zone, the focus should be on controlling residential and agricultural expansion, with a 200-meter buffer zone for groundwater use. In the recharge zones, priority should be given to preserving protected areas, limiting residential growth, and maintaining existing agricultural lands through the Protected Rice Field policy. The release zones, having minimal impact on spring flow, can be designated for development to accommodate population growth. Additionally, the study emphasizes the need for comprehensive conservation instruments, detailed zoning studies, and soil condition assessments to better understand land cover changes. These measures collectively aim to balance development needs with the spring's sustainability.

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