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Catchment Discharge Modelling for Maintaining Water Resources in the Lesti Sub-Catchment of Upstream Brantas

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Regional planning ignoring the level ability of area will cause the area damage and will influence the fluctuation of water ability in the catchment. The effort of evaluation and regional planning, which is based on water availability and demand, will give the benefit illustration in the water resources management. This study intended to analyse the discharge model for regional planning based on rainfall, evaporation, soil condition, and land use area in the catchment so that the impact of produced discharge of the regional function can be suitable. The water balance method is used for building the discharge model. The location of the study is determined by considering the data availability on the rainfall and the discharge recorder. The methodologies consist of the field survey, the analysis of the catchment map and the river network by using the geographical information system (GIS). The result of the discharge modelling in the Lesti sub-catchment shows that the influenced factors are rainfall, evapotranspiration, water holding capacity, and water surplus in the soil. The relation between the four factors indicates that the variance inflation factor (VIF) is less than 10. It means that there is no multi-co-linearity among the four independent variables. The discharge value is expected to be suitable to use as regional planning of the upstream catchment by considering water balance and catchment maintenance.

Keywords: model discharge, Lesti, water resources, catchment.

Introduction

The area for agriculture becomes more and more necessary. It is proportionate to the increase in human demand as the result of population growth (Kaimuddin, 2000, Tarawneh, 2013, and Pantouw et al., 2013). However, all of the area which is suitable for agriculture can be said to be better used as the agricultural area as well as the wood product using Soetopo, 2010, Elagib, 2013). The catchment damage in Indonesia increases more and more; it is proportionate to the opening of forest as the agricultural area as well as the wood product use. Some activities of the catchment management, which are implemented in the upstream like the activity of area management that does not attend the conservation system, can stimulate erosion (Mart, 2006, Neitsch et al., 2002, Gabr and Mohamed, 2013). It can affect the downstream in the form of shallowing of the river or irrigation channel because sediment comes from the upstream erosion. The upstream Brantas River catchment is part of the Brantas catchment where the river flow is towards the Karangkates Reservoir (Sutami Dam). Now, the area condition is critical because it is shallowing. The shallowing is due to the mud deposit that is less than 5.5 million m^3. The sediment storage is greater than the initial design with the sediment average of about 1.5 million m^3 per year.

The Lesti sub-catchment is part of the Brantas catchment in the upstream Brantas and is the priority sub-catchment; however, it has a complex problem of area damage, erosion, sliding land, fluctuation of the river discharge, and high sedimentation (Gabr and Mohamed, 2013). Therefore, serious handling to prevent continuous damage is necessary (Suhardjono et al., 2010a and 2010b). Part of the rainfall in the remaining basin which influences the Lesti River has the steep slope (s > 25%); thus, there is erosion. In addition, the sand that comes from the mountains every rainy season will increase the sediment which will accelerate the critical level of the catchment. Therefore, it is necessary to make the conservation effort based on the catchment condition (Runtunuwu, 2007, Rajiman, 1998). Although there is the soil cover vegetation on the upstream Lesti sub-catchment, the rainfall which drops to the surface soil does not intercept in the soil. Part of it will become the surface runoff and will cause erosion (Mulyantari and Adidarma, 2003, Susandi, 2008).

The effort of catchment conservation has given the stimulation for developing the catchment discharge modelling. It is intended to maintain water resources. However, the aim of this study was to build the modelling of catchment regional planning by using the information about the land use and the water balance. In addition, this study intends to obtain alternative catchment regional planning in the upstream for natural maintenance.

Materials and methods

Location, time and data

This study is conducted in the upstream Lesti sub-catchment, Malang Regency, East Java Province with the catchment area of 58.385 ha. The upstream outlet is in the Sengguruh. The Lesti River is the affluent of the Brantas River, which upstream is in the Semeru Mountain. The selection of the location is based on the availability of data.

The needed equipment

This study needs the following resources:

1. the automatic water level recorder (AWLR) located in Jabon village and managed by the Water Resources Department of Bangau-Gedangan Malang;

2 four daily rainfall recorders in the Lesti sub-catchment such as the rainfall stations of Tumpukrenteng, Dampit, Pagak, and Poncokusumo;
3 GPS for land use mapping (Prahasti, 2002, Tarboton, 2000);
4 soil mechanic equipment for taking the soil sample;
5 software of Arc View 3.3 (Chow et al., 1988);
6 the map of the location, presented in Figure 1.

Analysis of rainfall data

Consistency test of rainfall data

The rainfall data are the maximum daily rainfall in one year, expressed in mm/day. The rainfall data are obtained from the Water Resources Department for the rainfall station which is close to the study location. The minimum rainfall data are for 10 years.

The consistency test is a validity test of the field data which presents the real condition (Lestariya, 2005). If there are no rainfall data from the previous observed period, it has to be taken into consideration that the station may be moved or the rainfall recorder may be changed, etc., which will influence the recorded result. The method that is used for evaluating the changes of rainfall data is the double mass curve.

Analysis of regional averaged rainfall

The input of climate data for the WEPP model included the average daily rainfall data from the four rainfall stations during 10 years, such as the average daily rainfall from 1993 to 2002. The methodology is as follows (Limantara, 2010, Di Lazio M et al., 2002):

$$\overline{R} = \frac{1}{n}\left(R_1 + R_2 + R_3 + \ldots.. + R_n\right) \text{ or } \overline{R} = \frac{1}{n}\sum_{i=1}^{n} R_i \qquad (1)$$

Where: $\overline{R}$ –area rainfall depth; R_1, R_2, R_3 .....R_n – point rainfall depth; n – number of the rainfall recorder

Table 1 presents the analysis of averaged daily rainfall in the Lesti sub-catchment.

Analysis of evaporation

The meteorological data used in this study are obtained from the Department of Meteorology and Geophysics of Karangploso as the nearest station to the study location. The station is on the south longitude coordinate

Fig. 1

Map of location

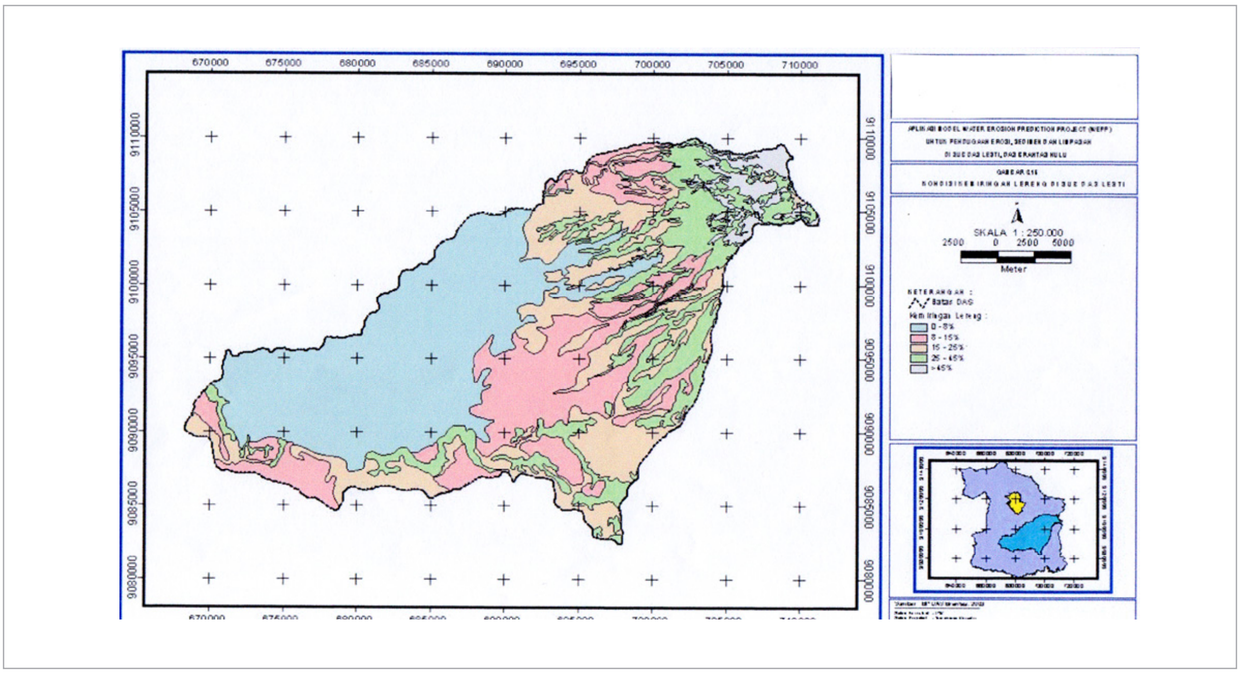


Table 1

Analysis of averaged daily rainfall in the Lesti sub-catchment

Month	Poncokusumo Station (mm)	Dampit Station (mm)	Tumpukrenteng Station (mm)	Pagak Station (mm)	Mean (mm)
1	2	3	4	5	6
January	402	338	351	328	354.75
February	307	218	134	192	212.75
March	343	331	322	421	354.25
April	107	42	19	128	74
May	58	39	50	168	78.75
June	0	0	2	0	0.5
July	0	0	9	0	2.25
August	0	0	0	0	0
September	0	0	1	10	2.75
October	59	45	17	93	53.5
November	212	101	41	191	136.25
December	346	438	379	333	374

Source: own study

of 7° 53' and east longitude coordinate of 122° 21' and the elevation of 575 m. The obtained data consisted of temperature, humidity, sunshine, wind velocity and air pressure in 2012. The analysis of evapotranspiration in this study used the CropWAT 8 Window, developed by FAO, and the result is presented in Table 2 below.

Table 2

Evapotranspiration in the Lesti sub-catchment

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
1	2	3	4	5	6	7	8
January	21.2	27.6	83	420	2.8	14.1	3.54
February	20.3	28.5	81	132	5.2	18.1	3.85
March	20.9	27.7	77	204	3.6	15.1	3.63
April	20.2	28.8	76	158	6.8	18.8	4.06
May	19.9	28.0	74	175	7.0	17.6	3.83
June	18.6	27.9	72	168	7.0	16.7	3.65
July	17.8	26.7	75	158	6.8	16.8	3.45
August	17.1	27.7	73	185	8.3	20.2	4.15
September	18.1	29.3	69	197	8.5	22.2	4.85
October	19.7	30.3	71	187	8.4	22.8	5.06
November	21.1	29.5	78	154	6.5	19.8	4.33
December	20.8	28.6	85	120	3.4	14.9	3.27
Average	**19.6**	**28.4**	**76**	**188**	**6.2**	**18.1**	**3.97**

Source: own study

Table 3

Soil texture and water holding capacity (WHC) in the Lesti sub-catchment

Analysis of water holding capacity in the Cobanrondo catchment in 1993					
Type	Area (%)	Texture	Water availability $cm^3.cm^{-3}$	Length of the root zone (m)	Water holding capacity (mm)
1	2	3	4	5	6
Forest	10.13	dusty clay	20.90	2.00	41.2294
Garden	54.65	sandy clay	23.20	1.67	198.764
Residence	20.51	sandy clay	20.70	0	0.0035
Rice irrigated area	14.71	sandy clay	19.50	1.00	39.4199

Source: own study

Water holding capacity

The soil condition in the Lesti sub-catchment has to be attended on its texture. The samples from the 4 districts have to represent the 4 types of land use and there is an effort for the distributed evenly in all of the catchment. Table 3 presents the soil texture and water holding capacity in the Lesti sub-catchment.

Results and discussion

Discharge modelling for catchment regional planning

Analysis of the discharge modelling of catchment regional planning in this study is based on the previous research about the discharge modelling due to the water balance of the Cobanrondo catchment. In the discharge modelling of the Lesti sub-catchment, it is necessary to calculate every component which influences the system, such as total rainfall, actual evapotranspiration, area of land use, and water holding capacity (Anataliki, 2005, Baumgartner, 1975, Mehta, 2006, Melese, 2006). The analysis in this study is based on the hydrological condition, such as total evaporation or generally mentioned as evapotranspiration. The catchment water balance is intended to predict the run-off in the catchment. Before building the discharge modelling, first, the run-off has to be obtained for each land use from January to December. This study uses the method of Thornwaite-Matter by assuming that 50% of the surplus water will become as the run-off and the rest will enter the soil and the rest of 50% will be going in the next month. This study is based on one year observed data because of limited availability of the land use map in the study location. The water balance is calculated in each area of the land use and observed year data by using the Thornwaite-Matter method with the programme Q-basic. The result is presented in Table 4.

Explanation:

- Total of (P-PE) = 1596.08, Total of positive (P-PE) = 1606.68, Total of negative (P-PE) = -10.6
- The average of drought index = 2.569997

The previous model in the upstream catchment of the Cobanrondo catchment (Suhardjono, 2010) was as follows:

1 Q(forest) = - 0.015578 - 0.000239 P(h) - 0.000222 EA(h) -0.000968 S(h) + 0.00304 WHC(h)a

2 Q(garden) = 0.369635 + 0.000211 P(k) - 0.00134 EA(k) + 0.000027 S(k) + 0.000355 WHC(k)

3 Q(residence) = - 80496 + 0.000026 P(m) - 0.000385 EA(m) + 0.000077 S(m) + 930.875 WHC(m)

4 Q(rice irrigated area) = - 0.29044 + 0.000018 P(w) - 0.000063 EA (w)+ 0.000299 S(w) + 0.012863 WHC(w)

5 WHC(h) = - 0.114 + 4.18 L(h)

6 WHC(k)= -4.21 + 3.56 L(k)

7 WHC(m) = - 0.000041 + 0.000174 L(m)

8 WHC(w) = 31.3 + 0.552 L(w)

9 Q(theoretic) = Q(forest) + Q(garden) + Q(residence) + Q(irrigated rice area)

10 Qmodel = 0.197 + 0.677 Q(theoretic)

Table 4

Analysis of water balance in Lesti garden in 2012. STO = 39.4 rainfall surplus total (P-PE) > 0

BULAN	P	PE	P-PE	APWL	ST	DST	AE	D	S	IK
1.0	354.8	3.5	351.2	0.0	39.4	0.0	3.5	0.0	351.2	0.0
2.0	212.8	3.8	208.9	0.0	39.4	0.0	3.8	0.0	208.9	0.0
3.0	354.3	3.6	350.6	0.0	39.4	0.0	3.6	0.0	350.6	0.0
4.0	74.0	4.1	69.9	0.0	39.4	0.0	4.1	0.0	69.9	0.0
5.0	78.8	3.8	74.9	0.0	39.4	0.0	3.8	0.0	74.9	0.0
6.0	0.5	3.7	-3.2	3.2	36.4	-3.0	3.5	0.1	0.0	3.4
7.0	2.3	3.5	-1.2	4.4	35.3	-1.1	3.3	0.1	0.0	3.2
8.0	0.0	4.2	-4.2	8.5	31.8	-3.5	3.5	0.6	0.0	15.0
9.0	2.8	4.8	-2.1	10.6	30.1	-1.6	4.4	0.5	0.0	9.3
10.0	53.5	5.1	48.4	0.0	39.4	9.3	5.1	0.0	39.1	0.0
11.0	136.3	4.3	131.9	0.0	39.4	0.0	4.3	0.0	131.9	0.0
12.0	374.0	3.3	370.7	0.0	39.4	0.0	3.3	0.0	370.7	0.0
	1643.8	47.7	1596.1			0.0	46.4	1.3	1597.4	30.8

Source: the output from the Arc Ciew 3.3 software

Where:

Q(theoretic) = theoretical discharge

Q(model) = model of discharge

Q(forest) = run off on the forest

Q(irrigated rice area) = run off on the irrigated rice area

Q(residence) = run off on the residence

Q(garden) = run off on the garden

WHC = water holding capacity

P(w) = rainfall

EA(w) = evapotranspiration

S(w) = surplus of groundwater

Analysis of the run-off discharge by using the Thornwaite method in Lesti sub-catchment is carried out for 7 conditions of the data. The result is presented in Tables 5 and 6 each for the theoretical discharge and the model discharge in the Lesti sub-catchment. However, the comparison between the model and the observed discharge in the Lesti watershed is presented in Table 7.

Table 5

Theoretical discharge in the Lesti watershed

No	Q forest (mm)	Q garden (mm)	Q residence (mm)	Q irrigated rice area (mm)	Q total (mm)
1	2	3	4	5	6
1	0.146	0.462	2.486	0.234	3.328
2	0.146	0.463	2.487	0.234	3.331
3	0.148	0.474	2.488	0.235	3.346
4	0.146	0.460	2.486	0.234	3.326
5	0.142	0.420	2.482	0.231	3.275
6	0.141	0.400	2.479	0.229	3.249
7	0.144	0.429	2.482	0.231	3.286

Source: own study

Table 6

Model discharge in the Lesti watershed

No	0.197	0.677 x Q theoretic	Q model (m^3/s)	Ratio between Lesti and Cobanrodo	Q model Lesti
1	2	3	4	5	6
1	0.197	2.253	2.450	34.691	84.989
2	0.197	2.255	2.452	34.691	85.062
3	0.197	2.265	2.462	34.691	85.409
4	0.197	2.252	2.449	34.691	84.959
5	0.197	2.217	2.414	34.691	83.755
6	0.197	2.200	2.397	34.691	83.145
7	0.197	2.225	2.422	34.691	84.006

Source: own study

Table 7

The comparison between the model and the observed discharge in the Lesti watershed

No	Q model (m^3/s)	Q observed (m^3/s)
1	2	3
1	84.989	81.418
2	85.062	94.166
3	85.409	86.506
4	84.959	81.832
5	83.755	54.496
6	83.145	36.538
7	84.006	52.426

Source; own study

Calibration of the model is carried out by building the regression equation with the minitab programme. The result is as follows:

Q observed = -609 + 8.06 Q(theoretic)

Regression analysis: C2 versus C1

The regression equation is

C2 = -609 + 8.06 C1

Predictor	Coef	SE Coef	T	P	VIF
Constant	-608.5	686.3	-0.89	0.416	
C1	8.056	8.152	0.99	0.368	1.000

S = 21.6245 R-Sq = 16.3% R-Sq(adj) = 0.0%

PRESS = 4899.07 R-Sq(pred) = 0.00%

Analysis of variance

Source	DF	SS	MS	F	P
Regression	1	456.7	456.7	0.98	0.368
Residual Error	5	2338.1	467.6		
Total	6	2794.8			

There are no replicates.

Minitab cannot do the lack of fit test based on pure error.

Durbin-Watson statistic = 0.751367

No evidence of lack of fit (P > = 0.1).

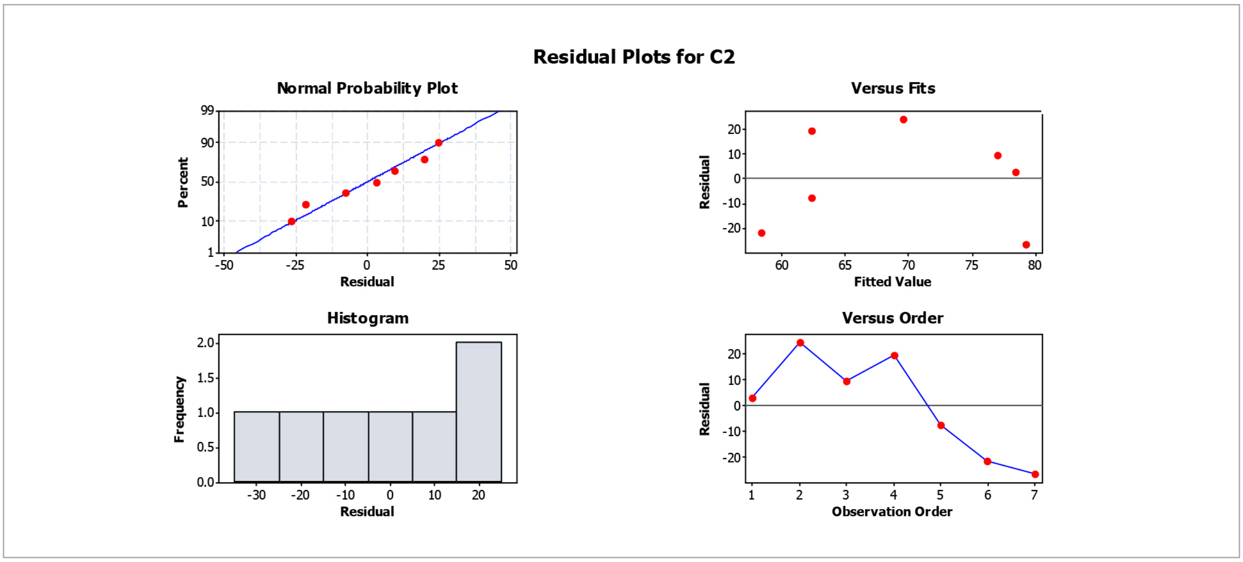
Residual Plots for C2

Figure 2 presents the result of regression analysis.

Therefore, the discharge model of the Lesti sub-watershed is as follows:

1. Q(forest) = - 609 + 8.06{ - 0.015578 - 0.000239 P(h) - 0.000222 EA(h) - 0.000968 S(h) + 0.00304 WHC(h)a}
2. Q(garden) = - 609 + 8.06 { 0.369635 + 0.000211 P(k) - 0.00134 EA(k) + 0.000027 S(k) + 0.000355 WHC(k)}
3. Q(residence) = - 609 + 8.06 {- 80496 + 0.000026 P(m) - 0.000385 EA(m) + 0.000077 S(m) + 930.875 WHC(m)}
4. Q(irrigated rice area) = - 609 + 8.06 {- 0.29044 + 0.000018 P(w) - 0.000063 EA (w)+ 0.000299 S(w) + 0.012863 WHC(w)}

Fig. 2



Source: own study

5 WHC(h) = -0.114 + 4.18 L(h)

6 WHC(k) = -4.21 + 3.56 L(k)

7 WHC(m) = -0.000041 + 0.000174 L(m)

8 WHC(w) = 31.3 + 0.552 L(w)

9 Q theoritic = Q(forest) + Q(garden) + Q(residence) + Q(irrigated rice area)

Conclusions

Based on the analysis above, the following conclusions are drawn:

1 The four independent variables consist of rainfall, evapotranspiration, water holding capacity, and water surplus, indicating the value of the inflation factor (VIF)≤10. It means that there are no multi-co-linearities among the four variables.

2 The theoretical discharge for the regional planning of the Lesti sub-watershed is as follows:

Q(forest) = - 609 + 8.06{ -0.015578 - 0.000239 P(h) - 0.000222 EA(h) - 0.000968 S(h) + 0.00304 WHC(h)a}

Q(garden) = - 609 + 8.06 { 0.369635 + 0.000211 P(k) - 0.00134 EA(k) + 0.000027 S(k) + 0.000355 WHC(k)}

Q(residence) = - 609 + 8.06 {- 80496 + 0.000026 P(m) - 0.000385 EA(m) + 0.000077 S(m) + 930.875 WHC(m)}

Q(irrigated rice area) = - 609 + 8.06 {- 0.29044 + 0.000018 P(w) - 0.000063 EA (w)+ 0.000299 S(w) + 0.012863 WHC(w)}

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Upės Brantas vandens išleidimo trasos modeliavimas

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Naujas regioninis planavimas, sukels žalą aplinkai ir darys įtaką vandens telkinių svyravimams. Vertinimo ir regioninio planavimo pastangos, grindžiamos vandens prieinamumu ir paklausa, bus naudingos vandens resursų valdymui. Šiame tyrime buvo siekiama išnagrinėti regioninio planavimo biudžeto įvykdymo modelį, pagrįstą kritulių kiekio, garavimo, dirvožemio būklės ir žemės naudojimo sritimi. Vandens balanso metodas naudojamas regiono modeliui kurti. Tyrimo vieta nustatoma atsižvelgiant į duomenis apie kritulių kiekį ir žemės naudojimo sritį. Metodologijas sudaro lauko tyrimas, baseino žemėlapio ir upių tinklo analizė, naudojant geografinę informacinę sistemą (GIS). Išleidimo modeliavimo rezultatas rodo, kad įtakojantys veiksniai yra lietingumas, išgaravimas, vandens laikymo pajėgumai ir vandens perteklius dirvožemyje. Keturių pakopų tyrimai rodo, kad dispersijos infliacijos koeficientas (VIF) yra mažesnis nei 10. Tai reiškia, kad tarp keturių nepriklausomų kintamųjų nėra daugelio linijiškumo. Numatoma, kad išleidimo vertė bus tinkama naudoti kaip upių baseino regioninį planavimą, atsižvelgiant į vandens balansą ir vandens telkinių išlaikymą.

Raktiniai žodžiai: regioninis planavimas, vandens resursai, vandens baseinas.