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Spatial Model of Post-Earthquake Spring Performance in the Watershed Areas

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ABSTRACT

The 7.4 Mw of tectonic earthquake caused liquefaction in Pasigala on September 28, 2018, happened due to the fault movement of Palu-Koro. It affected the water availability every spring. The research aim is to determine the spatial model of water production every spring after the natural tectonic disaster, especially in Palu and Poboya watersheds-a model built based on the integration between the spatial data overlaying and the statistical regression correlation. The sites are purposively selected at six springs spots and divided into four clusters (Poboya, Uemanje, Ranjuri Beka, Mantikole). The model assessment was generated based on the springs' performance from x variables (catchment area, land cover, aquifer, free-ground water depth, fault, number of springs users) and the y variable (water discharge). The result shows that Poboya's performance is bad-disturbed, while Uemanje, Ranjuri, Beka, and the performance of Mantikole are disturbed. The bad performance of springs requires conserving watershed areas through forest and land conservation, tree enrichment planting, wise land management, and good water use.

INTRODUCTION

Issues related to natural disasters have become a central issue in every country in the world (Albris et al. 2020, Galata et al. 2020). It has an impact on the economy, humans, and the environment (Botzen et al. 2019, Ali et al. 2020), especially in Asian countries that are prone to earthquakes, tsunamis, and liquefaction (De Goyet 2007, Wekke et al. 2019).

A natural disaster of the tectonic earthquake on September 28, 2018, followed by tsunamis and liquefaction, hit Palu, Sigi, and Donggala (Pasigala) in Central Sulawesi. It negatively impacted the infrastructures, causing severe land surface destruction and property loss. It cost billions of rupiahs or even human life lost. According to Nugroho (2018), the disaster on October 25, 2018, hitched 2,065 deaths in Pasigala, 15 deaths in Parigi Moutong, and 1 person death in Pasangkayu (West Sulawesi). Further, 4,438 were severely injured, 8,130 were injured, 1,309 were lost, 214,925 were refuged, and 21,321 had evacuated.

The earthquake caused by the Palu-Koro fault movement hit Pasigala with 7.4 Mw. Palu-Koro fault is an active segment of the Tumbu-Talise-Bora and Gumbasa-Kulawali segments). These cross to the western coastal area of Donggala Regency, Palu's Bay, and the South Kulawi district of Sigi Regency. The earthquake ground spot is in Tompe village, a part of the Sirenja district of Donggala Regency. This earth movement then predicted impacts the water resource availability of each spring, whether in a water basin (WB) or a non-water basin. Several water basins are spread across the Palu, Sigi and Donggala, such as the WB of Palu, Bobo, Tawaeli, Oti, Tompe, Labea, and Palado.

The earthquakes can cause hydrological responses, such as groundwater availability in and above the ground (Wang et al. 2004, Liao et al. 2015). Stockpiling a reservoir risks an earthquake (Xuan-Nam et al. 2020) and can cause landslides and soil erosion (Tunas et al. 2020, Naharuddin et al. 2021). Each of Palu's watershed and Poboya's watershed are equipped with springs. Both were affected by the Palu-Koro movement when the earthquake event occurred. The ground movement then predicts the impact of the Poboya Springs, Ranjuri Springs in Beka village, Mantiloke Springs in Mantiloke village, and Uemanje Springs in Uemanje village. Those springs are generally located in the tectonic fault pathway. The tectonic fault structure controls the emergence of water sources and water channels under the surface. The tectonic fault structure affects the emerging water sources (Santosa 2006).

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Research on the impact of the earthquake, tsunamis, and liquefaction in Palu and Donggala concerning water sources' performance has not been conducted. The research was carried out only on the focus on assessing the level of erosion hazard in some land uses after earthquakes and liquefaction (Naharuddin et al. 2020), mapping of post-disaster damage and liquefaction (Syifa et al. 2019), landslide study in the East Palu Valley after the earthquake (Mason et al. 2021). Earthquakes can cause hydrological responses, such as groundwater availability in and above the ground. This statement is in line with King et al. (2006) statement that there is a temporal change in underground water hydrology due to the earthquake. This knowledge is very important for watershed management planning and modeling of springs (Wilkerson 2008, Reghunath et al. 2009, Jakubis & Jakubisová 2019). The research on the water production in Palu's watershed and Poboya's watershed is interested in assessing water's present condition and availability at the ground and surface pathway. The research aims to determine the spatial model of springs' performance on water production post-impact of the earthquake at these sites. The research would provide spatial data and information on springs' performance. At the same time, the guideline of water resource recovery and the science and spatial technology of watershed management is also arranged as the basis for post-earthquake management planning.

MATERIALS AND METHODS

Study Area

This study was collaborative research involving the Palu Poso Watershed Management Center and the Forestry Faculty of Tadulako University. It will be conducted for two years, from May to October 2019, for data collecting and June to December 2020, for spatial model arrangement.

Technically, sites were divided into four clusters. The watershed in Palu consisted of 3 clusters: Ranjuri-springs, Mantiloke-springs, and Uemanje-springs. Furthermore, the last cluster chose Poboya-springs as a part of the Poboya watershed. Geographically the location is at the coordinate point, according to Table 1.The study sites are shown in Fig. 1.

Tool and Study Material

Data were divided into primary data collected by the collaborative team, including primary data on the field condition of each spring taken from May to October 2019, and secondary data types consisting of the map. These maps were collected from a particular center or agency. National Mapping Centre (NMC) provides spatial data with a scale of 1:50,000 – 1:100,000 consisting of digital maps such as Indonesian land cover, route map, river flow, and settlement area. Other data were prepared by the Palu Poso watersheds management center, such as the catchment area, land and geological map, rain intensity zonation map, and topographical and water resources.

While fault maps, water basin maps, and spatial planning maps are collected from the provincial planning agency with a scale of 1:100,000 – 1,250,000. Palu's regional forestry mapping agency provides land cover data and forest area. This kind of map is available for scale 1:100,000 – 1,250,000. Furthermore, those particular satellite images have been collected from the national space agency for SPOT6/7.

Research Methodology

A spatial analytical method has been implemented for this research, combined with overlaying spatial data and made a score through statistical analysis (regression-correlation). The spatial analysis, through overlying a basic map, thematic map, and SPOT image, tries to build parameter attributes and count the indicator values (Wahyuningrum & Putra 2018).

The spatial elements studied include the distribution of the fault path on September 28, 2018, geomorphological (river flow, tectonic surface pattern) and the river basin, aquifer, free land water depth, land texture, climate (the intensity of rain), topographic, land cover (vegetated or non-vegetated), water quality (discharge), catchment area

Table 1: Research locations.

Cluster		Geographical coordinate		Site/Area
Number	Code	East longitude (E)	South latitude (S)	
1	SP1	119°51'20.82"	0°59'28.20"	Ranjuri
	SP2	119°51'40.18"	0°59'48.25"	Ranjuri
2	SP	119°51'52.08"	0°04'51.60"	Mantiloke
3	SP	119°49'07.50"	0°58'45.42"	Uemanje
4	SP1	119°55'00.48"	0°53'00.72"	Poboya
	SP2	119°55'15.48"	0°52'50.76"	Poboya

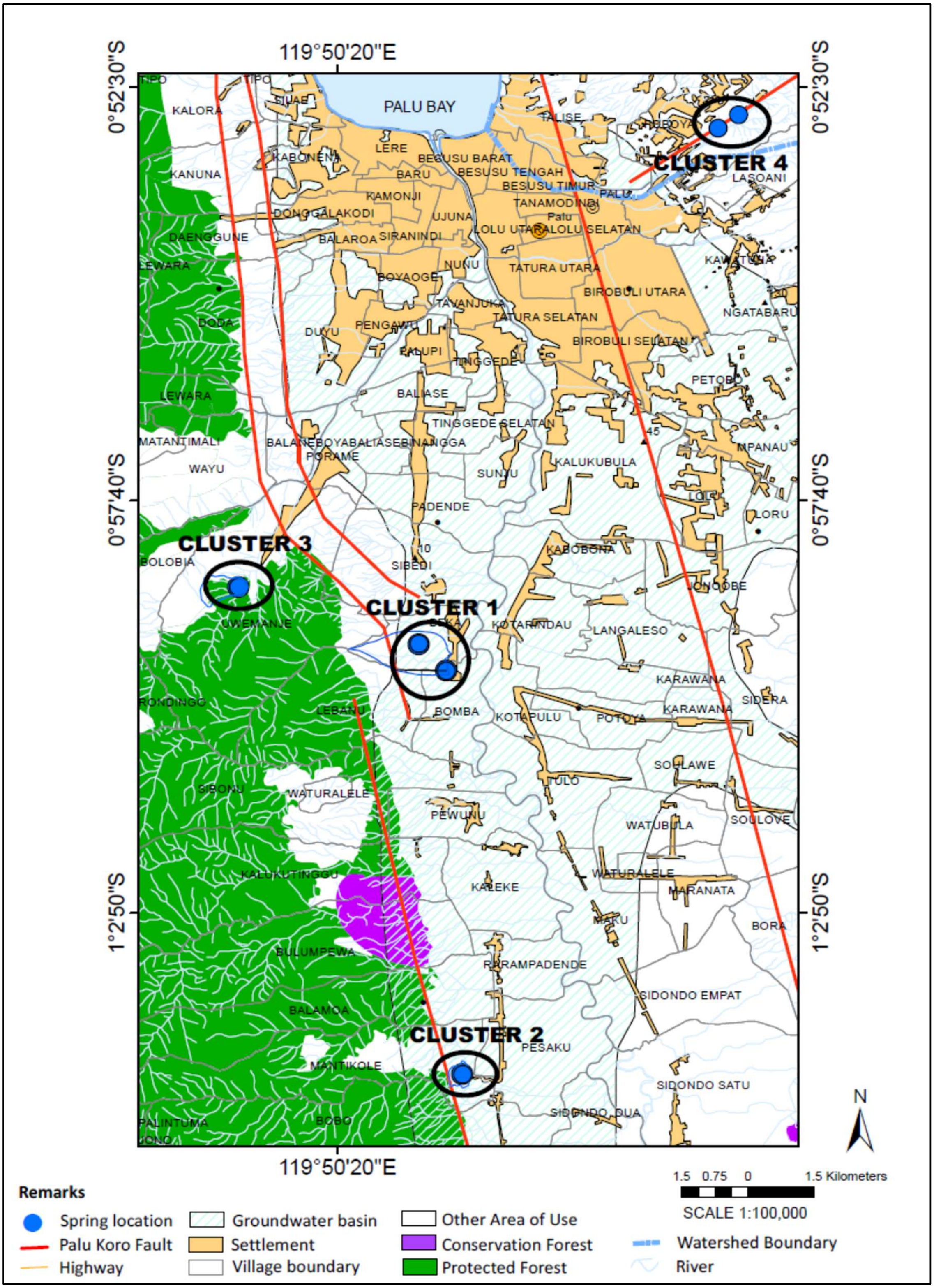

Fig. 1: Research location of Palu and Poboya watersheds.

and the various utilization of water by the local community. Besides, supplement data support the research, i.e., springs typology, geological, land texture, elevation, kind of land cover, land uses, land status, watershed area, accessibility, infrastructure, and community profile (number of residents).

The selection of springs locations that were examined for their spatial performance was done purposively as presented in Fig. 1 with the following considerations: (a) Poboya springs are located close to the tectonic fault lines, tectonic plains, non-forest areas, non-water basin area, typology of springs 'contact', type of land use in settlement area/ mining areas, owned land status; (b) the Uemanje springs is located a distance from the cesarean line, tectonic mountains, protected forest, non-water basin area, springs 'contact' typology, land use types in forest areas, state-owned land status; (c) Ranjuri springs is located near the cesarean line, river flow path, outside the forest state area, at the water basin area, 'depressive' springs type, residential areas land use type, land owned by the community/village property; (d) Mantikole springs is located near cesarean lines, hot springs, river flow paths, located in outside of state forest areas, in a water basin, 'depressed' springs type, agricultural land use type/ tourist areas, owned by the community/local government property. The springs' location selection is a catchment area typical of land cover, soil texture, water quantity (discharge), water quality, annual rainfall, and potential groundwater in aquifers.

The process of the research describes as follows:

1. The analysis process is based on inventory and identification data of springs.

   Overlaying and delineated boundary research areas (spatial and tabular): The boundaries of the Palu and Poboya watersheds, regencies/cities, districts, villages, and forest area boundaries (status/function of the area). Spatial tabulation and analysis based on the inventory and field identification of six springs locations into the four clusters) in the Palu and Poboya watersheds.

2. Spatial modeling of springs performance.

Springs performance modeling with a spatial data overlaying approach and regression-correlation analysis was made to determine the relationships and trends among variables. The water quantity/water discharge ($L.s^{-1}$) variable was analyzed with the cesarean moving path (kilometers), soil texture (related to infiltration/permeability), catchment area (ha), geomorphology (watershed /non-watershed in river flow paths, tectonic mountains, rainfall ($mm.y^{-1}$), aquifer productivity, free groundwater depth, slope (% slope), vegetated land cover (% of the coverage area), number of springs users (households, worship, offices, education, health, tourism, agriculture, etc.). The results of the regression-correlation analysis become a reference for the scoring and variable scores selection. Range correlation value (R) $\geq$ 0.50 were selected as modelers in the spatial analysis system of springs performance. The size of each chosen variable's scoring is determined based on the coefficient determination (the level of accuracy of the regeneration model) with a value of R2 $\geq$ 0.25.

The springs spatial performance criteria are as follows:

- Poor performance springs category: The springs' condition regarding water production has connected to a bio-geophysical and socioeconomic variable with a total weighting value of 20-46. Springs area recovery is recommended.
- Disturbed performance springs category: The springs' condition regarding water production has connected to a bio-geophysical and socioeconomic variable with a total weighting value of 47-73. Countermeasures action is recommended.
- Good performance springs category: The springs' condition regarded water production has connected to a bio-geophysical and socioeconomic variable with a total weighting value of 74-100. Prevention is recommended (The Ministry of Environment and Forestry 2017), (modified according to the research needs).

RESULTS AND DISCUSSION

The Springs Condition

Characteristics observation of groundwater has been conducted on the spot that naturally springs. The springs indicated groundwater comes out as surface runoff. The springs condition in Palu and Poboya watersheds in four clusters are shown in Table 2.

Spatial Model of Springs Performance

The spatial model of springs performance begins with regression analysis and correlation among the determining variables of the performance of springs concerning each spring's ability to produce water (discharge) in liters/second. There are ten variables: (a) The proximity of springs from the movable tectonic fault; (b) Soil texture related to the level of infiltration; (c) water catchment areas; (d) geomorphology of river flow paths, plains/hills/tectonic mountains in the water basin/ non-water basin areas; (e) rain intensity; (f) Aquifer productivity; (g) vegetated land cover; (h) topography class; (i) Number of springs users; (j) Depth of free groundwater. The results of regression and correlation are as in Table 3.

The regression correlation analysis in Table 3 used the transformed data from Table 2. The transformation for data

Table 2: Water discharge conditions, biogeophysical, and socioeconomic location of the springs.

Variable	Name of Springs					
	Cluster 4 Poboya		Cluster 3 Uemanje (SP)	Cluster 1 Ranjuri Beka		Cluster 2 Mantikole (SP)
	Springs$_1$ (SP1)	Springs$_2$ (SP2)		Springs$_1$ (SP1)	Springs$_2$ (SP2)	
Watershed area	Poboya	Poboya	Palu	Palu	Palu	Palu
Regency/city	Palu	Palu	Sigi	Sigi	Sigi	Sigi
Forest area	non-forest area		Protected forest	non-forest area		non-forest area
Land status	Community		Government	Community		Local government
Springs typology	Contact		Contact	Depressive		Depressive
Water catchment area [ha]	8.05	20.30	51.61	64.04	68.77	22.82
Water discharge [$L.s^{-1}$]	1.18	5.09	0.51	0.70	0.18	1.04
Tectonic fault distance from the springs [km]	0.02	0.03	17.04	12.75	12.17	11.19
Geomorphology	Non-water basin - tectonic land surface		Non-water basin - tectonic mountains	Ground water basin-river flow path		Ground water basin-river flow path
Aquifer productivity	Moderate		High	High		High
Ground-free water depth [m]	0.85	0.85	0.50	0.48	0.48	0.48
Elevation (meters above sea level)	175-200	150-200	550-650	75-125	25-125	75-200
Slope class [%]	25.06	23.05	43.20	12.75	11.05	50.28
Geology type and formations	QTms (molasa celebes sarasin and sarasin)/ Sediment)		Kls (latimojong); gr (intrusive rocks)/ Metamorphic)	Qa (AluviumCoastal sediment/ Alluvium)		QTms (molasa celebes sarasin and sarasin)/Alluvium)
Soil type	Red-yellow podzolic, litosol			Alluvial, Glei humus		Brown forest soil, alluvial
Soil texture	Clay	Clay	Sandy clay	Clay	Dusty clay	Dusty clay
Climate/Rain intensity [$mm.y^{-1}$]	D/ 800-1.000		D/ 1.200-1.400	D/ 800-1.000		D/ 1.200-1.400
Land use	Forests, mixed gardens, settlements, shrubs, grass, fields, open land		Forests, shrubs, open land	Shrubs, open land	Forests, Coconut groves, scrub, settlement	Coconut stand, shrubs, open land, tourist areas.
Vegetated land cover [ha]	7.46	17.01	42.98	60.25	61.03	20.23
Type of plant	Timber, coconut, banana, corn		Candlenut, tamarind, sugar palm, bamboo	Acacia, Jatropha	Manggo, coconuc, banana, timbers.	Timber, Lamtoro, Coconut, Banana, Guava, Mango
The Accessibility/ Infrastructure	Village Road		Village Road	Village Road		Village Road
Number of the population) (soul/head of household)	1.716/ 643		1.234/ 305	2.649/ 609		1.208/ 281
Population density [$souls.km^{-2}$]	27		74	1.172		96
Livelihood	Gold miners, farmers, gov. employee		Farmers	Farmers		Farmers
Community needs for springs (l/day / person/head of household)	50		50	50		50
Springs utilization (head of household)	643		305	609		281
Springs user	Household, agriculture)	Household, house of worship	House holds, baths, houses of worship, schools	Household, Agriculture	Household, houses of worship, and schools.	Household, Tourism, Agriculture

Source: Results of the 2019 springs inventory/identification; a result of the SPOT image analysis and maps; a result of socioeconomic data analysis (Central Statistical Agency Sigi Regency 2018 and Central Statistical Agency Palu City 2018).

consists of null with SQRT=√xi+0,5, and other than null, has transformed with SQRT=√xi. The qualitative data such as geomorphology, aquifer productivity, and soil texture are quantified by scores 1,2,3 according to the level. The high aquifer productivity received a score of 3, while the medium and low productivity levels received scores of 2 and 1, respectively. The same treatment is also done for the soil texture, scoring 3 for fine texture, 2 for fine soil texture, and 1 for rough texture. The geomorphological water basin path and tectonic land received a score of 3. The non-water basin received 2 and 1 for tectonic hills.

Table 3 shows the results of the regression analysis and the correlation between the response variable (Y) water discharge with explanatory variables (X1-X10), which are generally weak-moderate negative correlations due to the fewer water discharges (1.45 $L.s^{-1}$). SP2 Poboya became the only site supported by an adequate water discharge from those six springs locations, which is 5,09 $L.s^{-1}$. In contrast, the SP1 Poboya and SP Mantikole (hot springs) are supported by lower discharge, 1.18 $L.s^{-1}$ and 04 $L.s^{-1}$, respectively. Each SP1 Ranjuri, SP2 Ranjuri, and SP Uemanje supported the water flow of 0.70 $L.s^{-1}$, 0.18 $L.s^{-1}$, and 0.51 $L.s^{-1}$. The potential quantitative level of free groundwater (small-medium) and small potential (<1.0 $L.s^{-1}$) occupied the eastern part of the river basin in East Palu District, South Palu, Dolo. Medium potential (1.0-5.0 $L.s^{-1}$) covers the entire western part of the water basin and only 40% in Sigi Biromaru and Gumbasa Districts.

The fault movement may cause less water discharge in SP Ranjuri Beka and SP Mantikole. Somehow, cesarean has led to landslides upstream of the Beka Village, disrupting the existing water flow as springs. Generally, the pattern of springs is caused by groundwater level cross topography, so the springs seem depressed and associated with the presence of fault (Santosa 2006). The topography in Mantikole was impacted by water discharge. Steep topography with alluvium rocky type (Molas Celebes Sarasin and Sarasin) and the existence of fault movement affect the rock structure disruption (Fig. 2). Santosa (2006) suggested that hot springs appear due to non-gravitational power are located in the fracture of the long earth's crust, and very deep. The water source mostly comes from rainwater that falls around it, and only a small portion comes from inside the earth (magmatic). The falling rain infiltrates the ground and is heated by magma underneath, forming a large convection current that pushes to the ground's surface.

Poboya springs cluster outside the water basin area in tectonic plains and contain two springs with different discharges, namely springs (SP) Poboya with small water discharge and SP2 Poboya with moderate water flow. Both of these SP locations are very close to the tectonic fault movement, steep topography, rock type sediment (molasa Celebes Sarasin and Sarasin) (Fig. 3). Further, SP Ranjuri Beka and Uemanje have a small water discharge located outside of the water basin area and far from the fault movement (Fig. 4). The movement disrupted the rock structure so which affects water flow. Rock cracks could decrease slope stability. The landslide may occur the rainwater seeps into the crack or when the slope is shaken. The appearance of springs is mostly influenced by the tectonic fault structure, other than the rock's constituent condition. The tectonic fault

Table 3: The correlation regression analysis of water discharge with biogeophysical variables and springs users at six locations in four springs clusters.

The simple regression analysis variables		Regression model $\bar{Y} = a + bX$	Determi-nant coeffi-cient (R2)	Correlation (R)	(Test) F	
					F_{count}	$F_{tab.}(\alpha_{0,05,1,4})$
Explanatory variable X		Response variable Y Water discharge				
X1	Catchment area	$\bar{Y}$ = 0.17 – 2.06X	0.35	-0.59	6.15 ^{nr}	7.71
X2	Geomorphology	$\bar{Y}$ = 0.33 – 1.55X	0.02	-0.15	4.09 ^{nr}	7.71
X3	Distance Fault moves from the springs (The distance of tectonic fault from springs	$\bar{Y}$ = 0.26 – 1.70X	0.56	-0.75	9.14 ^{r}	7.71
X4	Aquifer Productivity	$\bar{Y}$ = 2.75 – 5.80X	0.47	-0.69	7.59 ^{nr}	7.71
X5	Depth of Free Groundwater	$\bar{Y}$ = 4.07+2.09-X	0.56	0.75	9.14 ^{r}	7.71
X6	Slope class	$\bar{Y}$ = 0.04 +0.83X	0.01	0.11	4.05 ^{nr}	7.71
X7	Soils texture	$\bar{Y}$ =-0.28 + 0.99X	0.07	0.26	4.30 ^{nr}	7.71
X8	Rain intensity	$\bar{Y}$ = 0.05 – 2.73X	0.05	-0.23	4.23 ^{nr}	7.71
X9	Vegetation Cover	$\bar{Y}$ = 0.18 – 2.07X	0.36	-0.60	6.29 ^{nr}	7.71
X10	Springs users	$\bar{Y}$ = 1.39 – 3.31X	0.29	-0.54	5.61 ^{nr}	7.71

Remarks: nr: not different; r: real

structure controls the appearance of springs and subsurface waterways (Rahayu et al. 2009, Santosa 2006).

The analysis of free groundwater depth (X5) shows a strong positive correlation (0.75) with water discharge and significantly affects spring supply. The level of free groundwater depth at the site was 0.61 m (<1.0 m). Therefore, the regression model explained that the shallower free groundwater from SP would better the supply of water sources. This is in line with research conducted by Zeffitni (2012), phreatic face level fluctuations in Palu's water basin are generally low (<1.0 m), lowest in the western basin in Dolo Barat District (0.48 m), highest in the eastern basin in Sigi Biromaru District (0.85 m).

The proximity analysis of the cesarean movement on September 28, 2018, shows a strong negative correlation (-0.75) with water discharge and significantly affects the water supply to the springs. The distance of the cesarean movement at the study site is an average of 8.87 km (somewhat close), so according to the obtained regression model explains that the closer the cesarean movement distance from the SP will, the greater disturbance to the water availability at the SP. According to the Meteorological, Climatological, and Geophysical Agency, the earthquake on 28 September 2018 was located at 119.85° E: 0.18° S about 80 km north of Palu City at 10 km depth. The earthquake occurred along the Palu-Koro on the eastern side along ± 160 km in three segments, two active fault segments on the tram-Talise-Bora ± 130 km long, and one segment of the active Gumbasa-Kulawi fault ± 30 km long (Soehaimi et al. 2018, Supartoyo et al. 2018).

The occurrence of a negative-moderate 'correlation between water discharge and Water Catchment Area (WCA), vegetated land, aquifer productivity, and springs users caused by less water discharge. Ideally, WCA and extensive vegetated area, high aquifer productivity, and many springs users, water discharge must also be larger to have a 'positive, strong correlation. The discrepancy between the response variable (Y) and the explanatory variable (X) in the four SP clusters in the Palu and Poboya watersheds can occur due to the fault earthquake on 28 September 2018. Each landform has characteristics of rock structure as a container aquifer groundwater (Sumartoyo 2010).

The determinant coefficient value (R2) in Table 3 shows the level of accuracy of the regression model, ranging from good (0.56) to very bad (0.01). The regression suggested that only those R2 with moderate to good category (0.29 – 0.56)

Table 4: Criteria and spatial modeling techniques for springs performance.

Criteria	Parameter	Indicator	Weight	Value	Total Value
Water quantity	Water discharge	Great): >10 l/s	50	5	250
		Moderate: 5-10 l/s		3	150
		Few: <5 l/s		1	50
Water catchment area	Large area	>50 ha	7	5	35
		10-50 ha		3	31
		<10 ha		1	7
Vegetation cover	Area of vegetation cover	> 50%	8	5	40
		25 -50%		3	24
		< 25%		1	8
Aquifer	Potential groundwater capacity	High productivity	9	5	45
		Medium productivity		3	27
		Low Productivity		1	9
Groundwater	Depth of free groundwater level	<1 m	10	5	50
		1-5 m		3	30
		>5 m		1	10
Faulting	The proximity of the fault moves with the location of the springs	>10 km	10	5	50
		5-10 km		3	30
		<5 km		1	10
Use of springs	Number of springs users	<2 users	6	5	30
		2-3 users		3	18
		>3 users		1	6

are suitable to build a performance model. Thus, the variable of free groundwater depth (X5), fault movement distance from springs (X3), aquifer productivity (X4), vegetated land (X9), catchment area (X1), and springs users (X10) as modelers' performance conditions in evaluation. Spatial modeling of SP performance conditions is approached by the weighting of variables X and Y. This was confirmed by Gunawan et al. (2016); weighting each parameter (factor) should be based on a correlation matrix between parameters.

Table 4 shows the X and Y variables formulated as a spatial model in evaluating SP performance conditions. The model explains the water catchment area (WCA) as a reservoir for rain, as a place for vegetation to grow, and various types of land use, soil type, and groundwater potential are also included. This aligns with Gunawan et al. (2016), who stated that catchment area condition depends on several factors, including land use, slope (topography), rainfall, soil type, and groundwater potential.

Formula: $\mathbf{TVS} = \sum_{\mathbf{n=1}}^{\infty} (\mathbf{weight\ x\ value / \max value})$ … (1)

Where:

TVS = Total Value of Springs;

Value = springs value of each criterion (springs value of each criterion);

The maximum value = each criterion 5 (criterion each of 5); maximum total value of 100 (maximum total value of 100.). (Ministry of Environment and Forestry 2017).

The results of spatial model performance for six springs locations in the four clusters are given in Table 5.

Table 5 shows 'bad' performance in one site, and the other five are disturbed. The correlation regression analysis between variables Y and X with negative regression coefficient values and moderate-strong negative correlations were analyzed as the factor of springs 'bad-disturbed' water production performance. The only variable X with a great positive regression-correlation coefficient value is the level of free groundwater that averages <1 meter so that the springs can still produce water throughout the year, even with small discharge. The catchment areas have a high ability to absorb rain to fill up the aquifers as a source of water. The catchment area depends on land use, slope, rainfall, soil type, and groundwater potential (Ministry of Environment and Forestry 2017, Gunawan et al. 2016).

A spatial model shows the exceed of water utilization. Several factors are identified, such as fault movement, shrinking water catchment coverage area (8.05-68.77 ha), shrubs and grasses dominated land cover or loss of trees.

The texture and depth of plant roots determine groundwater storage capacity. The deeper the roots are, the more water is stored in the soil (Sari & Prijono 2019). The soil's adequate depth determines the groundwater storage capacity in a land-use system, the distribution of soil micro-pore spaces, and the balanced soil particle size between clay and sand particles. Groundwater content values and soil physical properties influence groundwater reserves. Solum thickness affects water storage capacity (Rahayu et al. 2009, Sari & Prijono 2019).

Based on the bad-disturbed performance value of modeling, thus, could be analyzed that performance

Table 5: The performance of the spatial model of springs.

Variables	Total value					
	Cluster 4 Poboya		Cluster 3 Uemanje	Cluster 1 Ranjuri Beka		Cluster 2 Mantikole
	Springs1 SP1)	Springs2 (SP2)	Springs (SP)	Springs1 (SP1)	Springs2 (SP2)	Springs (SP)
Water discharge	50	150	50	50	50	50
Water catchment area	7	21	35	35	35	21
Vegetation cover	40	40	40	40	40	40
Aquifer	27	27	45	45	45	45
Free groundwater	50	50	50	50	50	50
A fault movement distance from the springs)	10	10	50	50	50	50
Use of springs	18	18	6	18	18	18
Total score	202	316	276	288	288	274
Springs performance value	40	63	55	58	58	55
Springs performance	bad	Disturbed	disturbed	disturbed	disturbed	Disturbed

Remarks: SP = springs

Fig. 2: Map of the spatial model of the post-earthquake springs performance conditions 28 September 2018 in the Mantikole Cluster 2 (Scale 1:50,000).

improvement and mitigation are needed through forest and land conservation, enrichment planting of trees, wise land management, and proper water utilization. Soil permeability in the secondary forest is faster than in mixed upland, monocultures, and paddy fields. Soil permeability in monocultures is higher than in mixed upland. The ability of forest areas to absorb water is faster than the rice field or even a mixed upland area. This finding is supported by Lopes et al. (2019), that the forest is a groundwater reservoir and provides a wide range of ecosystem services. It fasts in permeability and relatively fast on mixed land, has medium permeability on dry land and yard, and is slower on degraded land. Forest area consists of numerous trees and diverse upland areas provided by the better ability on water permeability. It makes

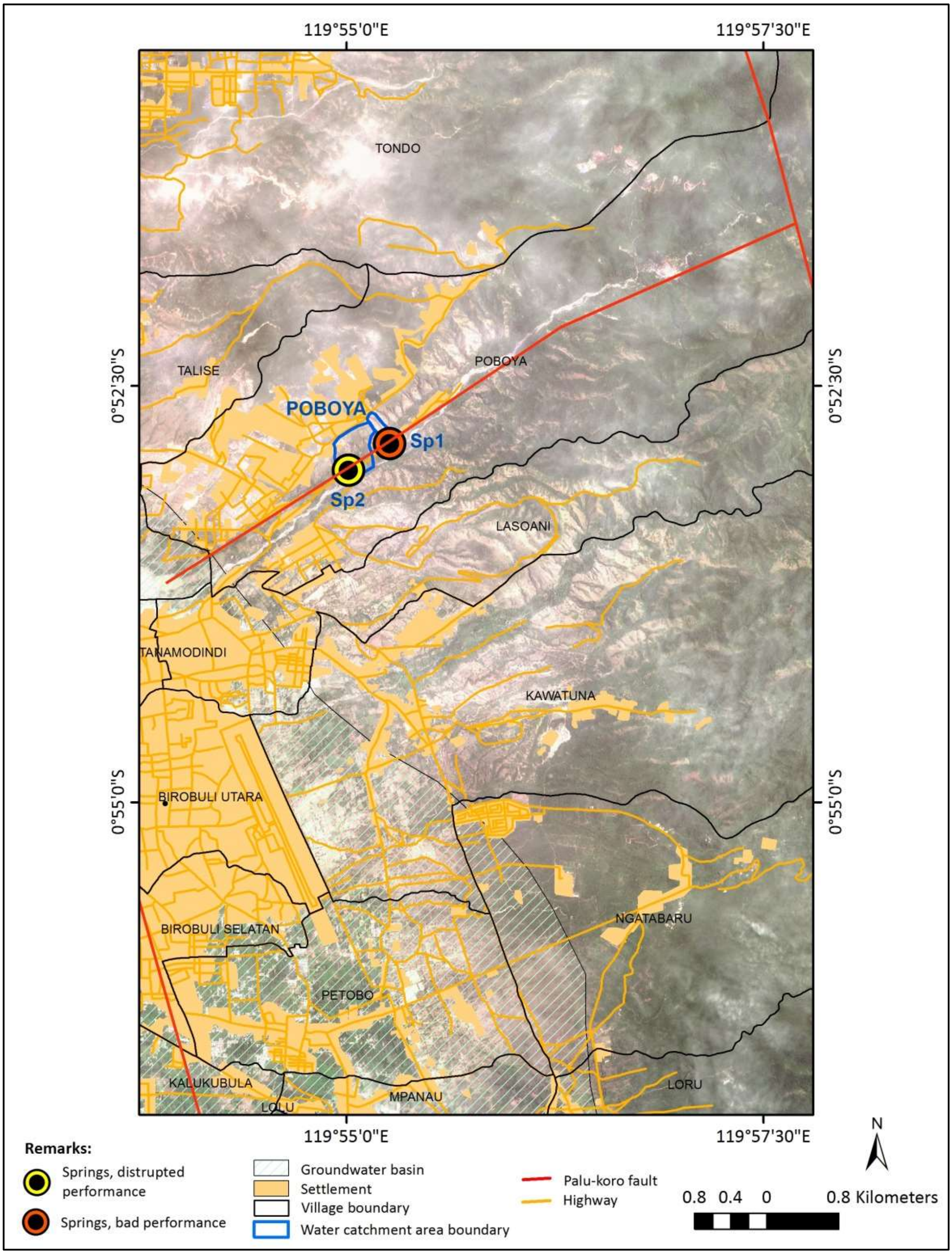

Fig. 3: Map of the spatial model of the post-earthquake springs performance conditions 28 September 2018 in the Poboya Cluster 4 (Scale 1:50,000).

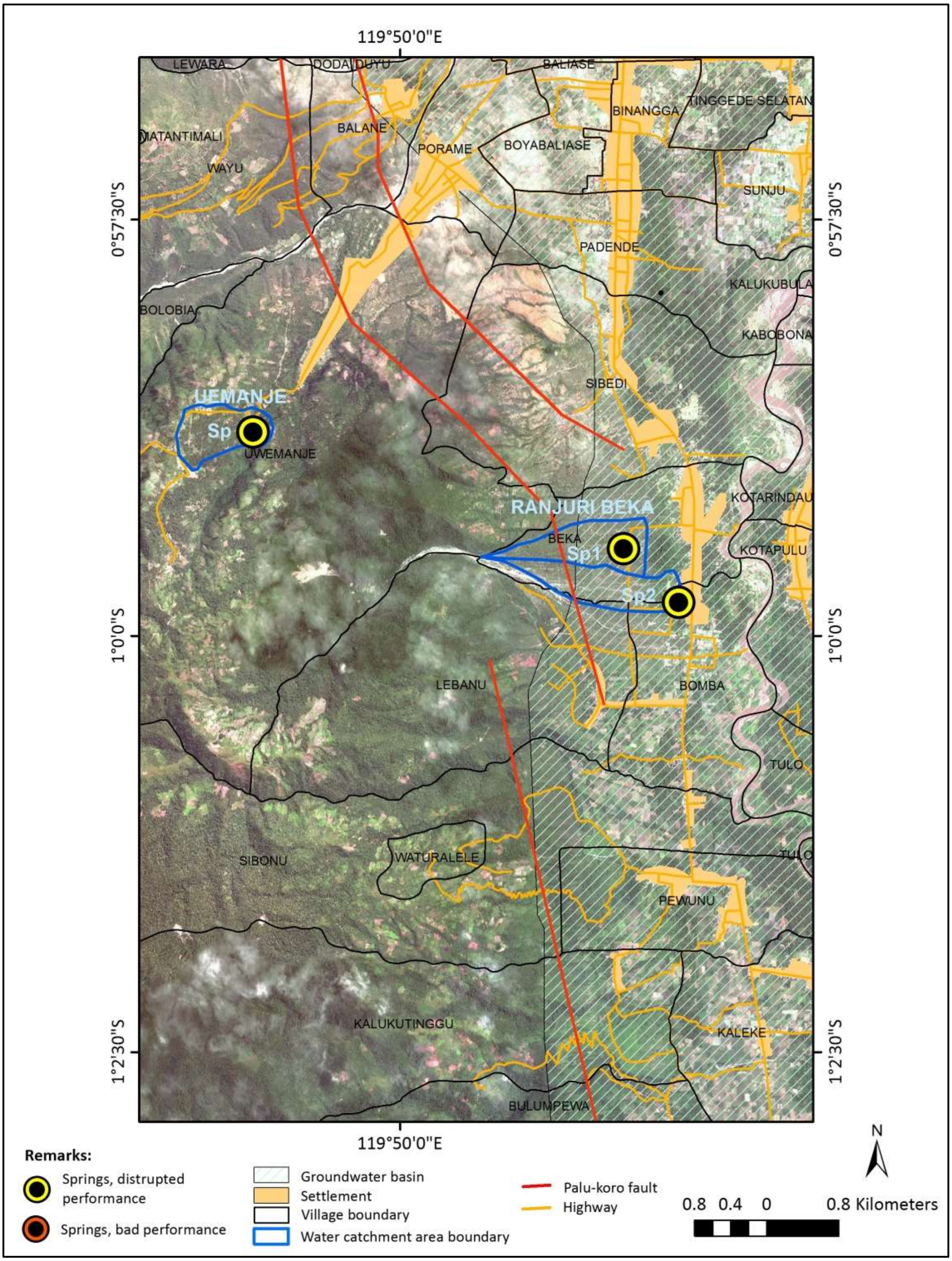

Fig. 4: Map of the spatial model of the post-earthquake springs performance conditions 28 September 2018 in the Ranjuri Beka Cluster 1 and Uwemanje Cluster 3 (Scale 1:50,000).

runoff occur less (Lisnawati & Wibowo 2010, Naharuddin et al. 2018, 2019).

CONCLUSION

From the results of spatial-statistical modeling, it is known that the condition of the springs in producing water after the tectonic earthquake in the Palu and Poboya watersheds has a "poor-disturbed" performance. This performance was caused by the use of water sources at each location of the springs that had exceeded its water production capacity, the movement of faults/faults, the water catchment area was not wide (8.05 - 68.77 ha), vegetation cover dominated by shrubs and grasses and a few forest trees. Considering these conditions, it is necessary to increase the recharge area and improve evapotranspiration through the enrichment of forest and annual plants, as well as protection around springs within a radius of 200 m from various land clearing activities. To maintain the performance of springs in areas prone to tectonic earthquakes with low-moderate aquifer productivity and the presence of deep-free groundwater, it is important to conduct scientific research related to the hydrogeological aspects of the area, which is integrated with trials of developing plant species that have high water storage capacity.

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