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Analysis of shallow well depth prediction: A study of temporal variation of GRACE satellite data in Tampan District-Pekanbaru, Indonesia

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ABSTRACT

Urban geographic areas that are far from surface water resources cause the availability of groundwater to be limited. Groundwater is the main source of water for urban communities today, however, groundwater does not always exist. Groundwater search continues with the old method which takes a long time. In this study, a groundwater search using a satellite imaging method is proposed to create work effectiveness and a faster time. This study aims to analyze the underground water reservoir in Tampan District using GRACE satellite data in the form of variations in total water storage and correlated with in-situ data. The method used is in the form of total water storage variation modeling in the form of multiple linear regression equations. Parameters that influence the modeling of total water storage variations are rainfall, evaporation, and run-off. The classical assumption test and model feasibility test are used to determine the parameter accuracy in data estimation. The results showed that the multiple linear regression model passed the assumption test and the model feasibility test. The value of the run-off coefficient is greater than the value of the precipitation coefficient. This is because Tampan District has sandy clay rock types and decreasing green open land, so the potential for groundwater loss in the Tampan District area is 1,180,326.63 m^3/month.

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1. INTRODUCTION

Underground water is a problem in various big cities, including Pekanbaru City, which has the most densely populated sub-district, Tampan District, arithmetic with a population density of 5,148 people/km^2 in 2018. This figure has increased by 6.96% from the previous year [1]. The population growth rate of Tampan District has caused the need for water resources to increase, so that there has been a significant change in the amount of groundwater and surface water [2]. This is exacerbated by the lack of rainfall and water extraction that seeps into the soil, local lithological and geological conditions that cause rainfall to flow as run-off and continue to the sea [3-5].

Analysis of changes in underground water storage needs to be carried out to anticipate the crisis of water availability in Pekanbaru City, particularly in Tampan District, where most of the people depend on underground water from shallow wells to meet their daily needs [6]. Apart from being a result of human consumption, changes in water storage are also influenced by the hydrological cycle [7-9]. Disruptions that occur in the hydrological cycle cause drought in the dry season [10] and cause flooding in the rainy season [11]. The effect of rainfall (precipitation) [12], evaporation [13], and run-off [14] in the hydrological cycle result in changes in underground water storage which results in a decrease in the depth of shallow wells owned by residents [15, 16]. Therefore, we need an equation model that can be used to describe the effect of the hydrological cycle on the decrease or increase in underground water storage and its effect on changes in shallow well depth.

Research on groundwater storage analysis using variations in the distribution of total water storage (ΔTWS) has been widely carried out by Śliwińska et al. (2019) who analyzed changes in groundwater storage in areas from the GRACE satellite gravity signal [17]. The same approach was taken by Frappart (2018) for the analysis of groundwater depletion globally [18] and by Hao (2019) in the Songhua River Basin region [19]. Xiao (2015) and Yin (2017) use global land data assimilation system (GLDAS) data [20, 21] or use hydrometeorological data [22].

2. MATERIALS AND METHODS

2.1. Tools and Materials

Table 1. Research tools and materials.

Tools and Materials	Information
Global Positioning System (GPS)	To determine the coordinates of the age of the population
Meter	To measure the depth of citizens
The area of Pekanbaru City	Topographic maps of the research area
Laptop device	To store, process and analyze thesis data
SPSS application	For data analysis and determination of multiple linear regression equations
Surfer application	For analysis of the contour data and groundwater distribution

2.2. Time and Place of Research

The research was carried out from July 2020 to August 2020. The study consisted of two stages, namely field survey activities in Tampan District with nine villages, as follows Air Putih Village, Bina Widya Village, Delima Village, Sialang Munggu Village, West Sidomulyo Village, Simpang Baru Village, Tobek Godang Village, Tuah Karya Village and Tuah Madani Village. The survey data were then further analyzed at the Earth Physics Laboratory, Riau University.

2.3. Research Scheme

The research scheme starts from the stages of observation and data collection techniques, data collection (in-situ measurement, Pekanbaru BMKG data and ΔTWS data from the GRACE satellite), lithology analysis of the research area, SPSS data management, classical assumption testing, model feasibility test, variation data analysis temporal from the GRACE satellite, analysis of shallow well depth predictions, determination of contour maps with the Surfer application, modeling of groundwater flow patterns based on profiles (See Table 1).

3. RESULTS AND DISCUSSIONS

3.1. Temporal Variation of Underground Water Deposits in Tampan District

Equivalent water height (EWH) data presented by the GRACE satellite shows dynamic changes over a period of 141 (one hundred and forty one) months of data collection. The graph in Figure 1 shows the correlation between the EWH data and precipitation, evaporation, and run-off.

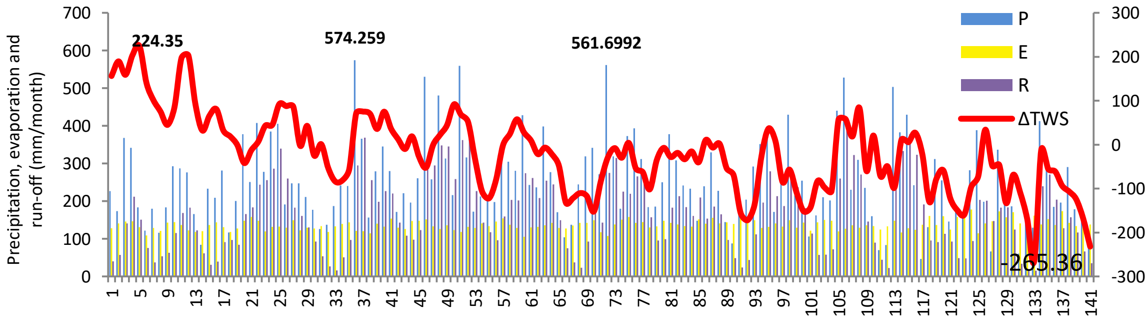

Figure 1. ΔTWS, precipitation, evaporation, and run-off relationships.

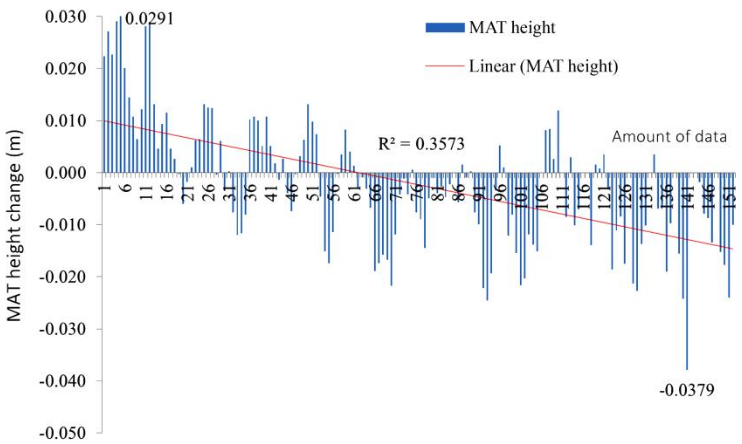

Figure 2. Change of groundwater level.

Changes in groundwater distribution ΔTWS affect changes in shallow well water levels. Figure 2 shows a significant decline starting from 2009 to the end of 2016. The level of the groundwater level tends to decrease over time, this is due to land conversion that occurred in the study area. Tampan Subdistrict, which initially had a large area of green open land, began to develop along with economic and social developments.

3.2. Groundwater Distribution Equation Model

The results of the multicollinearity test are shown in Table 2. The tolerance figure is close to 1 and the VIF value is less than 10, based on the classical linear OLS assumption requirements that the regression model is free from multicollinearity. Data analysis using the SPSS application provides the following multicollinearity test results:

Table 2. Results of multicollinearity test on different data periods.

Data	Model	Collinearity diagnosis		Regression model assumptions
		Tolerance	VIF	
2004 – 2016	Precipitation	0.521	1.918	The regression model is free of multicollinearity
	Evaporation	0.923	1.084	
	Runoff	0.493	2.028	
2004 – 2010	Precipitation	0.524	1.908	The regression model is free of multicollinearity
	Evaporation	0.951	1.052	
	Runoff	0.527	1.899	
2011 – 2016	Precipitation	0.501	1.996	The regression model is free of multicollinearity
	Evaporation	0.815	1.227	
	Runoff	0.433	2.311	

The best value is generated by the 2004 – 2010 data period with an average tolerance value of 0.667 and an average VIF value of 1.619.

3.3. Model Reliability Test (F Test)

The results of the model reliability test show that the calculated F test value is not too high (see Table 3). The greatest probability is owned by the 2004 – 2010 data, which is 0.241 which means that the regression does not have a significant effect and is not suitable to be used as a prediction.

Table 3. Model reliability test results (test F).

Data	F	Sig.	Information
2004 – 2016	12,647	.000b	the regression model has a significant F test
2004 – 2010	1,428	.241b	the regression model has a not significant significant F test
2011 – 2016	19,066	.000b	the regression model has a significant F test

3.4. Regression Coefficient Test (T Test)

The T test results of several data groups showed unsatisfactory results. The results shown in Table 4, that the 2004 – 2016 data had the most significant regression coefficients because it had two variable coefficients with a small probability value of 0.05.

Table 4. Regression coefficient test results (T test).

Data	Model	T	Sig.	Information
2004 – 2016	Precipitation	0.541	0.589	Regression coefficient has no significant effect
	Evaporation	-4.035	0	The regression coefficient has a significant effect
	Run off	2.195	0.03	The regression coefficient has a significant effect
2004 – 2010	Precipitation	-0.187	0.852	Regression coefficient has no significant effect
	Evaporation	-1.572	0.12	Regression coefficient has no significant effect
	Run off	0.934	0.353	Regression coefficient has no significant effect
2011 – 2016	Precipitation	-0.739	0.463	Regression coefficient has no significant effect
	Evaporation	-1.167	0.248	Regression coefficient has no significant effect
	Run off	5.014	0	The regression coefficient has a significant effect

The evaporation and runoff variables have a probability value t count smaller than 0.05 and have a significant effect on the ΔTWS variable or in other words, that the evaporation and precipitation values affect changes in groundwater level with a confidence level of 95%. Meanwhile, precipitation is too significant to influence it.

3.5. Determinant Coefficient Test (R)

This is used as a complementary condition in seeing the effect of the independent variable on the dependent variable. This test analysis can be used on two data groups that have a significant F test, namely the 2004 – 2016 data group and the 2011-2016 data group.

Table 5. Test results coefficient of determination (R).

Data	Adjusted R square	Information
2004 – 2016	0.2	The independent variable has an influence proportion of 20%
2004 – 2010	0.015	The independent variable has an influence proportion of 1.5%
2011 – 2016	0.492	The independent variable has an influence proportion of 49.2%

Table 6. SPSS data test results.

Data	Classic assumption test			Model feasibility test		
	Multicollinearity	Heteroscedasticity	Normality	F test	T test	R test
2004 – 2016	√	√	√	√	√	√
2004 – 2010	√	√	√			√
2011 – 2016	√	√	√	√		√

Table 5 shows that in 2004 – 2016 the value of precipitation, evaporation and runoff had the greatest proportion of influence 49.2% while the remaining 50.8% was influenced by other variables not in the regression model. The data for 2004 – 2016 has a lower proportion of influence, namely 20 percent and the rest is influenced by other variables not in the regression. The linear regression prediction model is obtained from predictive analysis or simplification of the symptoms found in nature based on the independent variables and the range of data used [23].

Tests conducted on the ΔTWS sample data and precipitation, evaporation, and runoff data contained in Table 6, indicate that the best data period used to predict shallow well depth is data with a longer year period, 2004 – 2016.

The data period 2004 – 2016 is the best data period to use in making a prediction model for shallow well depth. Although the multicollinearity test data for the years 2004 – 2010 had good results, the model reliability test (F test) and regression coefficient test (T test) did not pass the feasibility test. The data for 2011 – 2016 have the best results on the heteroscedasticity, normality and model reliability tests, but the regression coefficient test for these data does not pass the feasibility test.

The multiple linear regression equation model obtained from data analysis for 13 years of the GRACE satellite recording results is estimated in the following equation:

$$\Delta TWS_{2004-2006} = 215.9 + 0.046P - 2.055E + 0.221R \quad (1)$$

Shows the value of the runoff coefficient is greater than the value of the precipitation coefficient. Theoretically, precipitation has a greater effect as a source of groundwater infiltration, but based on this study, the run-off factor has a greater effect on changes in groundwater storage [24]. This happens because Tampan District has a large land cover in the form of asphalt/concrete roads, housing, offices and economic areas which make it difficult for water to enter the ground, so that when it rains, the water does not directly enter the ground but flows in the form of a runoff sewers to river basins DAS.

Figure 3 shows the prediction of changes in groundwater storage in Tampan District from February 2020 to January 2021.

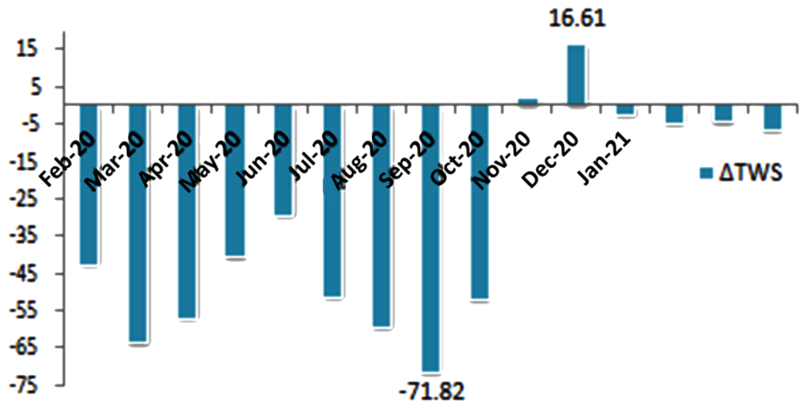

Figure 3. Prediction results of ΔTWS from 2004 – 2016 data period.

The highest decrease occurred in March 2020 due to the impact of the drought that occurred at the end of 2019. The peak of the dry season in 2020 occurred in July 2020 to August 2020 [25], causing a decrease in the ΔTWS value to -71.82 mm. BMKG predicts that the peak of the rainy season will occur in November 2020. This has a correlation with the prediction results of the ΔTWS value which shows that there will be an increase in groundwater storage up to 16.61 mm in the following month.

A significant increase in groundwater occurred in November 2020, due to the La Nina phenomenon which occurred in November. The time difference that occurs between the precipitation data and the runoff with changes in groundwater level has a lag of about 1 month, this is due to the geological effect of rock types in Tampan District, clay sandy [26]. Sandstone clay has porosity with infiltration time, so that when it rains more water flows on the surface.

3.6. Prediction of shallow well depth in Tampan District

Prediction of shallow well depth in Tampan District. The h value is shallow well depth data obtained from in situ data measurements in the study area as an initial reference and produces data as in Table 7 and Figure 4. The results show that shallow wells have the greatest average depth in August 2020 of 7.48 m, while the shallowest conditions occur in October 2020 of 6.24 m. The results of the prediction of variations in groundwater storage using multiple linear regression models provide an overview of the potential for groundwater loss in the Tampan District area of 1,180,326.63 m^3 per month. Therefore, the government needs to create a conservation program for Sustainable Use of Groundwater so that the quantity and quality of groundwater is maintained.

Table 7. Results of shallow well depth prediction in Tampan District.

Year	Month	Average shallow well depth (m)
2020	August	7.48381481
2020	September	6.76551817
2020	October	6.24183286
2020	November	6.25898703
2020	December	6.42507860
2021	January	6.40049122
2021	February	6.361989994
2021	March	6.309574914
2021	April	6.375903842

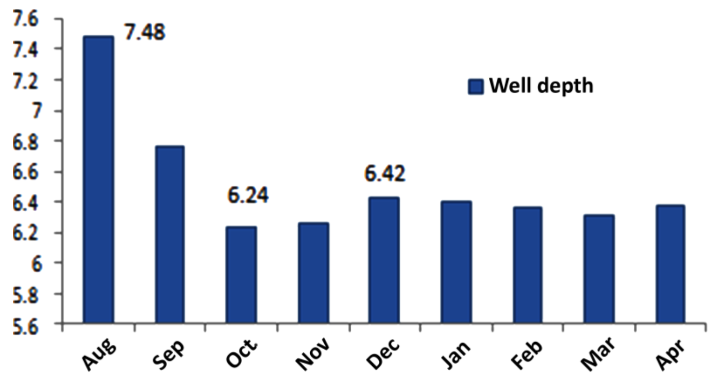

Figure 4. Graph of change in shallow groundwater depth.

3.7. Contour map

The 2D groundwater depth contour map is presented in Figure 5, where the highest position is located in the northern area of Tampan sub-district. The area that has the highest groundwater level is located on Jl. Asparagus 1 and the area with the lowest groundwater level is located on Jl. Jasmine III, Gg. Spruce 2.

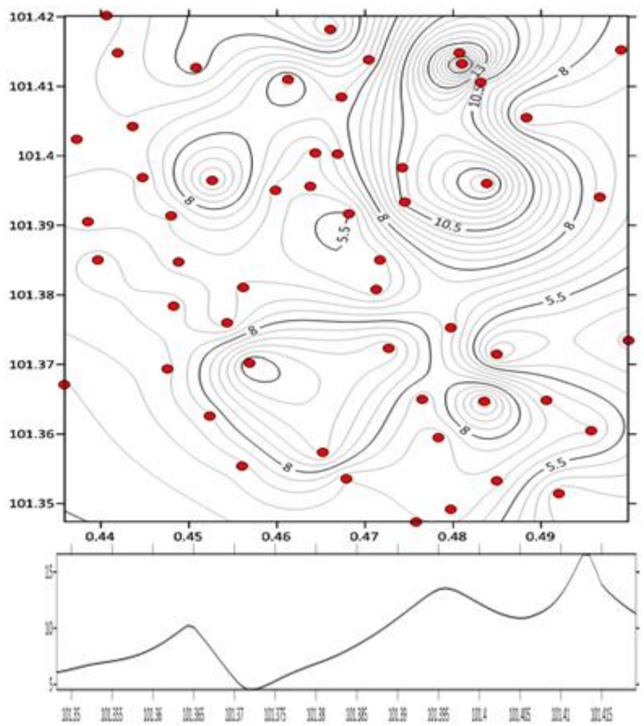

Figure 5. Contour plot Altitude groundwater level and saplings in the Tampan sub-district.

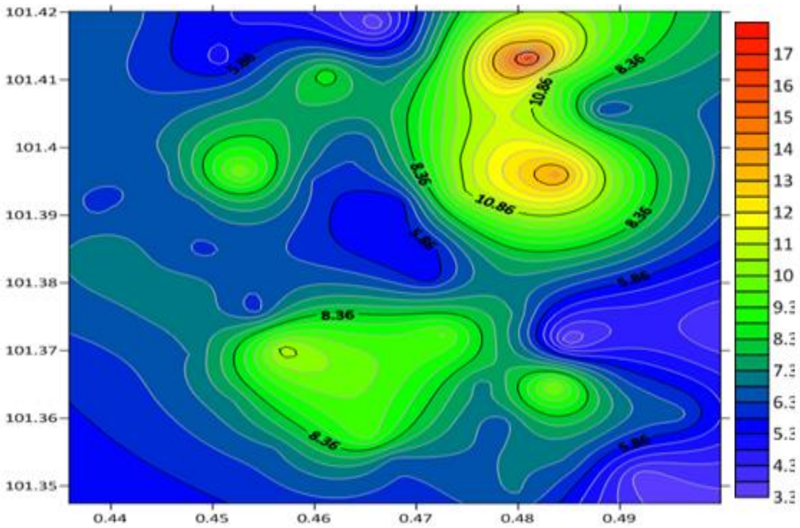

Figure 6. Map of the groundwater front of the month august 2020.

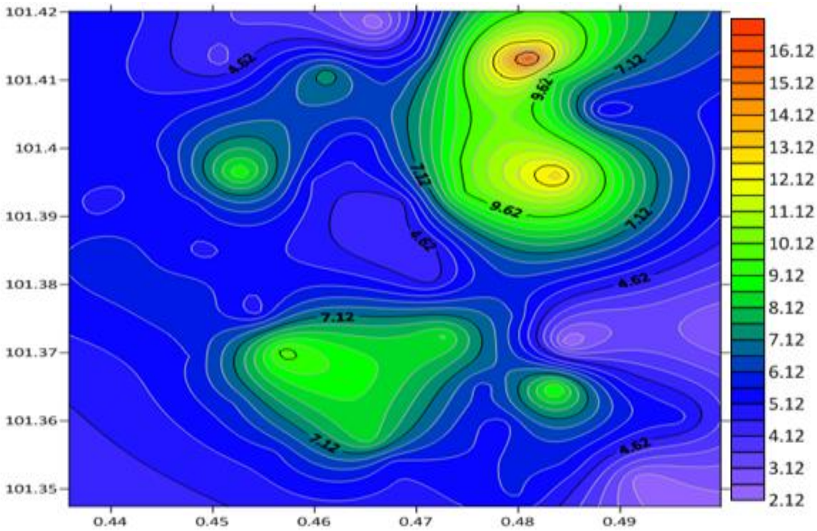

Figure 7. Groundwater front chart for october 2020.

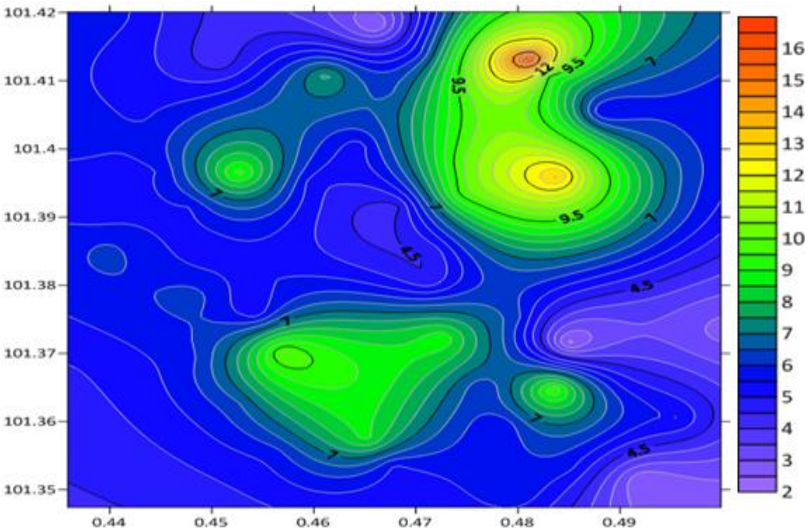

Figure 8. Prediction of groundwater surface contour for december 2020.

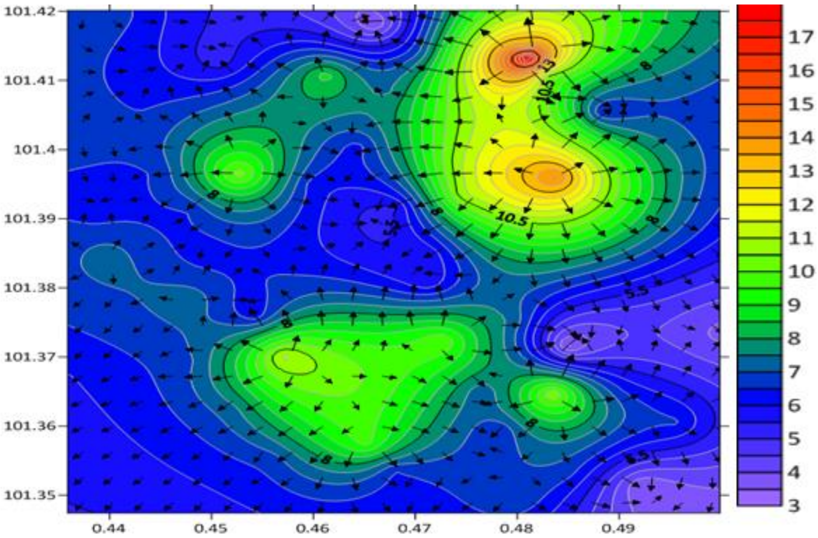

Figure 9. Groundwater flow pattern in the Tampan District area in the august 2020 2D model.

Sections of the cut across the contour map perpendicular to the north to south show the groundwater level from the range 3.36 m to 18.26 m. The depth of the groundwater level is highest in the north and the lower to the west (see Figures 6, 7, 8, 9, and 10).

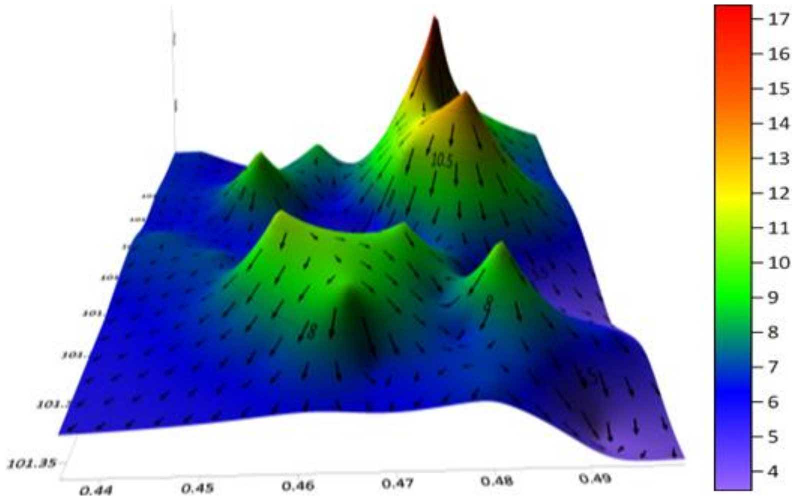

Figure 10. Groundwater flow pattern in the Tampan Subdistrict in august 2020 3D model.

4. CONCLUSION

Data on the temporal variation of groundwater distribution (ΔTWS) has a significant decline starting from 2009 to the end of 2016 due to land conversion in the study area. The most appropriate data period used to create linear regression models is the time period from 2004 – 2016, because passed all the classical assumption tests and model feasibility tests. Groundwater distribution models and their relationship with the precipitation, evaporation and runoff variables produce multiple linear regression Equations (1). Prediction analysis of shallow well depth shows that the highest increase occurred in October 2020 to December 2020 due to the La Nina phenomenon which will reach its peak in November 2020. The highest shallow well depth occurred in August 2020 at 7.48 m and the shallowest in October 2020 was 6, 24 m and rose again in December 2020 amounting to 6.42 m.

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