Impacts of dams on surrounding groundwater levels

by Heri Sulistiyono

IOP Conference Series: Earth and Environmental Science

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H Sulistiyono[1], D S Agustawijaya[1] and B W R Wardani[1]

[1]Faculty of Engineering, University of Mataram, Indonesia. 83125

h.sulistiyono@unram.ac.id

Abstract. The increasing number of dams built to address surface water problems has attracted the awareness of engineers about the impact of water in dams on surrounding groundwater levels. Some of the benefits of a dam include reducing peak flooding and storing excess water during the rainy season for use in the dry season. However, it is necessary to be aware that an increase in surface water in one place can have a negative impact on the surrounding environment. This paper describes the relationship between the water level in the dam and changes in the surrounding groundwater level. This study did not discuss the type of soil layer. The analysis was carried out by observing the level of the surrounding wells. Following Darcy's law of homogeneous isotropic steady-state flow, as well as the principle of the double-well pumping test, the well water level is used as a groundwater representation level. This research was conducted in the sub-districts around the Pandan Duri Dam. The results showed that water levels inside the dam had a significant impact on the surrounding groundwater levels. This is evidenced in this research that water levels of wells in Sakra District significantly changes following the change in water levels inside the Pandan Duri Dam.

1. Introduction

Dams are made for various purposes, including to overcome the problem of water shortages in the dry season and water excesses in the rainy season [1], [2], [3]. [4]. Besides providing advantages, the construction of dams can also cause various disadvantages. Advantages of dams are to reduce flooding, provide water for irrigation, supply household drinking water, provide water conservation, and facilitate water recreation. However, disadvantages of dams can include environmental damages, changes in sediment transport along river basins, disruptions of fish migration routes in riverside and unexpected rising groundwater levels [5].

Water inside a dam can cause the surrounding groundwater levels to rise [6]. The rising groundwater level can cause both positive and negative impacts on the environment. Positive impacts include ease of extracting water from the ground and increasing soil fertility. Negative impacts include decreasing soil stability, easily damaged foundations of buildings and roads, and an increasing risk of liquefaction [7], [8]..

This research aims to obtain the impact of water level inside a dam on the surrounding groundwater levels.

2. Literature review

Ardiansyah [8] conducted research on the Effect of Reservoir Water Fluctuations on Seepage Discharge Using the SEEP / W Model. The results of the model show the flow pattern reasonably follows the principle of the Casagrande method.

Hatmoko and Rauf [9]conducted research on Reservoir Water Level as an Indicator of Drought. Case Studies on Kedungombo Reservoir and Cacaban Reservoir. Results concluded that the reservoir water level can be used as an indicator of drought, is effective in early detection of drought disasters, and has a similar pattern to meteorological drought.

Meisyara and Fathani [10], conducted research on The Effect of Surface Water Reservoir Fluctuations on Deformation and Stability of Soil Dam-Test Model in the Laboratory. Results showed that the deformation that occurs in the soil dam model is more dominantly influenced by the water level. The higher the water level, the greater the deformation. Steeper upstream dam slopes cause greater deformation than gentle slopes. Deformation also occurs easily when the water level rises rapidly.

3. Methodology

The research procedure includes four following strategies: Preparations, Data Collections, Analisis, and Results. The proposed procedure is shown in Figure 1.

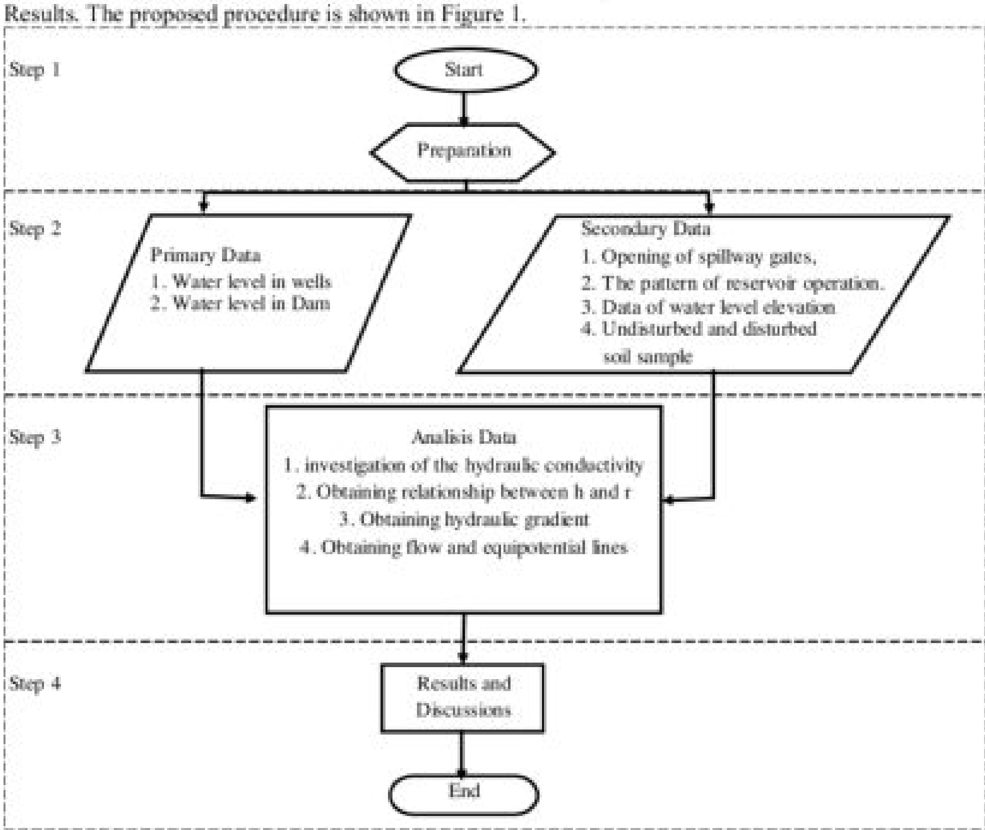

Figure 1 Proposed Procedure of the study

3.1. Preparations

3.1.1. Preliminary survey.

At this stage, observations were made starting from recording coordinates of the dam and wells, the physical condition and daily use of the wells, the administrative area, preparing well pumps and notebooks. Those wells are plotted in Figure 2 to Figure 7.

3.1.2. Research of literature.
The research of literature prepares references and theories needed to carry out research analysis. This research needs theory of groundwater flow patterns, information regarding the causes of groundwater fluctuation, and reasons why this research is important.

3.1.3. Summary of the problem.
At this stage the direction of the research must be ascertained so that the research can run well. In essence, this study will discuss whether the presence of water in a dam affects the surrounding groundwater level, provide a better understanding of flow patterns, and demonstrate the application of research to actual dams.

3.2. Data collections
Primary Data. Primary data in this research include levels of water inside the dam, also well water level data before and after daily uses. *Secondary Data.* Secondary data needed in this research are as follows: opening of spillway gates, the pattern of reservoir operation, data of water level elevation, and undisturbed and disturbed soil sample.

3.3. Analysis
The analysis begins with an investigation of the hydraulic conductivity in the field [11-14]. The strategy is through well pumping tests. The flow rate into the well which is assumed to be equal to the adjusted flow rate from well pumping is used to obtain the hydraulic conductivity in the equation below [4].

$$Q = -ki.A = -k\frac{dh}{dr}2\pi r \qquad (1)$$

with: Q = flow rate into the well (cm^3/s), k = soil permeability coefficient (cm / s), i = slope of the water energy line, A = cross-sectional area of flow (cm^2), h = depth of water in the well (cm), r = distance of the well to control (cm), π = mathematical constant (= 3.14159).

The integration between r_1 and r_2 with the corresponding heights h_1 and h_2 is obtained through

$$k = \frac{2{,}3Q\log\frac{r_2}{r_1}}{\pi({h_2}^2-{h_1}^2)} \qquad (2)$$

with: Q = flow rate into the well (cm^3/s), k = permeability coefficient (cm / s), h = depth of water in the well (cm), r = distance of the well to control (cm).

Flow nets are graphical representations of the flow of water through the soil mass. The net flow is formed by a combination of flow lines and equipotential lines. These lines help define the seepage graphically. The flow line is the path through which water seeps into the ground from upstream to downstream. Flow lines can be drawn at any point where water starts to seep. Each flow line has the same k value. A graph depicting flow lines and equipotentials is called flownets [15], [16]. The flownet is used to calculate the amount of seepage that may occur. The flow line shows the direction of groundwater flow from the red zone which represents the area that has a higher potential pressure to the blue zone which represents the area that has a lower potential pressure. The flow rate can be calculated based on the net flow line using the Darcy equation:

$$q = Aki \qquad (3)$$

With: q = flow rate (cm^3/s), A = cross-sectional area of flow (cm^2), k = permeability coefficient (cm / s), i = hydraulic gradient.

If the flow reviewed is only on one surface of the soil mass which is represented as flow between two flow lines in the flow net, then the equation (3) becomes:

$$q = k\frac{\Delta h}{l}b \qquad (4)$$

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With: q = flow rate on one surface of the soil mass (cm^3/s), k = permeability coefficient (cm / s), Δh= loss of potential energy between 2 successive equipotential lines, b = the distance between the two flow lines (cm), l = the distance between the two equipotential lines (cm).

4. Application

To demonstrate this research procedure, this research was conducted in several villages downstream of the Pandan Duri Dam in Sakra District, East Lombok Regency, West Nusa Tenggara Province as shown in Figure 2. Dam technical data that is important for this research include: inundation area: 315.70 Ha, storage volume: 27.20 million m^3, spillway width: 37.5 m, irrigation service area: 5168 Ha, peak elevation: + 284.00 m, riverbed elevation: + 246.00 m, normal MA elevation: + 281.50 m, MA flood elevation: + 282.75 m.

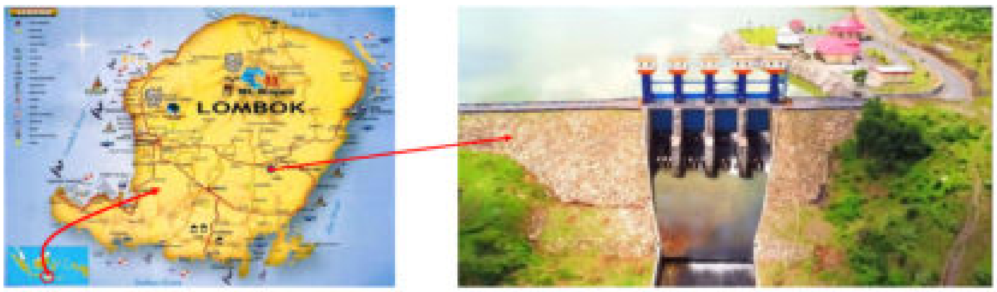

Figure 2 Study Location

4.1. Data collections

4.1.1. Primary data.

The survey was conducted in two periods: one is during a dry season and the other one is during a rainy season. The first period is carried out on 9 September 2019 during the dry season, and the second period is on 10 January 2020 during the rainy season. Each period measurement of the well water level elevation is carried out at 45 well points from 6 villages in the Sakra District area. The location and number of observations well points are shown in Figure 3 to Figure 8. The observation results are shown in Table 1 to Table 6.

Figure 3 shows locations of observation well in the Kelaga Dirik Village. Kelaga Dirik is the closest village to the dam. This village is about 80 to 200 meters downstream of the dam. The ten wells observed in this village are shown with yellow marks in Figure 3. Data from the observation wells in Kelaga Dirik Village are shown in Table 1. Table 1 shows the depth data for 10 wells in Kelaga Dirik Village taken during the dry season and the rainy season. From these data, it is known that the depth of groundwater is not always deeper during the rainy season. It was also noted that the closer the well to the dam does not necessarily have a higher groundwater level than the well further away from the dam. This is due to the variability of water use. Therefore, the calculation of the average is preferred in this analysis. In general, the condition of the wells in Kelaga Derik as follows: The average difference in groundwater level between the rainy season and the dry season is 0.22 m. The average depth of the groundwater level from the surface is 4.67 m. The average distance to the dam is 275 m. Figure 4 shows locations of seven observed wells in the Penujak Bongkot Village. They are shown with red marks in Figure 4. Penujak Bongkot is the second closest village to the dam. This village is about 420 to 740 meters downstream of the dam and located after Kelaga Dirik Village. Table 2 explains that the average difference in groundwater level between the rainy season and the dry season is 0.55 m. The average depth of the groundwater level from the surface is 3.97 m. The average distance to the dam is 281 m. At the same distance from Penujak Bongkot Village to the dam, to the right of Penujak Bongkot Village is Buwuh

Village as shown in Figure 5. Figure 5 shows locations of six observed wells with green marks in the Buwuh Village. Table 3 explains that the average difference in groundwater level between the rainy season and the dry season is 0.45 m. The average depth of the groundwater level from the surface is 3.43 m. The average distance to the dam is 240 m. Figure 6 shows five observation wells located in Dengkur Village. They are marked in pink in Figure 6. The village is located 1,800 to 2,100 meters downstream of the dam. Table 4 shows that the average difference in groundwater level between the rainy season and the dry season is 0.35 m. The average depth of the groundwater level from the surface is 3.32 m. The average distance to the dam is 1879.2 m. Figure 7 shows ten observation wells located in West Suangi Village. They are marked in white in Figure 7. The village is located 1,200 to 1,600 meters downstream of the dam. Table 5 shows that the average difference in groundwater level between the rainy season and the dry season is 0.28 m. The average depth of the groundwater level from the surface is 3.05 m. The average distance to the dam is 1399.3 m. Figure 8 shows seven observation wells located in Palung Dasan Village. They are marked in orange in Figure 8. The village is located 1,600 to 1,800 meters downstream of the dam. Table 6 shows that the average difference in groundwater level between the rainy season and the dry season is 0.41 m. The average depth of the groundwater level from the surface is 2.95 m. The average distance to the dam is 1720.9 m.

Table 1. Observations of 10 wells in Kelaga Dirik Village on Dry Season and Rainy Season

No of Well	Well Depth		ΔZ (m)	Distance to Dam (m)	Depth of Groundwater (m)
	Dry Season	Rainy Season			
1	9.6	9.27	-0.33	83.3	5.73
2	9.35	9.3	-0.05	105	4.7
3	6.2	6.5	0.3	106	3.5
4	9.2	9.4	0.2	109	5.6
5	9.33	9.55	0.22	110	4.45
6	3.8	3.9	0.1	114	6.1
7	6.43	7.1	0.67	144	6.9
8	3.26	3.58	0.32	148	4.42
9	7.35	7.88	0.53	169	2.12
10	6.53	6.78	0.25	212	3.22
Ave.	7.11	7.33	0.22	130	4.67

Table 2. Observations of 7 wells in Penujak Bongkot Village on Dry Season and Rainy Season

No of Well	Well Depth		ΔZ (m)	Distance to Dam (m)	Depth of Groundwater (m)
	Dry Season	Rainy Season			
1	9.20	9.82	0.62	575	2.10
2	23.25	23.88	0.63	657	5.18
3	7.33	7.90	0.57	687	2.01
4	17.32	17.90	0.58	722	3.24
5	16.27	16.76	0.49	732	2.10
6	24.23	24.99	0.76	738	1.12
7	15.78	15.99	0.21	749	12.01
Ave.	16.20	16.75	0.55	714	3.97

Table 3. Observations of 6 wells in Buwuh Village on Dry Season and Rainy Season

No of Well	Well Depth		ΔZ (m)	Distance to Dam (m)	Depth of Groundwater (m)
	Dry Season	Rainy Season			
1	5.12	5.35	0.23	1105	2.65
2	5.25	5.98	0.73	1099	2.02
3	6.40	6.78	0.38	1158	1.22
4	9.40	9.59	0.19	1178	1.41
5	8.23	8.80	0.57	1183	3.20
6	10.30	10.90	0.60	1235	4.10
Ave.	7.45	7.90	0.45	1159.7	2.43

Table 4. Observations of 5 wells in Dengkur Village on Dry Season and Rainy Season

No of Well	Well Depth		ΔZ (m)	Distance to Dam (m)	Depth of Groundwater (m)
	Dry Season	Rainy Season			
1	7.50	7.80	0.30	1863	2.50
2	9.55	9.95	0.40	1867	4.45
3	11.23	11.57	0.34	1884	3.77
4	11.44	11.84	0.40	1891	3.56
5	15.66	15.96	0.30	1891	2.34
Ave.	11.08	11.42	0.35	1879.2	3.32

Table 5. Observations of 10 wells in West Suangi Village on Dry Season and Rainy Season

No of Well	Well Depth		ΔZ (m)	Distance to Dam (m)	Depth of Groundwater (m)
	Dry Season	Rainy Season			
1	3.80	3.90	0.10	1322	3.10
2	4.78	4.98	0.20	1353	3.22
3	5.57	5.79	0.22	1354	2.43
4	7.65	7.84	0.19	1396	1.35
5	9.29	9.57	0.28	1404	5.76
6	12.85	12.98	0.13	1417	2.15
7	15.90	15.90	0.00	1419	2.10
8	16.25	16.87	0.62	1430	3.75
9	17.20	17.76	0.56	1444	2.80
10	18.20	18.67	0.47	1454	3.80
Ave.	11.15	11.43	0.28	1399.3	3.05

Table 6. Observations of 7 wells in Palung Dasan Village on Dry Season and Rainy Season

No of Well	Well Depth		ΔZ (m)	Distance to Dam (m)	Depth of Groundwater (m)
	Dry Season	Rainy Season			
1	4.25	4.50	0.25	1743	3.75
2	13.20	13.59	0.39	1725	1.80
3	13.26	13.78	0.42	1759	3.64
4	14.32	14.87	0.55	1665	2.68
5	15.25	15.83	0.58	1691	4.75
6	20.22	20.67	0.45	1722	2.78
7	20.75	20.98	0.23	1741	1.25
Ave.	14.46	14.89	0.41	1720.9	2.95

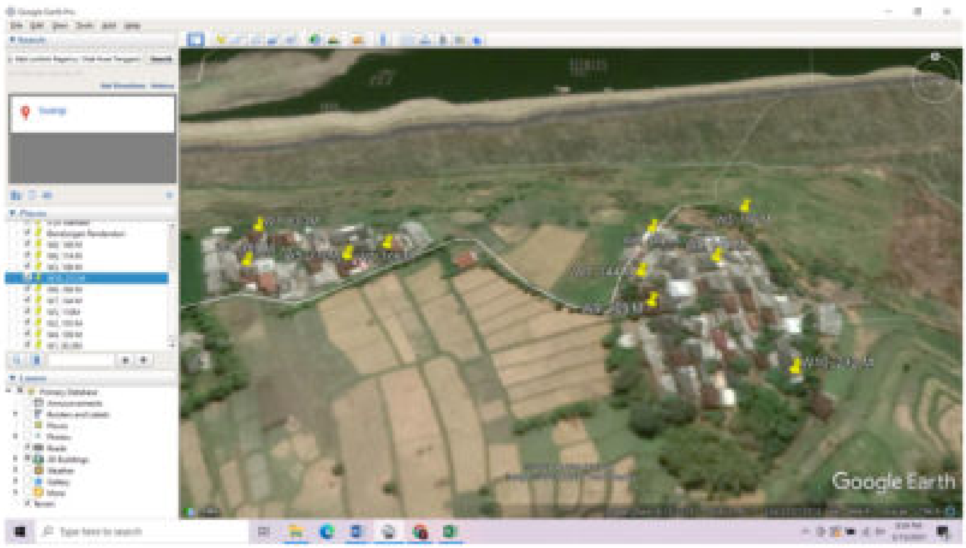

Figure 3. Map of Well Observation Location in Kelaga Dirik Village

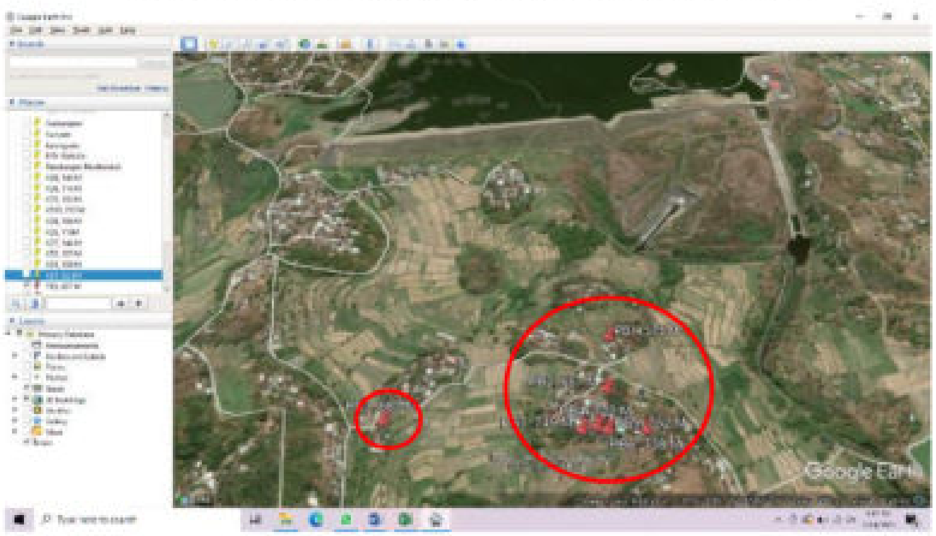

Figure 4. Map of Well Observation Locations in Penujak Bongkot Village

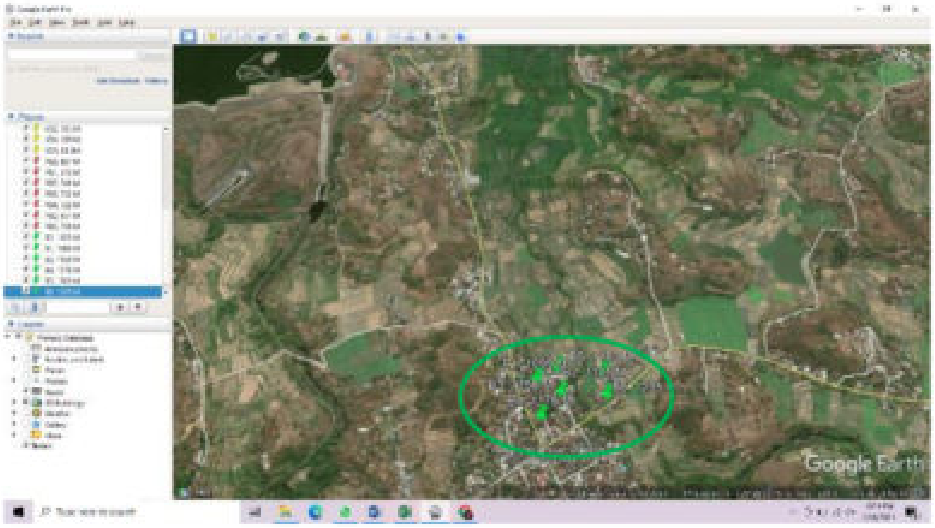

Figure 5. Map of Well Observation Location in Buwuh Village

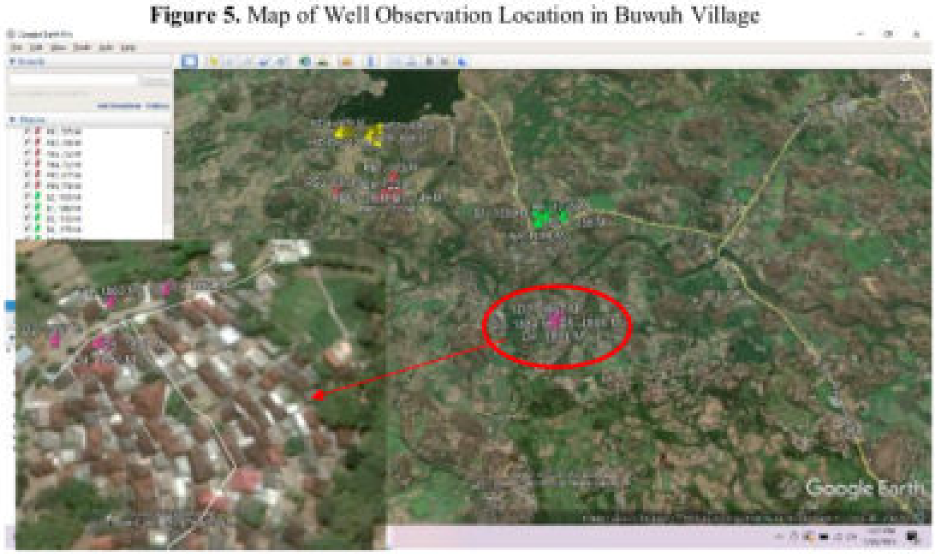

Figure 6. Map of Well Observation Locations in Dengkur Village

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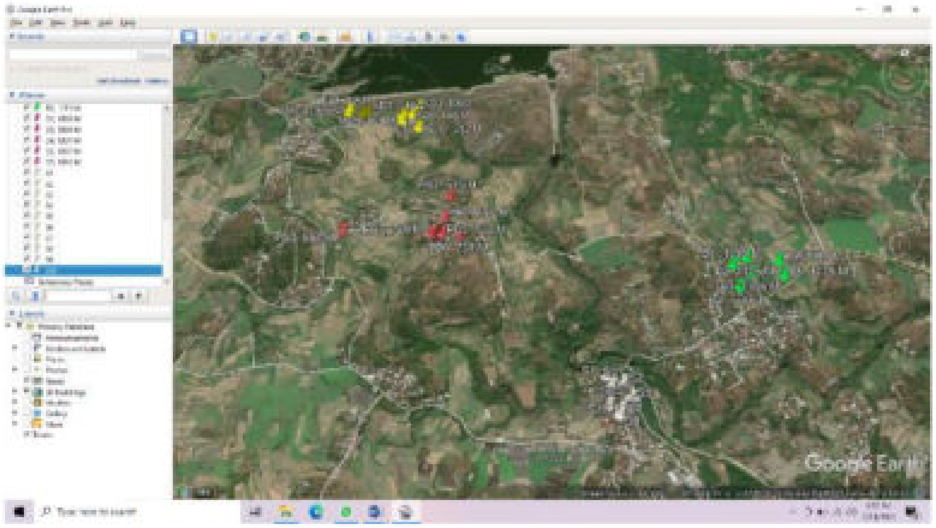

Figure 7. Map of Well Observation Location in West Suangi Village

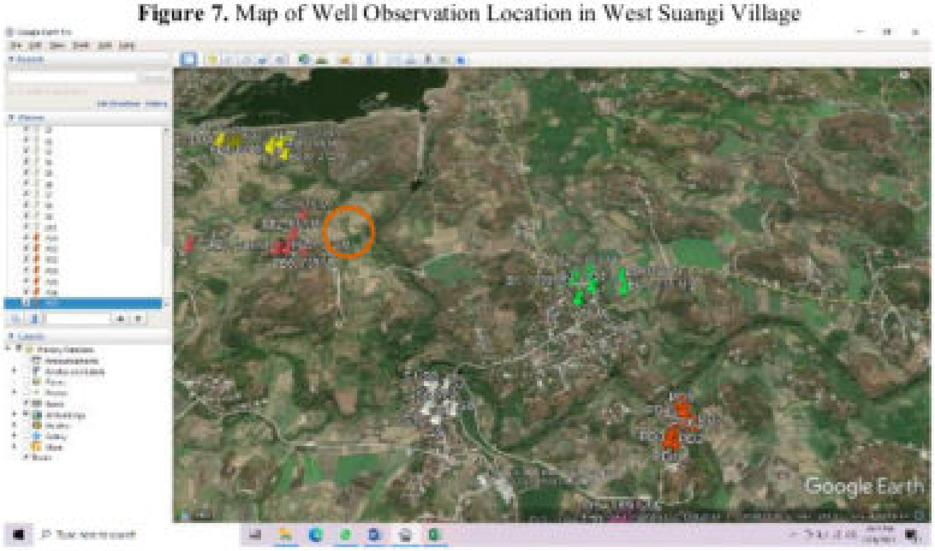

Figure 8. Map of Well Observation Locations in Palung Dasan Village

4.1.2. Secondary data.
Secondary data required is data in accordance with periods which include the following data: (a) Height Opening of the Pandan Duri Dam spillway gates from September 2019 to January 2020; (b) The pattern of reservoir operation; (c) Data of water level elevation of the reservoir inundation at Pandan Duri Dam; and (d) Undisturbed and disturbed soil sample

4.2. Analysis of groundwater level
To plot the groundwater level. The main reasons for drawing groundwater level contours are to visualize actual or theoretical groundwater levels, and to see groundwater distribution patterns or to find

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anomalies. Figure 9 shows the simulated groundwater surface contour image. It can be seen that the distribution of groundwater level contours in the red and blue areas in Figure 9 is denser than the contour distribution of the groundwater level in the yellow area. This indicates that the yellow area is more permeable. Next is to relate the groundwater level to the elevation of surface water in the reservoir and to compare the groundwater level to the results of flow nets due to seepage as explained in the next section.

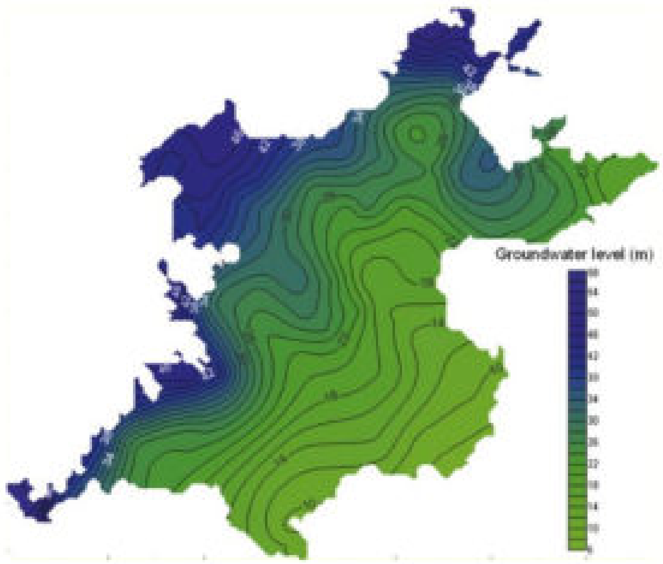

Figure 9 Groundwater level Map

4.3. Analysis of flow nets

From the comparison between equipotential lines due to seepage and the relationship between changes in reservoir water level and well water level, it was found that water inside the reservoir significantly affect to the surrounding groundwater levels. The results are presented in Figure 10. Figure 10 shows a significant relationship between the water level in the reservoir and the surrounding groundwater levels. It was found also in the simulation that the fluctuation of water level inside of the Pandan Duri Dam has a significant effect on the surrounding groundwater level.

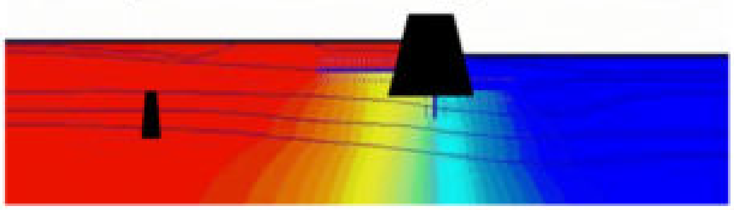

Figure 10 Flow Nets

5. Conclusion

Based on the results of the analysis, the following conclusions can be drawn:

a. This research was successful in proving that the presence of water in the reservoir of a dam affects the groundwater level of the surrounding area

b. This research proves that the groundwater flow pattern generally moves in and out of the groundwater filling system and is related to the fluctuation of the reservoir water level. This is especially evident during the rainy and dry seasons.
c. This research procedure was successfully demonstrated in the area around the Pandan Duri dam in Sakra District. East Lombok Regency. From the results of this research application. It is known that the water level fluctuation of Pandan Duri Dam has a significant effect on the groundwater level in the villages downstream of the dam.

References

[1] Suyono S and Takeda K 1977. Bendungan Type Urugan. PT. Pradnya Paramita. Jakarta.
[2] Hodge A 2000 "Reservoirs and Dams". Handbook of Ancient Water Technology. Technology and Change in History. 2. Leiden: Brill. pp. 331–339. ISBN 978-90-04-11123-3
[3] James P and Chanson H 2002 "Historical Development of Arch Dams. From Roman Arch Dams to Modern Concrete Designs". *Australian Civil Engineering Transactions*. *CE43: 39–56*.
[4] Ren K 2019 "A nature-based reservoir optimization model for resolving the conflict in human water demand and riverine ecosystem protection". Journal of Cleaner Production. 231: 406–418. doi:10.1016/j.jclepro.2019.05.221ICOLD-CIGB, 2017. Buletin 154. Dam Safety Management: Operational Phase of the Dam Life Cycle.
[5] Almeida R 2018 "A case study on environmental sustainability: A study of the trophic changes in fish species as a result of the damming of rivers through clustering analysis". Computers & Industrial Engineering. 135: 1239–1252. doi:10.1016/j.cie.2018.09.032
[6] Killian C D, Asquith W H, Barlow J R B, Bent G C, Kress W, Barlow P M, and Schmitz D W. 2019. Characterizing groundwater/surface-water interaction using hydrograph-separation techniques and groundwater-level data throughout the Mississippi Delta, USA. https://doi.org/10.1007/s10040-019-01981-6
[7] USGS. "About Liquefaction". Archived from the original on 2013-04-12
[8] Ardiansyah R, Sobriyah S, and Wahyudi A 2014 Pengaruh Fluktuasi Muka Air Waduk Terhadap Debit Rembesan Menggunakan Model SEEP/W (Effect of Reservoir Water Fluctuations on Seepage Discharge Using the SEEP / W Model). Matriks Teknik Sipil. eISSN: 2723-4223. https://jurnal.uns.ac.id/ matriks/article/view/37417
[9] Hatmoko W and Rauf A 2012 Tinggi Muka Air Waduk sebagai Indikator Kekeringan. Studi Kasus pada Waduk Kedungombo dan Waduk Cacaban (Reservoir Water Level as an Indicator of Drought. Case Studies on Kedungombo Reservoir and Cacaban Reservoir). Conference: Seminar Bendungan Besar 2012. Volume: 1.
[10] Meisyara N and Fathani T 2012 Pengaruh Fluktuasi Muka Air Reservoir Terhadap Deformasi Dan Stabilitas Bendungan Tanah-Uji Model Di Laboratorium (Effect of Surface Water Reservoir Fluctuations on Deformation and Stability of Soil Dam-Test Model in the Laboratory). Tesis. S2 Universitas Gadjah Mada.
[11] Darcy H 1856 Les fontaines publiques de la ville de Dijon. Paris: Dalmont
[12] Whitaker S 1986 "Flow in porous media I: A theoretical derivation of Darcy's law". Transport in Porous Media. 1: 3–25. doi:10.1007/BF01036523. S2CID 121904058
[13] Boersma L 1965 Field Measurement of Hydraulic Conductivity Below a Water Table. https://doi.org/10.2134/agronmonogr9.1.c14
[14] Fryar A and Mukherjee A 2021 Groundwater Hydrogeology. Editor(s): David Alderton, Scott A. Elias, Encyclopedia of Geology (Second Edition), Elsevier, Academic Press, 2021, Pages 399-407, ISBN 9780081029091, https://doi.org/10.1016/B978-0-12-409548-9.12115-3.
[15] Cedergren H H R 1977 Seepage, Drainage, and Flow Nets, Wiley. ISBN 0-471-14179-8
[16] Knappett J and Craig R F 2012 Craig's Soil Mechanics 8th edition, Spon Press. ISBN 978-0-415-56126-6

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