

Zone of Groundwater Quantitative Potential Based on the Characteristics of a Confined Aquifer at the Palu Groundwater Basin Central Sulawesi Province, Indonesia

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Abstract— Groundwater is water stored in aquifers in a groundwater basin, which is influenced by geologic, hydrogeological, tectonic forces, and the structure of the earth. Increased water demand causes problems in water management, which are characterized by a decrease in water availability, especially groundwater. Groundwater resources are renewable, but refill time is relative, depending on water availability, surface conditions, rainfall, lithology, hydraulic conductivity, topography, groundwater level depth, and the influence of the nature of unsaturated zones. These conditions cause a decrease in groundwater availability. This phenomenon is also found in Central Sulawesi Province, especially at Palu Groundwater Basin. The distribution of groundwater potential, which has the spatial and temporal characteristics of the confined aquifer, has caused insufficient water supply at Palu Groundwater Basin. Thus, according to the problem, the research objectives are to analyze groundwater quantitative potential based on the characteristics of a confined aquifer on each hydro-morphology and the hydrogeology units of the aquifer. The study of the groundwater quantitative potential is based on spatial, geomorphologic, and geologic approaches, and is required to be done with survey methods, and analysis using Darcy's Law. The research result indicates that: The characteristic of a confined aquifer consists of an aquifer system in alluvial plains together with denudation. Based on the topographic relief variation conditions, including the structure of the material and geomorphic process, the lithology and stratigraphy that sort Palu Groundwater Basin consists of Alluvium and the Pakuli Formation with the lithology variation. Confined aquifers are big (> 10.0 l/sec). The potency groundwater zone in the Palu Groundwater Basin is fluctuated greatly, ranging from high to medium. The groundwater potency based on a hydro-morphology at landform unit alluvial plains varies between medium to high potency.

Keywords— aquifer; basin; confined; groundwater

I. INTRODUCTION

Water problems are a global issue. In the world, more than 1.7 billion people live in watersheds. These people's use exceeds the flow of water flowing in the river, which leads to drainage of rivers, falling groundwater levels, and degradation of ecosystems. Two-thirds of the world's population will lack water in 2025 if consumption patterns like this continue to occur. Water demand is projected to increase by 55% by 2050. Approximately 40% of city populations live in groundwater basins that overlap two or more countries, which account for around 60% of global freshwater flow. These conditions' are happening right now. Water reserves in Indonesia are estimated to reach

3,221 billion m^3 /year, making this country one of the "wettest" countries in the world [4], [5].

Water is a significant factor in human life. Every day, it is estimated that people need a minimum of 100 liters of water / person, such as for drinking, cooking, bathing, washing, etc. Water potentials are the water resources that already exist today and those that meet the water needs for the future including agriculture activity [6], [10]. The impact of human activities in the hydrologic cycle and the quantitative estimates of water resources are essential and can be done by adsorption [7], [8], and water balance techniques [11], [12]. This water balance approach can be used to make a quantitative evaluation of water resources and its dynamic behavior under the influence of human activities [13]–[15].

It is argued that groundwater basins are a hydrogeological unit consisting of one or several parts of aquifers that are interconnected to form a system and can change due to changes in the environment [5], [16]. In other opinions [17], [18], it is explained that groundwater basins are an area with water originating from surface flow [19]. Groundwater basins are one example of a geomorphological system. The use of a geomorphological system is very appropriate to show the relationship between parts of a system in an object. Groundwater flow systems are influenced by several factors [20], [21]. Hubbert [22] added that groundwater flow is caused by potential differences in the fluid.

Groundwater is a vital natural resource for human activities that are extracted from the ground. The amount of water extracted without causing depletion in groundwater [23], depending upon the nature of the aquifer and the groundwater recharge [24]. Thus a quantitative measurement of space and time for groundwater recharge is a pre-requisite for the operating groundwater resources system [25], [26]. The availability of water is increasingly limited every year both in quality and quantity, while the needs are increasing, including the need for drinking water [27]. Some of the things that affect water scarcity are population growth, agricultural extension, industrialization, residential expansion, and other demographic changes [28]. The catchment area is vital for water resource conservation, both in terms of quality and quantity [29].

The imbalance between supply and demand of groundwater is a complex problem of water management in the Palu area. The increasing of the population numbers and development of various sectors such as domestic, industrial, agriculture, and other industries in Palu directly or indirectly also require the increasing provision of groundwater. The optimal pumping in an aquifer is essential for determining the level of water exploitation from the hydrogeology source, but in fact, it is difficult to be determined if it does not consider the quantitative and qualitative of hydrogeology potential. This condition will be increased if accompanied by a mistaken understanding of the hydrogeology characteristics, as well as the impact on development and human activity [35].

It is argued that the degradation of surface water availability in Palu previously had a capacity of 15 l/sec, now down to 10 l/sec [5]. The reduced flow of water in the river means that PDAM Palu city must rotate the distribution of water to customers. To meet the clean water needs of the Palu community, the PDAM must have a production installation with a capacity of 500 l/sec. The study determines the zone of groundwater quantitative potential based on the characteristic confined aquifer in the Palu Groundwater Basin (Fig.1).

II. MATERIAL AND METHOD

Groundwater is water stored in aquifers in a groundwater basin, which is influenced by geologic, hydrogeological, tectonic forces and the structure of the earth. Increased water demand causes problems in water management, which are characterized by a decrease in water availability, especially groundwater [30].

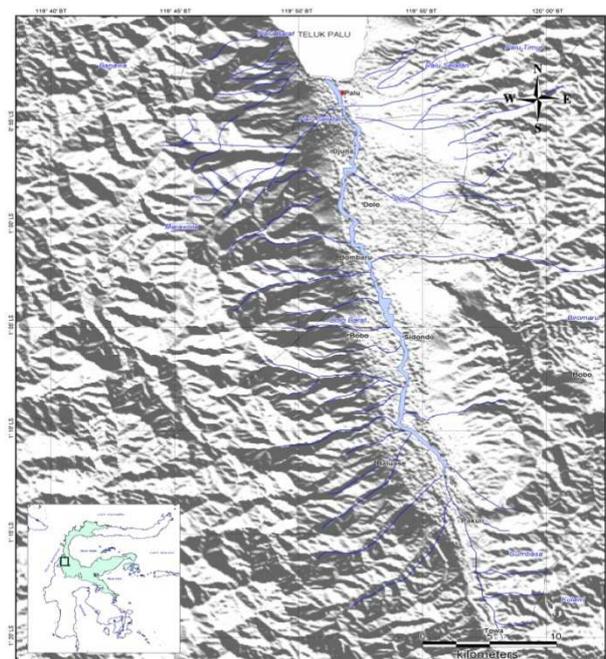


Fig 1. The Research area at Palu [30]

Groundwater resources are renewable, but refill time is relative, depending on water availability, surface conditions, rainfall, lithology, hydraulic conductivity, topography, groundwater level depth, and the influence of the nature of unsaturated zones [31]. Precipitation is the fundamental source of groundwater recharge, the amount of recharge depends upon the nature of rain, the duration it takes, the type of the soil, the antecedent soil moisture and usually the depth to the water table [33]. Recharge has been defined as the process of the addition of water to the saturated zone [32]. In [22], the limits are the hydraulic conductivity or the value of permeability, as well as the speed of water flowing into the soil. Permeability value is a function of porous media that has porosity, the level of relationship between texture and material sorting. Calculation of groundwater availability can be done by static or dynamic methods. If groundwater is considered stationary, then it can be calculated based on specific parameters, namely: the thickness of the aquifer, the particular yield according to the composition of the material making up the aquifer, and the area of each zone of potential groundwater. In fact, groundwater in aquifers flows at a certain speed, which means that groundwater is dynamic. Therefore, to calculate groundwater availability based on Darcy's principles (Fig.2).

$$Q = K \cdot I \cdot A \quad \text{or} \quad Q = T \cdot I \cdot L \quad (1)$$

Explanation:

Q: Debit (m^3/day)

K: Permeability on average (m/day)

I: Hydraulic Gradient

I : dh/dl (ramps hydraulics)

A: Cross-sectional area of the aquifer (m^2)

T: transmissibility = KD (m^2/day)

D: Aquifer thickness

L: Cross-section of the aquifer (m)

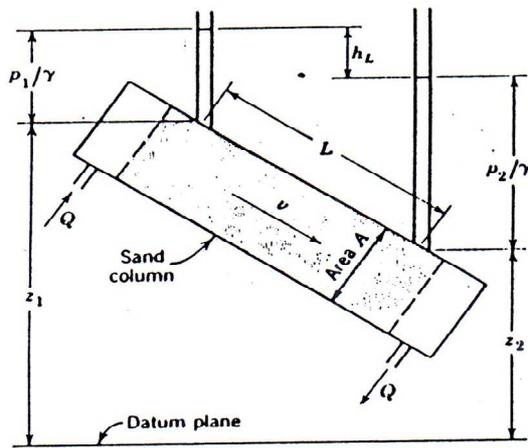


Fig 2. Darcy law [5]

Landform units generally affect groundwater distribution [34], [35]. The geomorphological approach to groundwater studies is to compile hydro-morphology maps [39]. The characteristics of aquifers are determined by the parameters and physical properties of the rocks that constitute the aquifers, namely: permeability, transmissibility, and yield of

species. The quantitative potential of distressed groundwater is highly determined by type debit (Q_s) and optimum discharge (Q_{opt}). In [37], this goes from the concept that the type of Discharge is a debit that can reduce groundwater level per meter (l/sec/m). Optimum discharge is a discharge that can reduce the groundwater level (drawdown_{opt})/m with groundwater level (PWL_{opt})/m.

Data analysis in this research is based on survey results and primary data from several bore wells in each unit of landform in the Palu Groundwater Basin. Configuration of aquifer systems includes the determination of the lateral and vertical distribution of the aquifer and non-aquifer that have relatively similar hydraulic characteristics and are grouped into one aquifer system [38]. The aquifer configuration can be known from the hydrogeological cross-section and the determination of the upper and lower limits of the aquifer system. The depth of the upper limit of the depressed aquifer is critical to optimum discharge (Q_{opt}). The drilling data in CAT Palu amounts to 78 wells, and only 23 wells have the pumping test data, namely 5 exploration drilling wells (SE) and 18 production drilling wells (SD) in Table 1.

TABLE I
FONT SIZES FOR PAPERS CHARACTERISTIC OF AQUIFER BASED ON PUMPING TEST AND BORE DATA AT CAT PALU

No	Kode Well	Location	Elevati (m wsl)	Dept Well (m)	Characteristic of aquifer				Geology	
					K (m/day)	T (m ² /day)	Sy (%)	Qs (l/sec/m)	Litology	Formation
I. East Aluvial Plain										
District Biromaru										
1	SE-TW-108	Sidera	13.6	65	65	559.8	56	6.8	GRV.SND	Pakuli
2	SE-TW-109	Sidera	13.7	65	67	647.5	56	0.4	GRV.SND	Pakuli
3	SD-DTW-110	Souluwe	17.8	105	47	3,452.0	51	5.2	SND.GRV	Pakuli
4	SD-DTW-111	Souluwe	16.4	105	48	3,128.9	51	8.2	SND.GRV	Pakuli
5	SD-DTW-112	Watunonju	21.5	105	68	1,067.9	55	9.6	SND.GRV	Pakuli
6	SD-DTW-113	Sidera	17.8	105	67	649.7	56	2.1	GRV.SND	Pakuli
7	SD-DTW-114	Bora	15.6	105	49	1,238.0	52	2.0	GRV.CLY	Pakuli
8	SD-DTW-115	Bora	14.5	102	43	3,478.0	51	6.7	GRV.CLY	Pakuli
9	SD-DTW-120	Sidera	16.4	105	65	790.6	56	0.9	GRV.SND	Pakuli
10	SD-DTW-121	Sidera	21.5	105	65	329.0	58	0.4	GRV.SND	Pakuli
11	SD-DTW-122	Souluwe	14.5	105	49	4,517.0	55	5.2	GRV.SND	Pakuli
12	SD-DTW-123	Watunonju	20.9	105	67	1,054.0	52	1.2	GRV.SND	Pakuli
13	SD-DTW-124	Bora	15.6	105	47	3,162.0	55	3.7	SND.GRV	Pakuli
14	SD-DTW-125	Bora	14.7	105	15	1,437.0	31	8.6	SND.CLY	Pakuli
15	SD-DTW-126	Bora	15.3	105	15	7,114.0	31	9.2	SND.CLY	Pakuli
16	SD-DTW-127	Bora	13.4	105	12	5,270.0	30	6.1	SND.CLY	Pakuli
17	SD-DTW-128	Bora	15.2	105	48	9,034.0	30	10.5	SND.CLY	Pakuli
18	SD-DTW-129	Bora	15.6	105	45	7,905.0	30	2.3	SND.CLY	Pakuli
19	SD-DTW-130	Bora	14.8	105	45	2,964.5	30	9.2	SND.CLY	Pakuli
20	SE-TW-131	Bora	16.3	105	68	12.4	55	0.0	GRV.SND	Pakuli
21	SE-TW-132	Pombewe	23.5	105	12	527.0	53	0.6	SND.CLY	Pakuli
22	SE-TW-133	Lolu	45.2	105	76	10.0	51	0.0	GRV.SND	Aluvium
II. West Aluvial Plain										
District Marawola Kabupaten										
23	SD-DTW-105	Binangga	34.0	105.0	57.0	4,350.9	51.0	13.1	SND.CLY	Aluvium

Source: Analysis Report

III. RESULT AND DISCUSSION

A. Contour and Direction of Confined Aquifer Flow

Based on the results of contour analysis and the direction of groundwater flow, that enters the Palu Groundwater Basin is calculated by the flownet. Conceptually, the pattern of the confined aquifer is relative to the topographic profile and geomorphological conditions and is mostly determined by the path of the rock being traversed. In order to get the correct value of electrical resistivity, it is needed to get the level of soil moisture. The electrical resistivity values from each treatment should be compared to electrical resistivity values of good lithology [24], [36].

Observations on confined aquifer systems are stressed on drill wells: exploration wells (SE) and production wells (SD) [36], [37]. The results of contour and direction analysis of groundwater flow using the 2002 version of the Rockworks program. To be able to determine the possible quantitative level of the confined aquifer in the Palu Groundwater Basin, it is necessary to analyze: the contour and direction of groundwater flow are enclosed, the depth of the piezometric, and the depth of the upper limit of the confined aquifer.

Based on the data analysis, the depth of the upper limits of the confined aquifer in the eastern groundwater basin averaging 36.00 meters while in the western part, it averages 37.50 m. The thickness of the upper limit of this distressed aquifer belongs to the moderate class (20.00 - 50.00 m) The Palu groundwater basin is grouped into 2 aquifer systems. The alluvial plain aquifer system is a potential primary aquifer, composed of coarse sand, fine sand, and clay. This aquifer system is dominated by a free aquifer with a thickness of > 83.24 m (Fig. 3, 4,5).

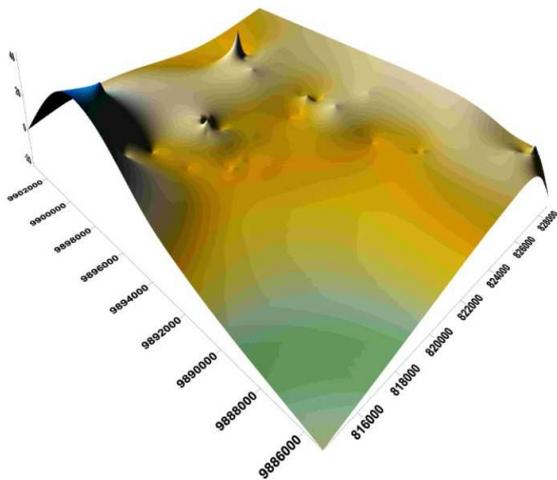


Fig 3. Piezometric level the Palu groundwater basin

B. Depth of Piezometric of Confined Aquifer

Based on the results of interpolation and analysis of field data, there is a correlation between geomorphological and geological conditions with confined aquifer depth [13]. In the Palu Groundwater Basin, the piezometric level ranges from shallow to deep. Shallow piezometric level (<5.0 m) distribution in eastern and western groundwater basins. On the east part of the groundwater basin in the District of East

Palu, the distribution is in the form of alluvial plains in the Alluvium Formation. The lithology of aquifer consists of gravel and clay sand. In the western part of the groundwater basin covers the sub-districts: South Palu and Marawola, with distribution on alluvial plains and floodplains, in the Alluvium Formation. The lithology of aquifer consists of gravel sand and clay-sand.

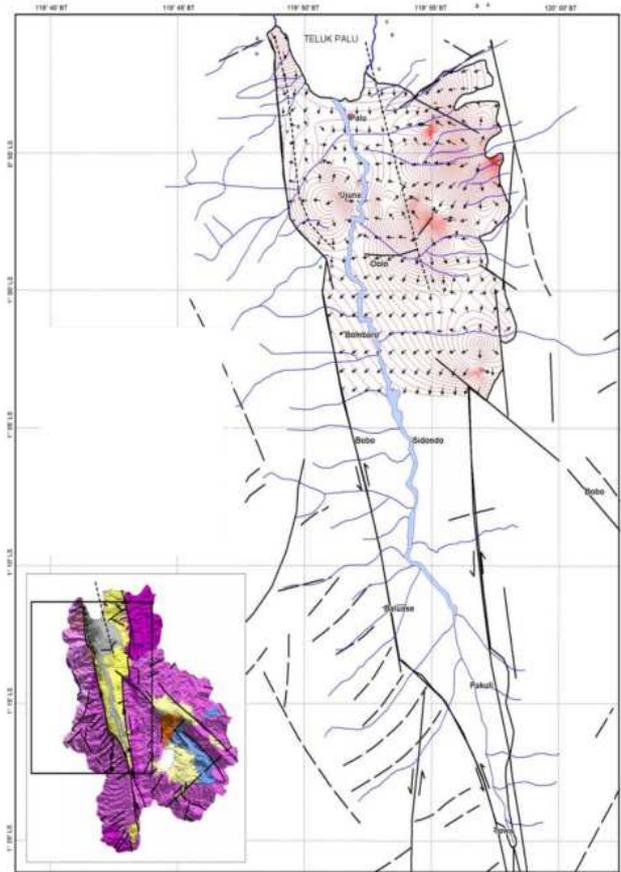


Fig 4. Map of contour and direction of confined aquifer flow of groundwater Palu basin

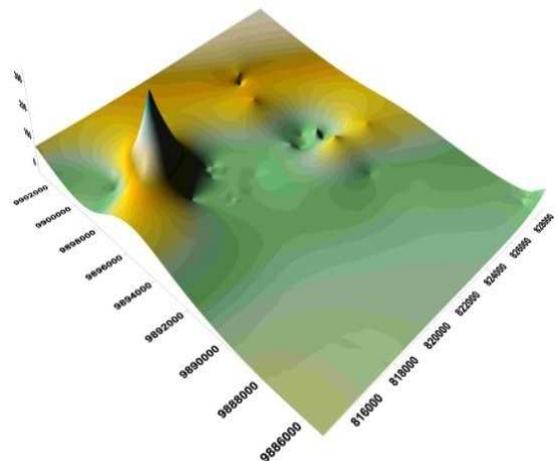


Fig 5. Hydraulic of confined aquifer in the Palu groundwater basin

In figure 4, based on the geological conditions in the Alluvium Formation and Pakuli, the lithology making up aquifers consists of: gravel sand, clay sand, and sand gravel.

This is in the western groundwater basin in the West Palu District, on the alluvial plains and denudation hills in the Alluvium and Pakuli Formations. The lithology of the aquifer consists of granodiorite and gravel sand.

In figure 5 and 6, the deep of piezometric (> 10.0 m) spread in the eastern and western groundwater basins. In the eastern groundwater basin, in the South Palu and Biromaru sub-districts, namely in the alluvial plains and floodplains, and in the denudation hills (Ngatabaru area).

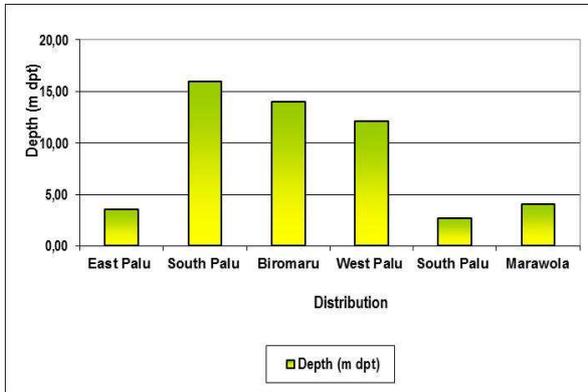


Fig 6. Graph of piezometric depth in the groundwater Palu basin

C. Boundary Depths of Confined Aquifers

The depth limit of the confined aquifer determines the optimum discharge. The depth limit of the confined aquifer is analyzed based on pumping test data. The number of bore wells in the Palu Groundwater Basin, is 78 bore wells, and is distributed in the eastern part of the groundwater basin, namely in the Districts of East Palu, South Palu and Biromaru.

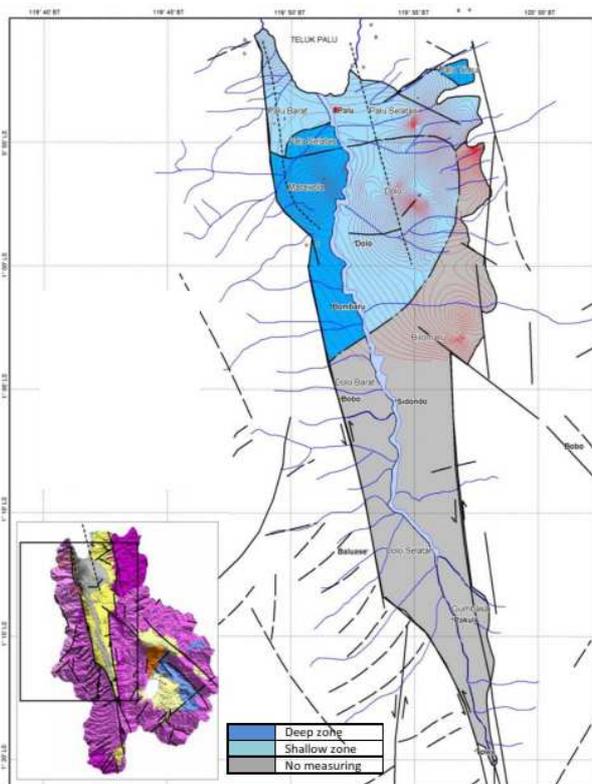


Fig 7. Map of piezometric zone in the Palu groundwater basin

In the west, namely in the Districts of West Palu, South Palu, and Marawola, the 78 drilling wells, only 23 wells have pumping test data, namely 5 exploration drill wells (SE) and 18 production drill wells (SD). Based on the results of data analysis, the depth of the upper limit of confined aquifers in the eastern groundwater basin is 61.30 m while in the west, the average is 62.25 m. The thickness of the upper limit of the compressed aquifer is included in the class (> 50 m) (Fig.8).

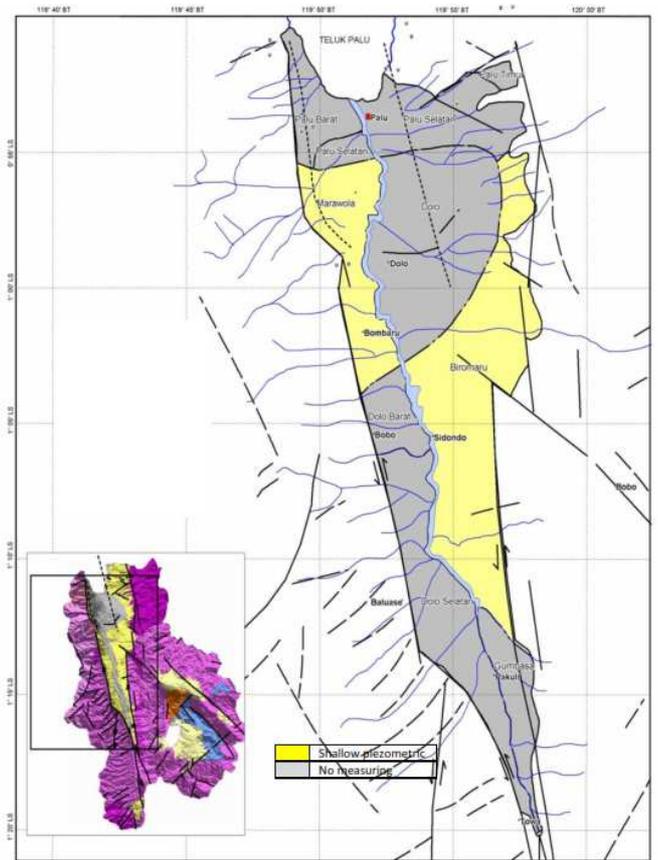


Fig 8. Map of depth zone confined aquifer in the Palu groundwater basin

D. Level of Quantitative Potential of Confined Aquifer

The results of the calculation and analysis of data show that in the Palu Groundwater Basin, the standard type of discharge is 4.86 l/sec/m. Type discharge with medium class, the distribution in the eastern groundwater basin is 4.49 l/sec/m. The delivery is in the District of Biromaru, in the form of alluvial plains, floodplains, and denudation hills, in the Formations of Alluvium and Pakuli.

Lithology composing aquifers: sandstone gravel, gravel sand, clay gravel, and clay sand. Debit types with a large class, the distribution in the western groundwater basin are 13.10 l/sec/m. The delivery is in Marawola Subdistrict, in the form of floodplain land in the Alluvium Formation with lithology composing aquifers: clay sand (Fig.9). The results of the calculation and analysis of the data show that in the Palu Groundwater Basin, the optimum discharge averages 54.24 l/sec.

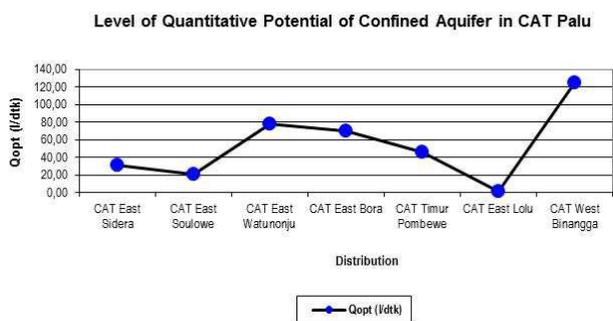


Fig 9. Level of quantitative potential of confined aquifer in the Palu groundwater basin

In the eastern groundwater basins, the average number is 51.02 l/sec and in the west, the average amounts to 124.90 l/sec. Based on the criteria of the reference and actual conditions in the field, the optimum discharge is classified as significant (> 10.0 l/sec) (Fig.10).

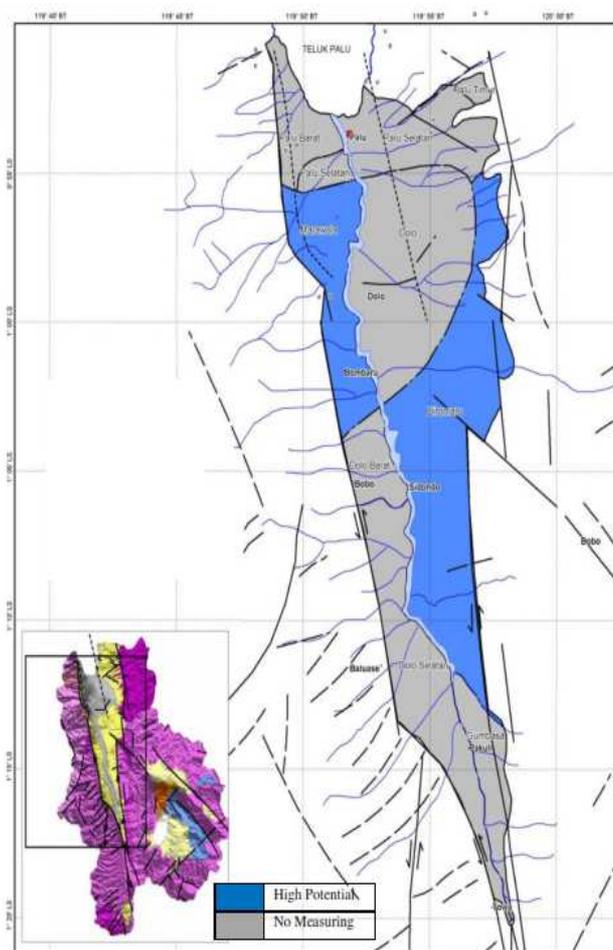


Fig 10. Map of zone of quantitative potential confined aquifer in the Palu groundwater basin

IV. CONCLUSION

Configuration of aquifer system in the Palu Groundwater Basin consists of aquifer system alluvial plains and denudational hills. Lithology and stratigraphy that describes the Palu Groundwater Basin consists of Alluvium and Pakuli Formation with the lithology variation. Confined aquifer is big (> 10.0 l/sec). The potency groundwater zone in the Palu

Groundwater Basin is very variable with its fluctuations ranging from high to medium. Groundwater potency based on a hydromorphology at the landform unit of alluvial plains is medium – high potency.

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