Incorporation Groundwater Recharge with AVSWAT Model Streamflow by Using Water Table Fluctuation

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Abstract

This research investigated contribution of sustainable management water resources in the Upstream Lesti Watershed. The main objective of this research predicted recharge of groundwater using water table fluctuation (WTF). The groundwater recharge prediction will be added as a result from deep aquifer with the performance of AVSWAT (Arc View Soil Water Assesment Tool) model by comparing observed streamflows with simulated streamflows at outlet. The water table fluctuation method from 4 well was used in the Upstream Lesti Watershed to evaluate seasonal and annual variations in water level rise and to estimate the groundwater recharge prediction (deep aquifer). Based on standard values of specific yield and water level rise, the groundwater recharge prediction from the Upstream Lesti Watershed at the outlet of sub basin 39 was 736 mm in 2007; 820,9 mm in 2008; 786,7 mm in 2009; and 306,4 mm in 2010, respectively.

Keyword : AVSWAT, Groundwater Recharge, Water Table Fluctuation, Streamflow

Introduction

The development of groundwater resources in watershed must be well managed particularly in areas where the sustainability of the resources could be threatened by over exploitation and contamination, as well as by climate change (Principe, 2012). A basic prerequisite for efficient and sustainable management of groundwater resource is the groundwater recharge (Lerner et al., 1990; Scanlon and Cook, 2002, Chand et al.,2005). Quantification of the recharge is needed, for example, to estimate sustainable yield of groundwater aquifers and for rational and sustainable exploitation of the resource. This research will seek to contribute to the sustainable management of water resources in the Upstream Lesti Watershed by investigating the recharge to groundwater especially in dry season which can cooperating with the performance of using AVSWAT (Arc View Soil Water Assesment Tool) model (Luzio et al., 2002) model by comparing observed streamflows with simulated streamflows the outlet of Upstream Lesti watershed.

Since AVSWAT is a semi distributed model (Raposo et al., 2012), it is not suited to accurately reproducing groundwater hydrographs. In AVSWAT model assumes that water entering the deep aquifer is not considered in the future water budget calculations and can be considered lost from the system, so the model only focus from shallow aquifer which contributes to streamflow. This study uses the deep aquifer from well water level observed using water table fluctuation (WTF) (Healy and Cook, 2002) surrounding of the Upstream Lesti Watershed in order to estimate groundwater recharge which contributes to streamflow. It may not be necessary to develop a new model, but only modify an existing hydrologic model, in order to extract additional information for streamflow AVSWAT simulation model.

Study Area Description

Lesti watershed is the source of the Brantas River, located in the eastern foothills Anjasmoro, which flows through 8 districts (Malang, Blitar, Tulunggung, Kediri, Nganjuk, Jombang, Mojokerto, Sidoarjo) and 6 Cities (Batu, Malang, Blitar, Kediri, Mojokerto and Surabaya).

The area of study is one of the main tributaries of the river upstream of the Lesti river.

Based on the interpretation of satellite imagery and topographic maps scale 1: 50,000, it is known that the area around the whole Lesti watershed is 59963 hectares, divided into 3 sub watershed. The map of the study area is shown in **Fig.1**.

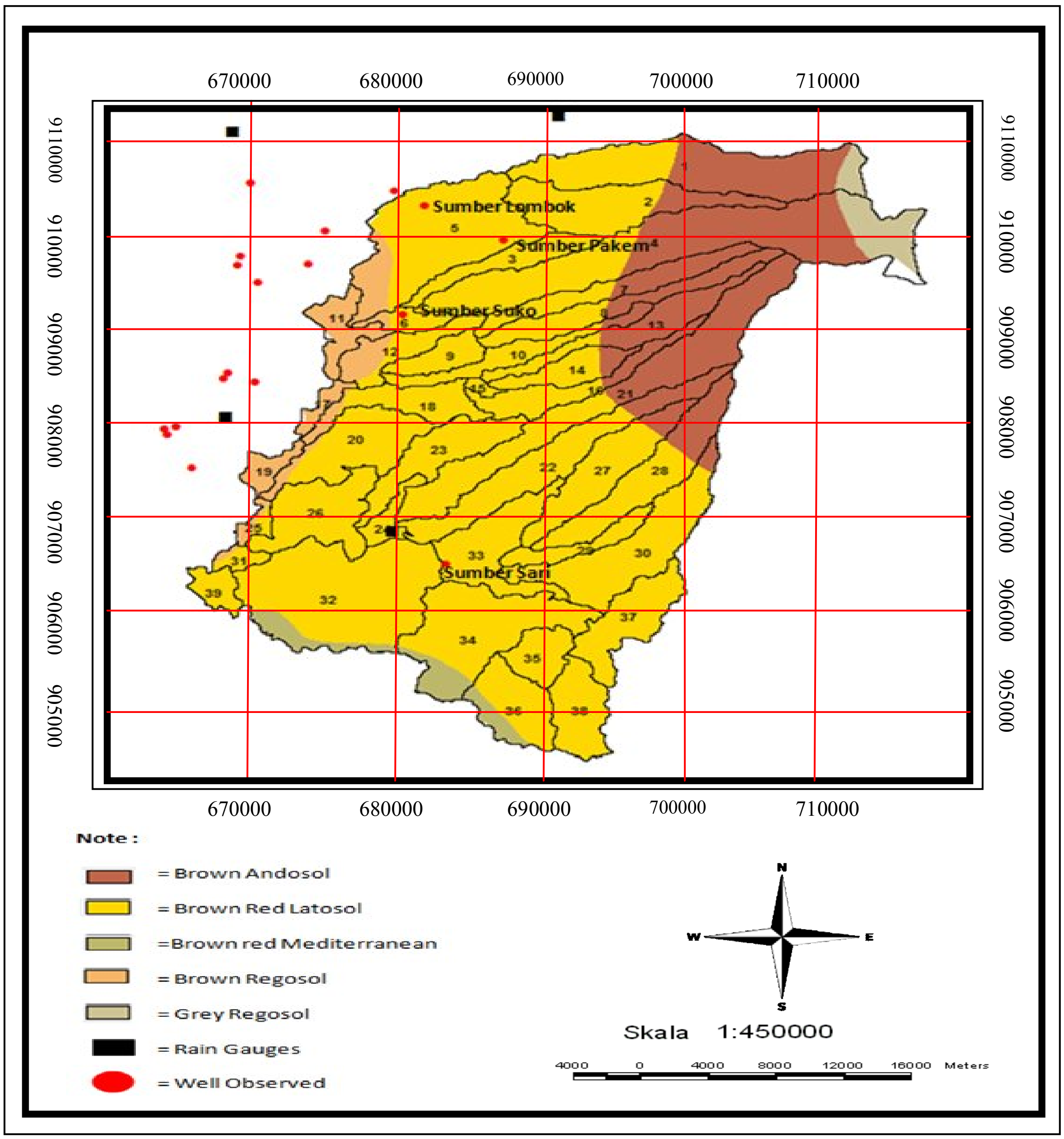

Fig 1. Upstream Lesti Watershed map

Groundwater Recharge Prediction

This study is focused on recharge from precipitation, since it is the most important category of recharge in the Upstream Lesti Watershed.

The main focus in previous studies has been primarily on aquifer management. For example, groundwater recharge could not be considered in terms of hydrological processes, which are directly related to precipitation, evapotranspiration and surface runoff (Kim et al., 2008).

Peterson and Hamlett (1988) found the AVSWAT was not able to simulated baseflow due to the presence of soil fragipans. While AVSWAT has its own module for groundwater components (Arnold et al., 1993), the model itself is lumped and therefore distributed parameters such as hydraulic conductivity distribution could not be represented. Moreover, the AVSWAT model creates difficulties when expressing the spatial distribution of groundwater levels and recharge rates.

One of the most essential components of an efficient groundwater model is the accuracy of recharge rates within the input data. The conventional groundwater flow analysis performed by extension MODFLOW program in AVSWAT (Kim et all., 2007) often overlooks the accuracy of the recharge rates that are required to be calculated into the model. A procedure to compute perched groundwater support by DRAINMOD theory have already used Amabile and Engel (2005) in order to expand AVSWAT's capabilities.

This study used water table fluctuation method based on the premise that rises in groundwater level due to recharge arriving at water table. Favorable aspects of the water table fluctuation method include its simplicity and ease of use (Sharma, 1989) and can be applied for any well that taps the water table.

Groundwater in AVSWAT model

For AVSWAT, water that moves past the lowest depth of the soil profile by percolation lag between the time that water exits the soil profile and enters the shallow aquifer will depend on the depth to the water table and the hydraulic properties of the geologic formations in the vadose and groundwater zones (Yan et all., 2010). The shallow aquifer contributes base flow to the stream within the subbasin. Shallow aquifer plays a key role contributing streamflow to the overlaying soil layers by capillary pressure or by direct absorption by plant roots (**fig 2**).

AVSWAT model results revealed that baseflow is an important component of total discharge within the study area (Chekol et al., 2007 ; Luo et al., 2011). Therefore, streamflow in AVSWAT is composed of groundwater flow from shallow aquifer located below the soil and by lateral flow from the soil saturated zone (Alansi et al., 2009).

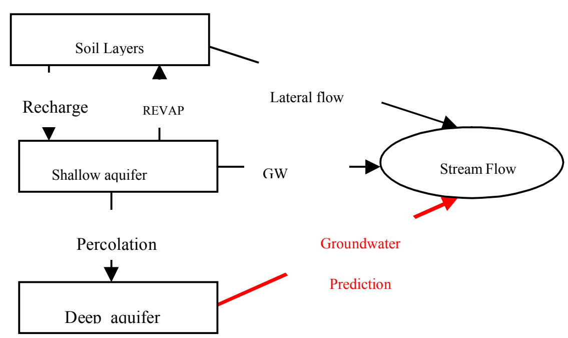

Fig. 2. : Groundwater mechanism in AVSWAT

Estimation of Water Level Rise (Δh) and Specific Yield

The water level rise (Δh) in the observed wells was estimated using the recorded water level data. The water level rise is generally computed as the difference between the peak of a water level rise and the value of the extrapolated antecedent recession curve at the time of the peak. The recession curve is the trace that the well hydrograph would have followed had there not been any recharge (Delin et al., 2007).

In simple terms, the specific yield is a fraction of the porosity of an aquifer that can be drained by gravity. The value depends on the grain size, shape and distribution of pores and compaction of the strata (Gupta and Gupta, 1999).

In theory, specific yield is treated as a storage term that does not depend on time, accounting for instantaneous release of water from storage. In practice, however, the release of water is often not instantaneous but time dependent (Healy and Cook, 2002; Lerner, 1990; Nachabe, 2002). This is more evident in situations of relatively fast lowering of the water table, in which case the drainage from the unsaturated zone may lag behind depending on the soil properties (Storm, 1988). Specific yield is affected by lithology, temperature (Meizer, 1923 cited in Healy and cook, 2002) and depth to water table.

In this study, the exact specific yield values for the aquifer material in the study area were not determined. Specific yield values were selected from literature, based on the values used in India and the range of specific yield value (0.12 - 0.18)

Result Discussion

Simulation results from AVSWAT model were taken from outlet of sub basin 39 and will be compared with observed flow data recorded on AWLR (Automatic Water Level Recording) Tawangrejeni.

From the **fig. 3**, it can be seen that the results of flow simulation from AVSWAT showed few different compared with flow observations data. Annual Flow of AVSWAT model and observation are 1937 mm/year and 2610 mm/year respectively. Especially in the dry season, the observed showed high values because there are many laterals along the Lesti river.

Water balance equation can be used to describe the flow of water in and out of a system. The calculation is done by calculating the weighted average for 10 years (2001 -2010) from every area of the sub basin. Thus, the area of each sub basin must be known in order to calculate the weighted average.

Based on the principle of water balance, precipitation is transferred into either discharge, evopotranspiration, or stored in soil. In AVSWAT, the hydrologic cycle is simulated based on the water balance equation, where the discharge ($\sum Q_{flow}$) includes $\sum$precipitation and $\sum$evaporation.

Water yield and $\sum Q_{flow}$ (mm) is the net amount of water that leaves the subbasin and contributes to streamflow in reach during the time step. Water yield includes surface runoff (SUR_Q), lateral flow (LATQ) and return flow (GW) is calculated according to the formula in AVSWAT guide, and all of the value output of water yield and simulated streamflow was taken from the result running in .rch file output of AVSWAT. Generally, there is similarity among the results of flow simulation, water yield, and watershed discharge ($\sum Q_{flow}$) (**fig. 4** and **fig 5**). Such similarities make it clear that the AVSWAT model can reasonable with simulated streamflow in terms of the abundance of rain. It all revealed by same theory when it heavy rains then discharge river will increase, however there is no rain then the discharge will decrease. Nevertheless, the opposite happens on **fig. 6**, if we compare the results of calculation of water balance with flow observation, we can see that the differences are quite significant.

Table 1. Description of parameter value output in this research

No	Description	Value (mm/year)
1	Annual precipitation for 10 years	2456,04
2	Evapotranspiration for 10 years	344, 54
3	Surface Runoff (SUR_Q) for 10 years	1069,75
4	Groundwater shallow (GW) for 10 years	451,74
5	Water Yield (WYLD) for 10 years	2011,05

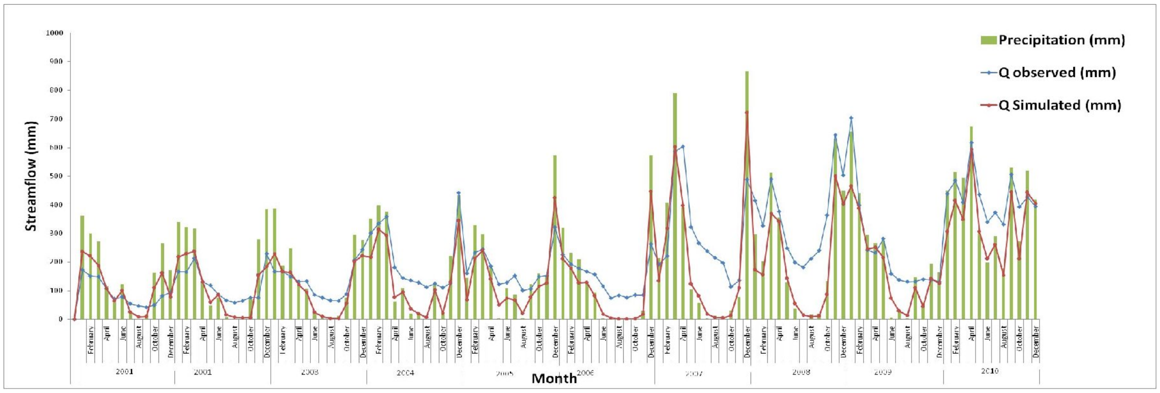

Fig. 3. Comparison between flow simulated and flow observed

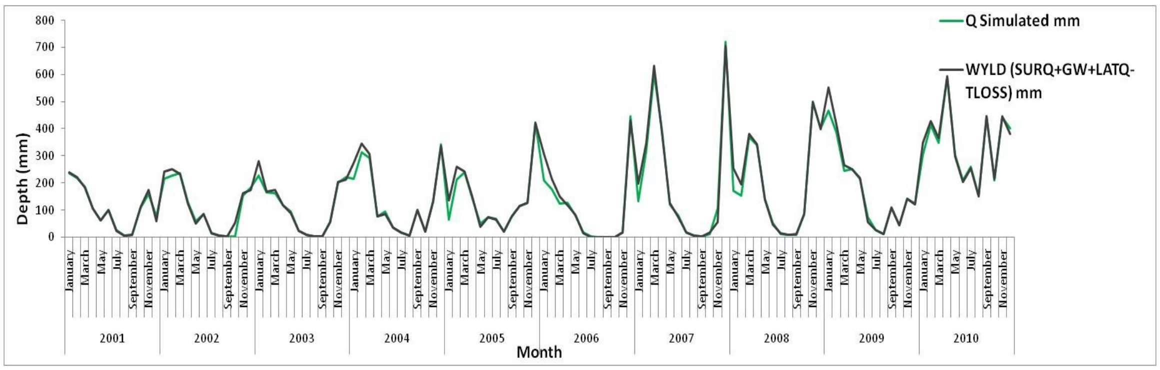

Fig 4. Flow simulated and water yield

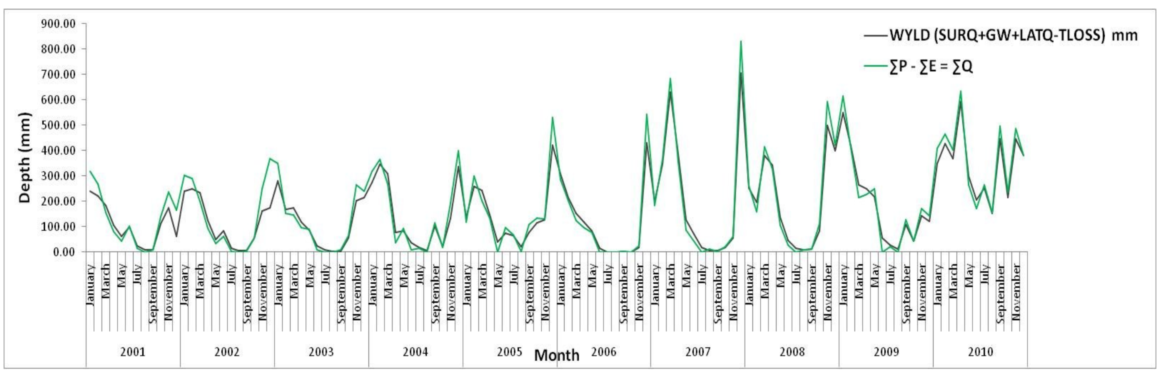

Fig 5. Water balance (∑Q) and water yield

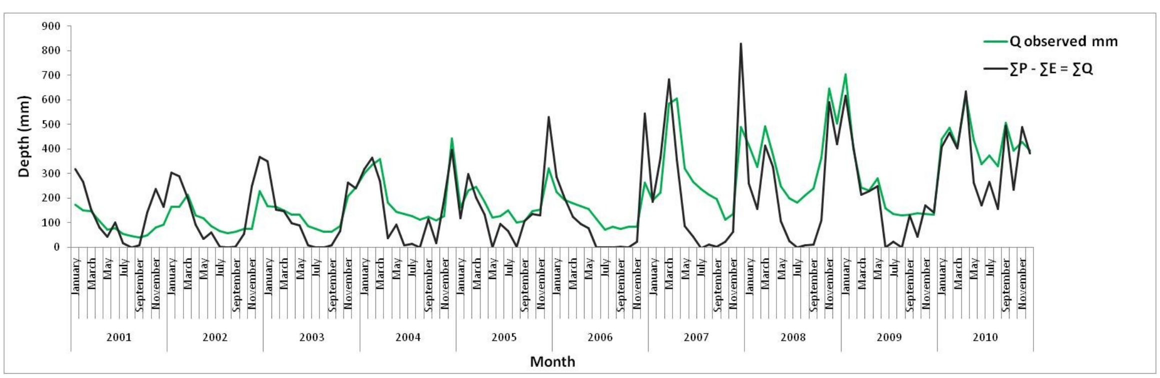

Fig 6. Water balance (∑Q) and flow observed

Water Table Fluctuation from Well Observed (Groundwater Recharge)

The water table fluctuation method (WTF) is one of the most widely used techniques for estimating groundwater recharge over a wide variety of climatic conditions (Scanlon et al., 2002; Hall and Risser, 1993; Healy and Cook, 2002). The use of the method requires knowledge of specific yield and changes in water levels over time. Healy and Cook (2002) have suggested that the wide use of this method could be attributed to the abundance of available water level data and the simplicity of estimating recharge rates from temporal fluctuations or spatial patterns of water.

Groundwater levels were monitored in 4 observation wells equipped with manualy water level recorders (data-logger divers) spread across the study area. The monitoring of the 4 wells are part (Perum Jasa Tirta 1) information services.

Water Level Rise

The highest monthly rainfall for the study area were measured in November – April (rainy season). Although the rainy season in the study area starts in November, water level in all wells started to rise in May/April.

The month lag between the start of the rainy season and water level rise can be described as a period of refilling of the soil due to moisture deficit inherited from the past dry season (**fig 7**). The lag suggests that there are threshold effects and a non-linear relationship between rainfall and recharge in the study area. Findings from water table monitoring from 4 well observed (Sumber Lombok, Sumber Pakem, Sumber Suko, and Sumber Sari) show high annual and spatial variations in the water table rise, with a range of 2800 mm - 5700 mm in 2007, 3900 mm - 4700 mm in 2008, 3200 mm – 5100 mm in 2009, and 2800 mm – 4600 mm in 2010. The groundwater recharge for each of the observed wells was calculated by multiplying the water level rise with the specific yield values of the aquifer.

In this research, the groundwater recharge prediction is very usefull to help the result of simulated flow from AVSWAT approach with the observed ones especially in dry season. The result of groundwater recharge can be used (added directly) by adding together with simulated streamflow AVSWAT in the outlet of sub basin 39. The 4 well observed in this study spread from upstream to downstream (**fig. 1**) however, it only located in certain sub basin (sub basin 5, 6 and 33). In this study assume that the water level rise from four well observed can represent the groundwater recharge in all of sub basin from sub basin 1 until subbasin 39. Firstly, from the whole Upstream Lesti Watershed, it can be divided into two part : groundwater side 1 and groundwater side 2. Groundwater side 1 include some sub basins 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 21. Groundwater side 2 include sub basin 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, and 39. The recharge in groundwater side 1 can be contributed to groundwater side 2, and then can be summarized in the outlet of sub basin 39. Total area Upstream Lesti Watershed is about 380,93 km^2, from the output of AVSWAT explained about the total area from each sub basin, therefore the total area groundwater side 1 and groundwater side 2 can be seen. The increasing in groundwater level can be used to predict annually groundwater recharge. The well observed that the existing Sumber Lombok, Sumber Pakem, and Sumber Suko represent groundwater prediction in upstream side, while the Sumber Sari representing most side of sub basin downstream.

From the **table 4** below, it can be seen that the highest groundwater prediction from the volume for each year divide by total area Upstream Lesti

Watershed, and got the highest depth prediction 820,9 mm in 2008, and the lowest prediction groundwater occur in 2010. From those result every year, can give a prediction of discharge in the river by dividing certain month in dry season. The addition of groundwater prediction done at the table where fluctuations water dropping until at low point from fluctuations water table.

The estimated additional groundwater prediction at every year can be seen on **table 5**.

Table 3. Range of mean recharge prediction in every year

Year	Range of Mean Recharge Prediction (mm)	Represent of annual rainfall
2007	420 to 855	14,21 to 28,92 %
2008	585 to 705	21,03 to 25,34 %
2009	480 to 765	18,97 % to 30,23 %
2010	420 to 690	8,67 % to 14,25 %

Table 5. The Final groundwater prediction in every year

Year	Month	Groundwater Prediction (mm)
2007	July – October	184
2008	July – November	164,2
2009	July – November	157,3
2010	July – September	102

Table 4. Groundwater prediction in 39 basin

Year	Groundwater 1 (m3)	Groundwater 2 (m3)	Outlet discharge (m3) in subbasin 39	The depth of discharge (mm)
2007	133410060,0	146959999,6	280370059,6	736,0
2008	155716920,0	156979999,5	312696919,5	820,9
2009	129337380,0	170339999,5	299677379,5	786,7
2010	23208840,0	93519999,72	116728839,7	306,4

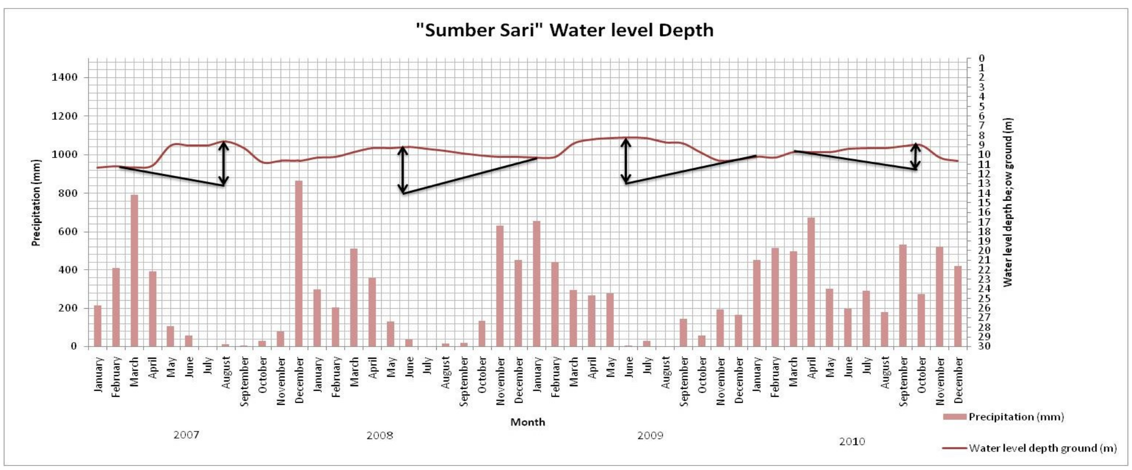

Fig 7. Water level in Sumber Sari Well

Prediction value of groundwater for each month can be assumed as a contribution from the deep aquifer (>20 m) (Rao and Yang, 2010) which is AVSWAT does not take into account the problems in detail. Prediction of groundwater each month can be added directly with surface runoff, lateral flow and transmission losses, resulting in a flow simulation that approximates the flow observations.

Conclusion

The WTF method was applied in Upstream Lesti Watershed in 2007 - 2010 to quantify groundwater recharge prediction come from deep aquifer which can add together with flow simulated AVSWAT and to analyze the fluctuations in the water table. The water table fluctuation (WTF) method requires data of specific yield and changes in the water table over time. It is best suited for areas with distinct periods of recharge.

The use of the method is not restricted by the presence of preferential flow paths at a study site. The main limitation of this method is the difficulty in obtaining specific yield values that are representative of the aquifer materials in the study area. Besides the specific yield limitation, there are only a few wells for monitoring water table data, which affects the reliability of the recharge estimates.

Final results of the incorporation of groundwater prediction (deep aquifer) with flow simulation AVSWAT in every month, especially in dry months, showed much better results and a very significant improvement when compared to prior to the addition of groundwater prediction.

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