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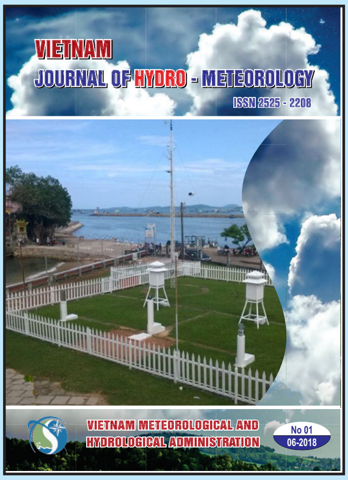

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Research Paper

INTEGRATION OF SWAT AND MODFLOW MODEL TO ASSESS THE SURFACE AND GROUNDWATER AVAILABILITY: A CASE STUDY OF DONG NAI BASIN IN 2015 - 2016

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ABSTRACT

Water is one of the most essential natural resources . A good assessment of both surface and groundwater always leads to an effective and sustainable water resources management. In Vietnam, the management of water resources has mainly focused on surface water, however, the problems related to groundwater have not been managed properly. This study aims to assess surface and groundwater availability in Dong Nai river basin by integrating SWAT and MODFLOW models. These models run individually and integrated through the recharge rates. The simulation results were then compared and showed good agreement with observed data. The results showed Tuyen Lam, Da Huoai and Dak Song districts are the locations which have high surface water availability, in the range of 40 - 50 l/s/km^2*. The groundwater simulation indicated the areas having high groundwater availability are located at the same places with the regions having high surface water. Dak Song is the region having the highest groundwater availability with around 9 l/s/km*^{2}*.*

***Keywords**: Surface water, groundwater, SWAT, MODFLOW, Dong Nai, recharge rates.*

1. Introduction

These days, water scarcity is a widespread problem around the world. Water availability becomes a matters of interest in everywhere, especially in arid or semiarid areas.Traditionally, management of water resources has concentrated on surface water or groundwater as if they were separate entities (Winter et al., 1998). However, surface water and groundwater are not separate components in the hydrological cycle (Dowlatabadi et al., 2015). In Vietnam, water resources management has mainly focus on thesurface water (Chau and Khanh, 2017, Au et al., 2013; Phung et al., 2014), while problems related to groundwater have not been managed in a rigorous manner. In most of the studies have been done, modellingis the most suitable method for simulating surface and groundwater availability.

The Soil and Water Assessment Tool (SWAT) and MODFLOW are 2 well-known and widely-used surface and groundwater models, respectively.These two models represent two different environments and each is limited in its simulation domain with their corresponding strong points and drawbacks. In one side, SWAT is a basin scale, semi-distributed model and is often used to simulate hydrological processes in surface and in shallow aquifer. Its calculation is based on hydrological response units (HRUs), which are conceptual units of homogeneous land

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use, management, slope, and soil characteristics that extend below the surface to a soil profile depth (Arnold et al., 1998). SWAT model can only simulate shallow groundwater flow in a restricted layer, around 6 m below ground surface, in which the seepage below it is assumed to be lost and out of the system(Neitsh et al., 2011). In the other side, MODFLOW presents as a three dimensional, distributed finite - difference groundwater model and it can simulate ground water flow for variably saturated subsurface systems including shallow and deep aquifers. However the model is limited to investigating groundwater-surface interaction, as it cannot simulate surface process. On the other words, the groundwater model was not adequately linked to surface water model(Anh et al., 2009; Hiep et al., 2012; Quynh et al., 2014). In those studies, groundwater recharge, an important input for groundwater model, could not be calculated from hydrological components, which are precipitation, evapotranspiration and surface runoff, however it was determined through trial and error method during calibration process.

In recent decades, there were some conjunctive simulations of surface water and groundwater using SWAT and MODFLOW (Putthividya et al., 2017; Kim et al., 2008; Guzman et al., 2015; Dowlatabadi et al., 2015).In those studies, there were several methods to integrate SWAT and MODFLOW, however the integration through recharge rates between HRUs in SWAT and cells in MODFLOW is the most feasible method. Those studies were successful in evaluation of water availabilityin various regions of the world and became a useful data to support the water management policy.

Dong Nai river basin is one of four major river basin in Central Highland in Vietnam. This region were dominated by many ethnic populations whose have low standard of living. Their income mostly comes from agricultural products including perennial tree such as coffee, rubber and pepper or annual trees which are much dependent on water resources. The role of surface and groundwater in this area is both very important. Therefore an adequate assessment of water availability for surface and groundwater is really necessary.This study aims to integrate SWAT and MODFLOW model to assess the surface and groundwater availability in Dong Nai river basin. The model accuracy was ensured through the calibration and validation process with observed data.

2. SWAT, MODFLOW and their integrated structure

2.1 SWAT model

SWAT is a physically based and semi-distributed model developed by Agricultural Research Services of United States Department of Agriculture. It is a basin scale model using to simulate: hydrology of basin, water quality, climate change, crop growth, sediment yield and impact of land management practices (Fadil et al. 2011). In SWAT the basin is divided in to sub-basin and the sub-basin are further divided into Hydrologic Response Units (HRUs) which present as units with similar land use, slope and soil type. The model calculates the water balance for each HRU base on the following equation (Eq. 1) (SWAT user manual)

$$SW_t = SW_o + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{qw})_i \quad (1)$$

Where SW_t is the final soil water content at time t (mm), SW_o is the initial soil water content (mm), R_{day} is precipitation in day i (mm), Q_{surf} is the amount of surface runoff in day i (mm), E_a is the amount of return flow in day i (mm), Q_{seep} is the amount of water entering the vadose zone from soil profile in day i (mm) và Q_{qw} is the amount of return flow in day i (mm).

Recharge to both shallow and deep aquifers is estimated

$$w_{rchrg,i} = \left(1 - exp\left[-1/\delta_{gw}\right]\right).w_{seep} + exp\left[-1/\delta_{gw}\right].w_{rchrg,i-1} \quad (2)$$

Where $w_{rchrg,i}$ is the amount of recharge entering the aquifer on day i (mm); δ_{gw} is the delay time or drainage time of the overlying geologic formations (days); w_{seep} is the total amount of water exiting the bottom of the soil profile on day *i* (mm); and $w_{rchrg,i-1}$ is the amount of recharge entering the aquifer on day *i-1* (mm).

The basic input required for SWAT simulation are topography, land use map, soil map and weather data. Figs. 1 - 2 show some important features in Dong Nai river basin. Out of the total study area, 56.5% is covered by forest, 36.2 % is covered by agriculture land and the rest is shared by other classes. The elevation ranges from 59 m to 2282 m. Fluvisols, Acrisols and Ferralsols are the major soil association of Dong Nai basin. The locations of 7 rain gauge stations including Dak Nong, Duc Xuyen, Dai Nga, Dai Ninh, Lien Khuong and Da Lat were presented in Fig. 1a. There were two water level stations in Dong Nai basin. They are Dak Nong and Thanh Binh station and will be used for calibration and validation processes.

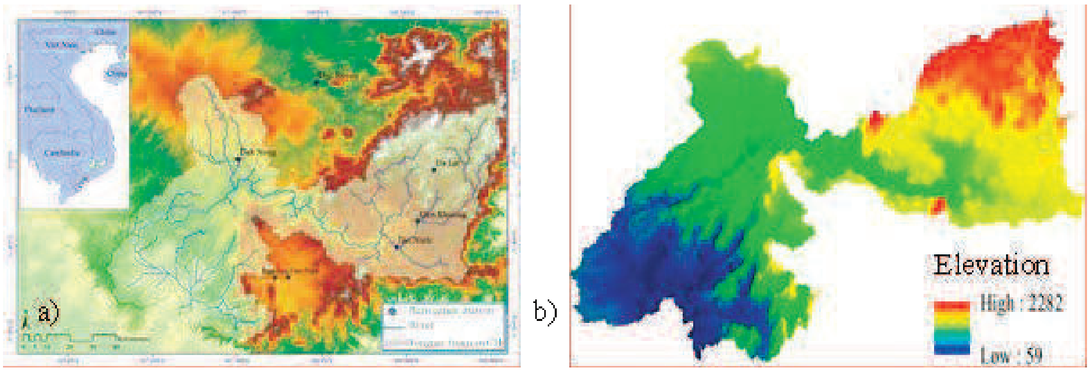

Fig. 1.a) Location and b) topography data in Dong Nai river basin

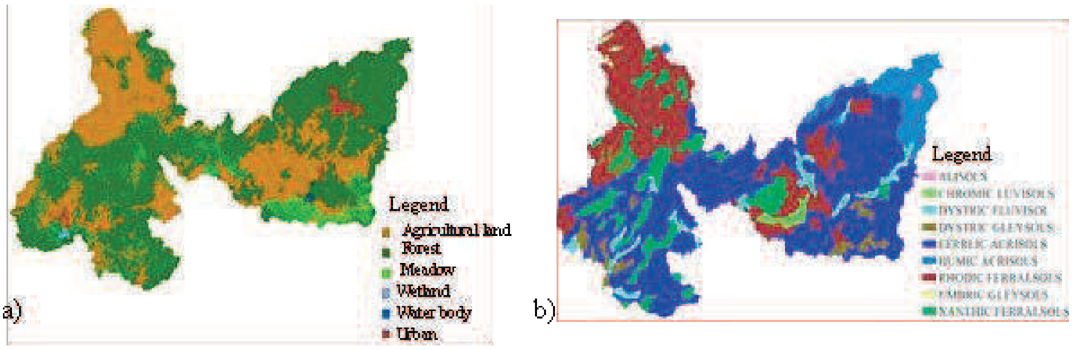

Fig. 2. a) Land-cover and b) soil data in Dong Nai river basin

2.2 MODFLOW model

MODFLOW is a three - dimensional finite-difference groundwater flow modelling program written by the United States Geological Survey (USGS). Its graphical User Interface (GUI), including Visual MODFLOW was developed by Waterloo Hydrogeologic. The model can simulate steady and non-steady flows in a saturated system, in which aquifer layers can be confined, unconfined, or a combination of confined and unconfined (Dowlatabadi et al., 2015).The model can consider all common boundary conditions including fixed pressure head, groundwater recharge, variable or constant fluxes and etc. In MODFLOW, the aquifer system is meshed by a discretized domain consisting of an array of node and associated finite difference cells (Chiang and Kinzelbach, 1998). It is governing equation is based on Darcy's law which is described by the following partial differential equation

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)-W=S_s\frac{\partial h}{\partial t} \quad (3)$$

where K_{xx}, K_{yy} and K_{zz} are the hydraulic conductivities along the x, y and z axes parallel to the major axes of hydraulic conductivities, h is the piezometric head, W is a volumetric flux per unit volume representing sources/sink of water, S_s is the specific storage of the porous medium, and t is time.The ground surface of basin has been created by using the 30 m resolution Digital Elevation Map (DEM) (Fig. 3a). The main geometric-structure and hydrogeological characteristics of the study area were based on the geological and lithological descriptions of 400 boreholes located in Central Highland areas.Their characteristics are very complex, however they can be categorized in to four main geological layers (Table 1). The grid size of the model is 1 km x 1 km (Fig. 3b) and the boundary condition are river network, recharge rate and pumping wells.

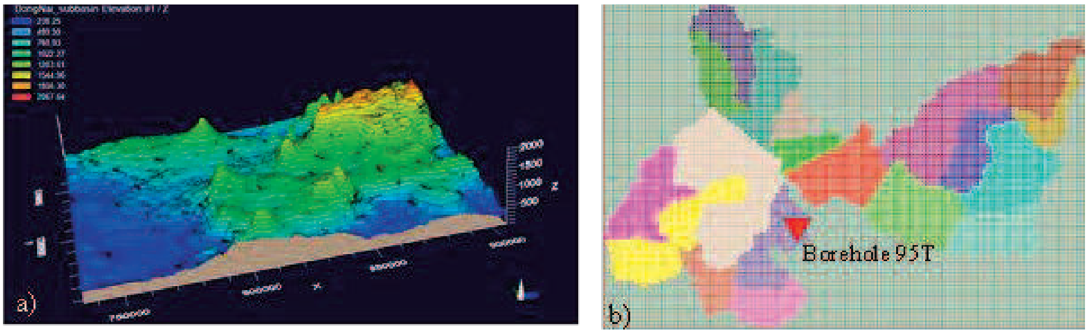

Fig. 3. Three dimensional visualization of model

Table 1. Geometric-structure and hydrogeological characteristics of basin

Layer in model/ Geological type	Lithological description	Average Thickness (m)	Hydraulic Conductivity (K, cm/s)		Storage (S)			
			Range of *K* (cm/s)	Average *K* (cm/s)	Specific Yield: S_y (-)	Specific Storage Coefficient: *Ss* (1/m)	Effective porosity (-)	Total porosity (-)
Layer1: Quaternary (Q)	Alluvium sand, silty clay, gravel	5 ÷ 10	2.3E-05 ÷ 1.8E-02	1.90E-03	9.30E-02	1.00E-05	7.50E-02	9.40E-02
Layer 2: Neogen (N)	Sandstone, gravestone, agrilitxe with peat, diatomite and tholeit basalt	50	3.0E-05 ÷ 1.5E-02	2.10E-03	8.80E-02	1.00E-05	7.10E-02	8.90E-02
Layer 3: Basalt Pleistocene (Q_{II})	Weathering basalt and porous basalt with tuff	70	1.2E-07 ÷ 6.9E-01	8.80E-03	8.80E-02	1.00E-05	7.00E-02	8.80E-02
Layer 4: Basalt Neogen-lower Pleistocene (bN_2-Q_I)	Basalt compact alternate with porous basalt	30	4.6E-05 ÷ 9.9E-03	1.70E-03	7.50E-02	1.00E-05	6.00E-02	7.60E-02

2.3 Structure of integrated SWAT and MODFLOW model

Fig. 4a shows the schematic diagram of combined surface water model (SWAT) and groundwater model (MODFLOW). The upper layers including root zone, vadose zone and shallow aquifer are belong to SWAT model, and the lower layer - deep aquifer is belong to MODFLOW model.

In this study, SWAT and MODFLOW were setup to run individually and integrated through the recharge rates. These recharge rates were firstly estimated by SWAT model and presented as groundwater recharge values in HRUs level.

In the integration process, the recharge rate of the HRU should be exchanged with cells and used as input data for MODFLOW (Fig. 4b). Due to the semi-distributed features of SWAT, spatial location of each HRU in sub-basins cannot be determined. Thus, to reflect HRU locations, one HRU is created for each sub-basin by dominant land use, soil and slope option (Dowlatabadi et al., 2015)

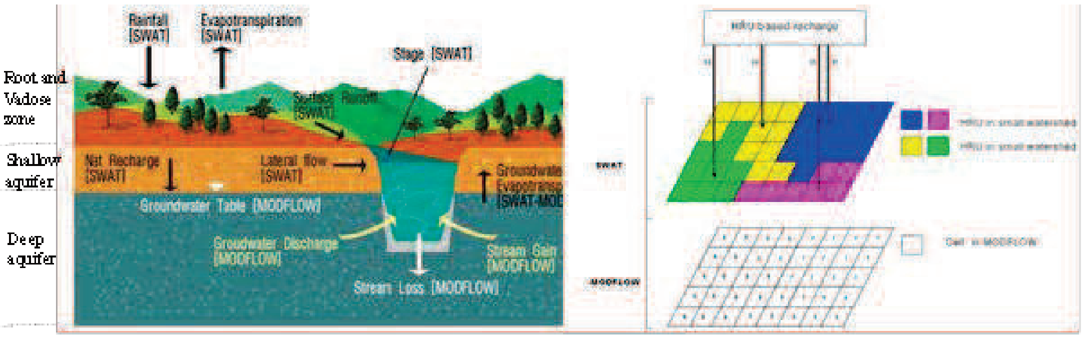

Fig. 4. Schematic diagram of a) combining SWAT and MODFLOW b) exchange recharge rate from SWAT to MODFLOW (Kim et al., 2008)

3. Results and Discussions

3.1 Surface water availability in Dong Nai river basin

Dong Nai river basin was divided into 19 sub-basins as shown in Fig.3b. Fig. 5 shows the comparison between simulated and observed monthly stream flow from 1986 to 2010 in Dak Nong and Thanh Binh stations. There were a good agreement between simulated and observed in term of graph's shape and their corresponding peaks. The NSE and R^2 coefficient in calibration process are shown in Table 2.Table 3 presents some major parameters as hydrology component of SWAT that much affect to the simulation results. The best ranges of these parameters were found through the calibration process and were used for validation step. Fig. 6 shows the validated results in 2015/2016 year in Dak Nong and Thanh Binh station, respectively. Their NSE and R2 coefficient also were presented in Table 2. According to Moriasi et al. 2007,with the value of R2 is larger 0.5 and NSE is greater than 0.75 the simulation results can be judged very well.

Table 2. Results of calibration and validation

Station	R^2		NSE	
	Calibration	Validation	Calibration	Validation
Dak Nong	0.83	0.93	0.82	0.94
Thanh Binh	0.74	0.81	0.74	0.80

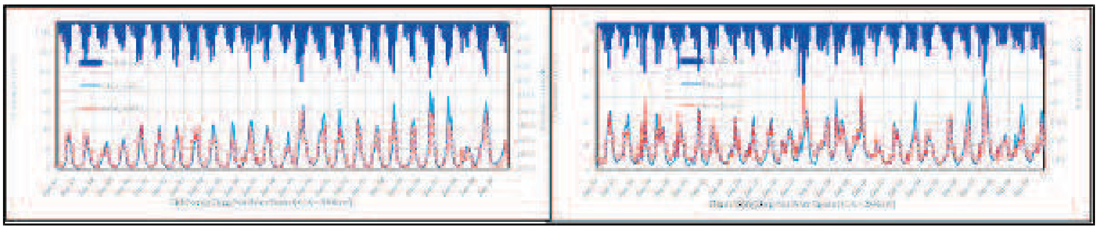

Fig. 5. Comparison between simulated and observed monthly stream flow in calibration process (1986 - 2010)

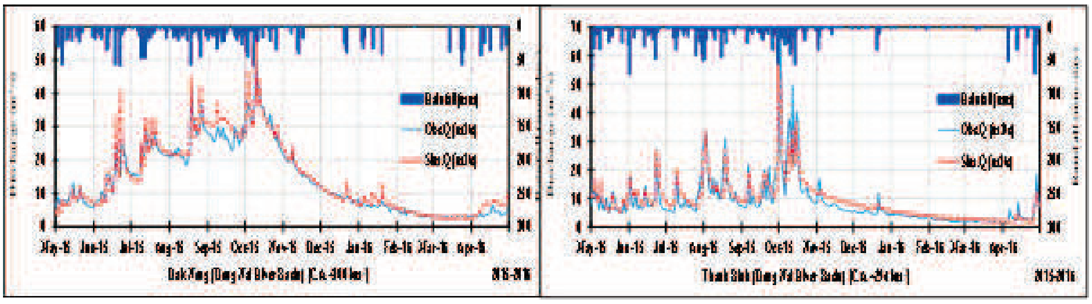

Fig. 6. Comparison between simulated and observed monthly stream flow in validation process (2015/16 year)

Table 3. Calibrated SWAT parameters, their description and best range value

No	Parameters	Definition	Range
1	ALPHA_BF	Base flow alpha factor (*days*)	0.1-0.2
2	GW_DELAY	Groundwater delay time (*days*)	31-51
3	CN2	SCS runoff curve number of moisture condition II	60-70
4	ESCO	Soil evaporation compensation factor	0.5-0.9
5	REVAPMIN (*mm*)	Threshold water depth in the shallow aquifer for revap to the deep aquifer	300-500
6	GW_REVAP	Groundwater revap coefficient	0.02-0.2
7	QWQMIN (*mm*)	Threshold water depth in shallow aquifer required for return flow to occur	600-800
8	SOL_AWC	Soil available water storage capacity(*mm H2O/mm soil*)	0.2-0.4
9	R_RCHRG	Groundwater recharge coefficient for deep aquifer	0.05-0.4
10	SOL_K	Soil conductivity (*mm/hr*)	15-50

The surface water availability in Dong Nai river basin in 2015/16 was presented in Figure 7. The areaswhich have high surface water potential are Tuyen Lam, Da Huoai and Dak Song districts in whichflow module are in the range of 40 - 50 l/s/km^2. In contrast, the Proh and Phuoc Trung communes are the locations that having lowest flow module with around 15 - 20 l/s/km^2.

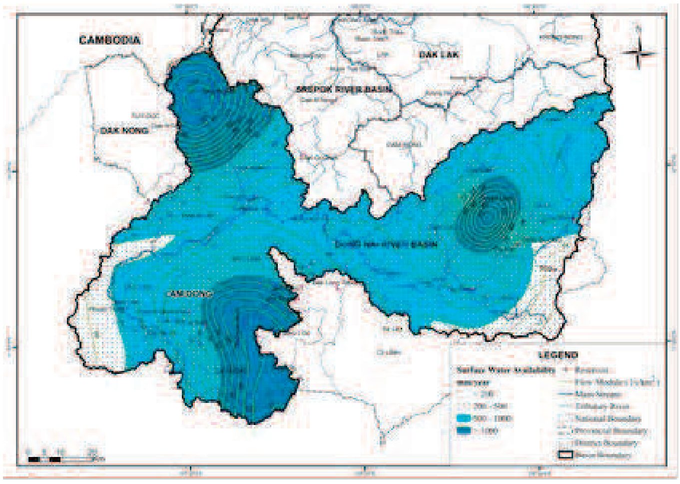

Fig. 7. Surface water availability in Dong Nai river basin in 2015/16

3.2 Groundwater availability in Dong Nai river basin

The groundwater model was setup to run in turn in 2 conditions of flow a) steady state to get the initial water head for transient state and b) transient state to get groundwater availability. The model was first calibrated to fit the observed groundwater levels until it reached to an acceptance normalized root mean square (RMS). Fig. 8 a shows the scatter diagram of calculated and observed head.The RMS was 3,062%, indicated a good simulation results.Fig. 8b shows the comparison between simulated and observed groundwater level from 2008 to 2016 in borehole 95T. The graph showed a good match between observed and simulation result in term of thegraph's shape and their corresponding peaks.

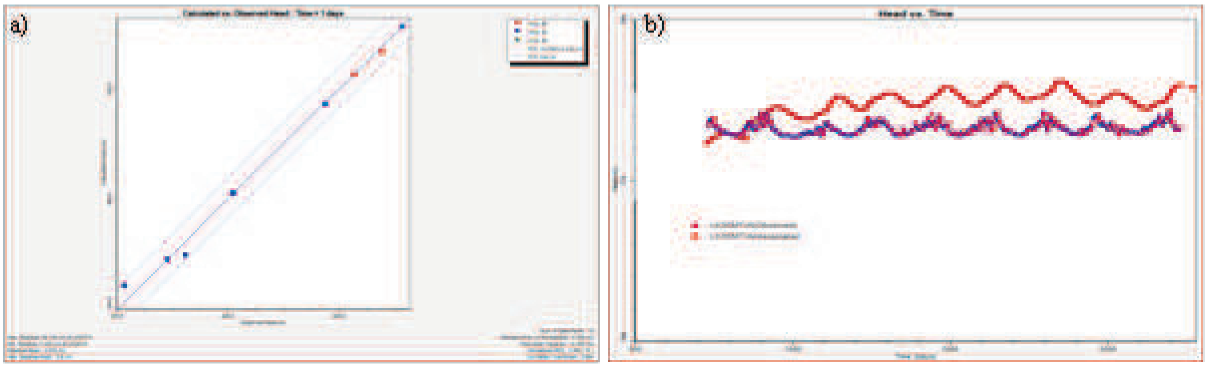

Fig. 8. Comparison between observed and simulation groundwater level in borehole 95T

Fig. 9 illustrates the groundwater level a availability in Dong Nai river basin in 2015/16. It showed that the areas having high groundwater availability locate at the same places with the areas having high surface water availability. Dak Song is the region havingthe highest groundwater availability with around 9 l/s/km^2. The other districts such as Da Huoai and Tuyen Lam also have high water potential with approximately 1.21/s/km^2.

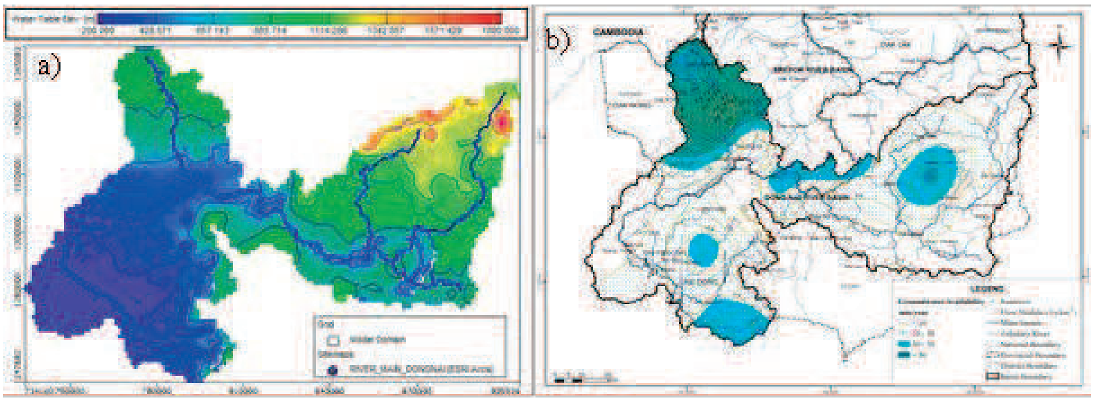

Fig. 9. Groundwater a) level and b) availability in Dong Nai river basin in 2015 - 2016

4. Conclusion

In this study, the SWAT and MODFLOW models were used for combined simulation of surface and groundwater in the DongNai basin. The SWAT and MODFLOW were run individually and linked together with recharge rates. The recharge values extracted from the HRUs of SWAT model were used in the cells of MODFLOW as the hydrological input. The simulation results including the stream flow and groundwater level of two corresponding models were then compared and showed good agreements with observed data. The results showed Tuyen Lam, Da Huoai and Dak Song districts are the locations which have high surface water potential which is in the range of 40 - 50 l/s/km^2. In contrast, the Proh and Phuoc Trung communes are the regions that having lowest surface flow module with around 15 - 20 l/s/km^2. The groundwater simulation indicated the areas having high groundwater availability are located at the same places with the regions having high surface water availability. Dak Song is the region havingthe highest groundwater availabilitywith around 9 l/s/km^2. Da Huoai and Tuyen Lam are also the areas which have high water potential with approximately 1.2l/s/km^2.

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