Assessment of the impacts of climate change on groundwater resources in Ca Mau peninsula

Dao Hong Hai, Nguyen Dinh Tu

Abstract— **A quantitative assessment of impacts of groundwater abstraction and climate change on groundwater resources in Ca Mau peninsula by using groundwater flow and transportation models is presented. Intensive and uncontrolled groundwater abstraction activities and climate change in research area caused reduction of groundwater level and saline water intrusion in aquifer system. The existing groundwater abstraction was inventoried and the aquifer system is characterized. Seasonally groundwater recharge at present and in future under different scenarios of climate change were calculated using WetSpass software. Groundwater flow and transportation models were set up to assess the impacts of groundwater abstraction and climate change on groundwater resources (the recharge outputs calculated by WetSpass software were used as inputs for these groundwater models). Results show that, due to groundwater abstraction during a period of 2000 to 2010, the groundwater level decrease at the rate of 0.33; 0.31; 1; 0.91; 0.52m/year for aquifers qp_3, $qp_{2\text{-}3}$, qp_1, n_2^2, n_2^1 and n_1^3, respectively; and since 2004, the yearly change of storage is negative meaning that groundwater resources is under depletion. Under the different scenarios of climate change, the groundwater level in all aquifers decrease at the rate from minimum of 0.016 to maximum of 0.248 m/year; the yearly change of storage of the whole Ca Mau peninsula in 2090 is negative and groundwater resources still under depletion; last but not least, the areas having salt groundwater in all aquifers increased with the rate from minimum of 17.91 to maximum of 100.65 km^2/year.**

Index Terms— **Climate change, groundwater recharge Ca Mau peninsula, saltwater intrusion.**

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1. INTRODUCTION

Climate change is one of the greatest challenges in the 21st century. The expressions of climate change, such as temperature increasing, sea level rise, ice-melting result negative effects to quantity and quality of regional water resources. While climate change impacts surface water resources directly through changes in the major long-term climate variables such as precipitation, air temperature and evapotranspiration, the relationship between the changing climate variables and groundwater is more complex and difficult to estimate.

There is significant evidence showing the change of global climate. According to the Intergovernmental Panel on Climate Change (IPCC, 2001), global mean temperatures have risen 0.3 – 0.6^{o}C since the late 19th century and the global sea levels have risen between 10 and 25cm. As a direct consequence of warmer temperatures, the hydrologic cycle will undergo significant impact with accompanying changes in the rates of precipitation and evaporation. The global temperatures will continue to rise by between 1.4 and 5.8^{o}C by 2100 relative to 1900 due to the emissions of greenhouse gases. As the warming continues, it will result numerous environmental problems.

Fresh water is such a vulnerable, valuable and finite resource. According to United Nations Development Program (UNDP), Asia is one of the most vulnerable and scarce fresh water resources areas in the world, including Vietnam. It is predicted that will be scarcer in the future because of climate change impacts. Those changes will impact to the annual amount of water flow in particular areas. Since then, it finally affects to the groundwater recharge of such areas. Groundwater recharge is affected by many complex parameters and processes, which themselves are influenced by many factors. Precipitation is affected by climatic factors such as wind and temperature, resulting in a very complex and dynamic distribution.

Groundwater is the huge sources of water for drinking and irrigation in the area where the surface water resources are not able to meet the increasing demand. This is because ground water is unexposed and slow to respond to change in precipitation regime and thus acts as a more resilient buffer against the rapid changes over the ground. Compared to surface water, groundwater use often yields larger economic benefits per unit volume, due to its availability at local level, drought reliability and good quality requiring minimal treatment [1].

The use of groundwater has particular relevance to the availability of many potable-water supplies because groundwater has a capacity to balance large swings in precipitation and associated increased demands during drought and when surface water resources reach the limits of sustainability. During extended droughts the utilization of groundwater for irrigation is expected to increase, including the intensified use of non- renewable groundwater resources, which may impact the sustainability of the resource. However, global groundwater resources may be threatened by human activities and the uncertain consequences of climate change [2].

There are more than 2 billion people depending on groundwater for their daily supply [3]. Furthermore, groundwater forms the biggest proportion (97%) of the world's fresh water amount. By maintaining surface water systems through flows into lakes and base flow to rivers, groundwater performs the important role of maintaining the biodiversity and habitats of sensitive ecosystems [4]. The role of groundwater is becoming even more prominent as the more accessible surface water resources become less reliable and increasingly exploited to support increasing populations and development. Climate change impacts may add to existing pressure on groundwater resources by impeding recharge capacities in some areas.

Climate change impacts to Vietnam are serious, a challenge to the cause of hunger eradication and poverty reduction, millennium development goals, and countries sustainable development. Most vulnerable sectors and regions to climate change are water resources, agriculture and food security, public Health, deltas and coastal areas. Due to the complexity of climate change and limitation of our knowledge in climate, both in Vietnam and in the world, together with the consideration of mentality, economy, uncertainty in greenhouse gas emission, the medium scenario is, therefore, harmonious and recommended for climate change impacts assessment and action plan development for Vietnam [5].

Groundwater provides valuable services to the Ca Mau peninsula. These include the supply of drinking water to millions and the prevention of salt water intrusion [6]. About 7.1 million people depend upon groundwater for drinking. Due to the going up of population, surface water resources will not be able to meet the demands, groundwater extraction has increased rapidly and declining groundwater levels now pose an immediate threat to drinking water supplies, farming systems, and livelihoods in the area. Furthermore, climate change might add more pressure on groundwater by affecting groundwater recharge rates and changes the availability of groundwater.

Although groundwater plays an important role, there has been quite little research conducted on groundwater comparing to surface water resources, especially in the climate change impact assessment context in Vietnam. Most of the climate change impact research concentrated on surface water [7]. It is also true in the case of Ca Mau peninsula, where there are very few studies of climate change impacts on groundwater. Therefore, investigating and modeling the temporal variance of rainfall, both of intensity and frequency, temperature and associated changes in evaporation and evapotranspiration, and the impacts these factors have on groundwater recharge and resources across different aquifer types in Ca Mau peninsula under different climate change scenarios are needed and urgent. The objectives of this study is to assess the impacts of groundwater abstraction and climate changes on groundwater resources through the change of future climate variables such as emperature, precipitation, evaporation and sea levels.

2. MATERIALS AND METHODS

2.1 *Materials*

2.1.1 *Study location*

Ca Mau peninsula in Vietnam is of 16.940 km² area, located at the Southern part of Hau river, limited by West Sea, East Sea to the South and the East, Cai San canal, to the Northwest, and Hau river in the North. Ca Mau peninsula is relative plain and low. The average elevation is from 0 – 1.0 m. In addition, there are some coastal dune which are quite high.

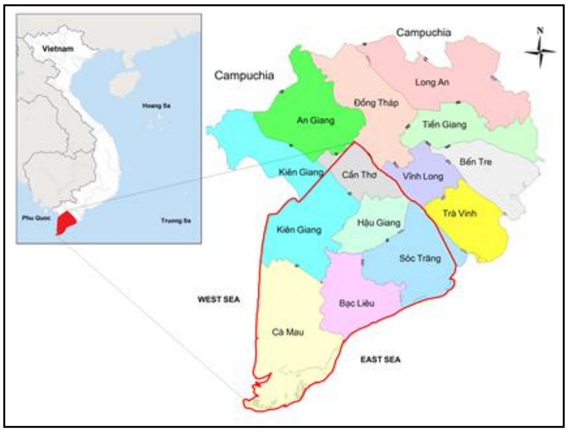


Figure 1. SEQ Figure * ARABIC. Map of Ca Mau peninsula location

2.1.2 Climate

The climate of Ca Mau peninsula (CMP) is equatorial monsoon climate and is devised in two seasons: the rainy season and dry season. The annual rainfall varies from 1,400 – 2,400 mm/year. Rain time very unevenly distributed in the year, more than 90% of the annual rainfall is in rainy season from May to November, and less than 10% of the annual rainfall is in dry season from December – April. The open pan evaporation ranges from 800 to 1,300 mm/year with the lowest evaporation in October and the highest in March. The humidity is generally high varying from 75% during the dry season to more than 90% in the wet season. The temperature varies between 24-25.5ºC in the coolest month January and 28-30ºC in the hottest month of May.

2.1.3 Hydrology

CMP river system consists of the natural river systems and the manmade canal systems. The main natural river system are Hau river system; Cai Lon and Cai Be river system. The system of manmade canals in CMP was developed primarily during the past century, with the primary purpose to develop agriculture and transportation.

2.1.4 Geology

Stratigraphy of CMP consists of intrusive, extrusive rocks and sedimentary formations of Devon to Quaternary age. They were formed indifferent tectonic phases. The intrusive and extrusive rocks act as a basement, while the sedimentary formations are the cover layers. The intrusive rocks consist of upper Trias (T_3) and upper Jura - Creta (J_3-K) formations. The extrusive rocks consist of Devon- lower Carbon (D-C_1), Permi- lower Trias (P-T_1), upper-middle Trias (T_{2-3}), and Paleogen (Eocen-Oligocen, E_{2-3}) formations. The sedimentary formations consists of middle-upper Miocen (N_1^{2-3}), upper Miocene (N_1^3), lower Pliocene (N_2^1), middle Pliocene (N_2^2), lower Pleistocene (Q_1^1), middle- upper Pleistocene (Q_1^{2-3}), upper Pleistocene (Q_1^3), lower- middle Holocene (Q_2^{1-2}), middle-upper Holocene (Q_2^{2-3}), and upper Holocene (Q_2^3) formations. Each formations is sub-divided into units that these dements have differen to rigins. Generally, each formation has been divided into two parts. The upper part is composed of a low permeable silt, clay or silty clay. A lower rather permeable part consists of fine to coarse sand, gravel, and pebble.

2.1.5 Hydrogeology

There are eight distinguished aquifers in CMP, namely Holocene (*qh*), Upper Pleistocene (qp_3), Upper- middle Pleistocene (qp_{2-3}), Lower Pleistocene (qp_1), Middle Pliocene (n_2^2), Lower Pliocene (n_2^1), Upper Miocene (n_1^3) and Upper-Middle Miocene (n_1^{2-3}) aquifers. Generally, lithology of each aquifer consists of fine to coarse sand, gravel, and pebble. The two cross sections (Fig.2) illustrated in Fig. 3 and Fig. 4 provide an overview of the spatial distribution and interconnection of aquifer system of the CMP' subsurface. Basically, the aquifer system in CMP has an artesian basin structure.

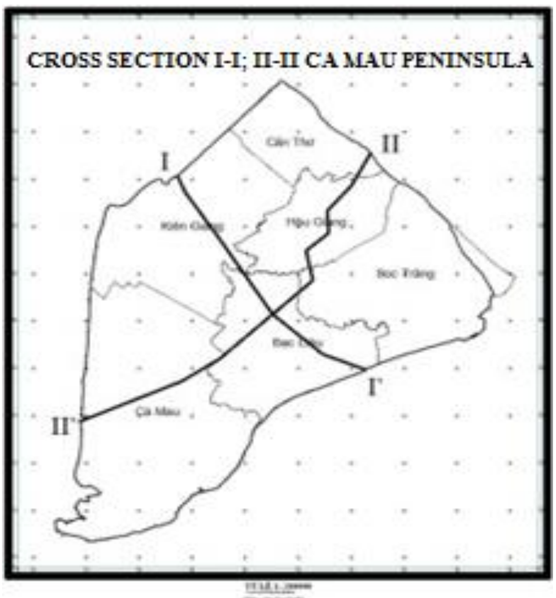


Figure 2. Cross-section layout

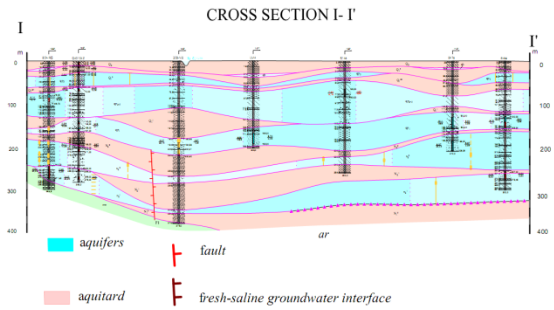


Figure 3. Hydrogeological cross-section I-I

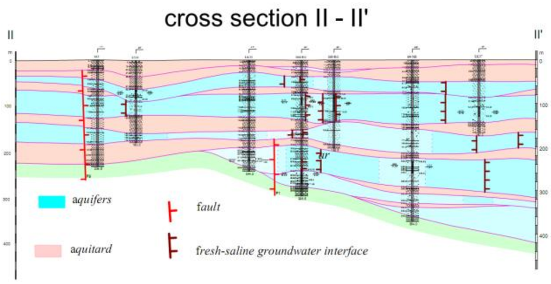


Figure 4. Hydrogeological cross-section II-II

2.1.6 Groundwater development

Recent investigation [8]shows that the amount of groundwater abstraction in CMP is about 999,895 m^3/day, of which the amount of groundwater abstraction in qp_3, qp_{2-3},qp_1, n_2^2, n_2^1, *and* $n_1^3$52,528; 650,666; 116,244; 165,210; 3,933; 11,314m^3/day, respectively. The number of abstraction wells is more than 330,998 of which, about 572 abstraction wells having a capacity of greater than 200 m^3/day.

2.1.7 Climate scenarios

According to MONRE (2012)[9], three scenarios of climate changes and sea level rise for Vietnam are summarized in the below table.

Table 1. Summary of three scenarios of climate changes and sea level rises for Vietnam

Scenario of climate	High emission, A2
Average annual temperature	- The increase in average annual temperature is from 1.1 to 1.4°C (until 2050) and from 2.5 to 3.3°C (until 2100). - In dry season: the increase in average temperature is from 0.9 to 1.4°C (until 2050); and from 1.9 to 3.3°C (until 2100). - In rainy season: the increase in average temperature is from 1.2 to 1.6 until 2050; and from 2.5 to 3.8°C until 2100.
Annual rainfall and seasonal rainfall	- Annual rainfall increases from 2.3 to 4.4% (until 2050) and from 5.2 to 10.2% (until 2100). - Dry sessional rainfall decreases from 2.4 to 8.3% (until 2050) and from 5.5 to 19.3% (until 2100); - Rainy sessional rainfall increases from 1.6 to 8.8% (until 2050) and from 3.7 to 20.2% (until 2100);
Sea level rise	- Sea level rises from 26 to 29cm until 2050, and from 78 to 95cm until 2100. - Sea level at East Sea rises from 26 to 30cm until 2050, and from 79 to 99 cm until 2100 - Sea level at West Sea rises from 28 to 32cm until 2050, and from 85 to 105 cm until 2100.

2.2 Method

2.1.8 General framework

The main objective of this study is to evaluate the impacts of groundwater abstraction and climate change on groundwater resources. These require developing a series of model such as water & soil balances and groundwater model. Firstly, the scenarios of future climate change will be generated by Simclim2013. The simulated results of SimClim are spatial maps of temperature, precipitation as well as sea levels rise by 2090. Secondly, present and future climate from the previous step together with some unchanged input maps such as land-use, topography, soil texture, slope and wind-speed are put in a hydrological model called Wetspass to simulate the present and future groundwater recharge. Finally, a calibrated groundwater model using GMS (Groundwater Modeling System) software will be set up to estimate the impacts of groundwater abstraction on groundwater resources. Then the calibrated model was used to simulate the impacts of climate change on groundwater resources under scenario A2. The required inputs of this model are future recharge from the second step and some other inputs.

Development of present and future climate scenarios

The monthly data on evaporation, temperature, rainfall at 14 meteorological stations during period of 1999-2010 and the monthly data on rainfall at 87 rainfall stations (during period of 1999-2010 were used to build 22 maps of average evaporation, 22 maps of average temperature, 22 maps of average rainfall on dry and rainy season for each year from 1999-2010. The monthly data on abosolute elevation of river stages during a period of 1999-2010 at 39 hydrological stations were used to interpolated the absolute average elevation of river stages in rainy and dry season of each year.

The scenario of future climate (high emission A2) in evaporation, temperature, rainfall and sea level generated by SimClim [7] were used to build the projected 54 maps of average evaporation, projected 54 maps of average temperature, 54 projected maps of average rainfall, 54 maps of absolute average elevation of river stages at the 39 hydrological stations and 54 maps of absolute average elevation of sea level at 30 estuary locations in rainy and dry season of each ten years from 2020-2090.

Estimation of groundwater recharge

WetSpass model (***W***ater and ***E***nergy ***T***ransfer between ***S***oil, ***P***lants and ***A***tmosphere under quasi-***S***teady ***S***tate)[10] is used for the estimation of long-term average spatial patterns of groundwater recharge, surface runoff and evapotranspiration employing physical and empirical relationships. The required inputs of WetSpass model include a combination of ArcInfo/Arcview tables (dbf files) and grid files, which are shown as below:

ArcView/ArcInfo Grid files	*Tables (dbf)*
Soil	Soil parameter
Topography	Runoff Coefficient
Slope	Land-use parameter
Land-use (dry and rainy season)	(dry and rainy season)
Temperature (dry and rainy season)	
Precipitation (dry and rainy season)	
Pan evaporation (dry and rainy season)	
Wind-speed (dry and rainy season)	
Groundwater level(dry and rainy season)	

In the period of 1999-2010, model for groundwater recharge estimation is developed by seasonally, rainy season (from June to November) and dry season for the rest months. Maps of soil texture, slope, land-use, topography and wind-speed will not be changed during the simulated period while the rest maps of precipitation, temperature and evaporation will be the maps of average evaporation, of average temperature, of average rainfall in dry and rainy season for each year of this period. The parameters in the three input tables (dbf files) will be also unchanged in order to evaluate clearly the impacts of climate variables change on groundwater recharge.

The future groundwater recharge will be simulated by 15 years period namely 2015s (2015-2030), 2030s (2030-2045), 2045s (2045-2060), 2060s (2060-2075), 2075s (2075-2090). In each period, groundwater recharge will be estimated by dry season and wet season respect to the scenario A2. Required input data for the model contains maps of land-use for two seasons, soil texture, slope, topography and wind-speed which are also unchanged like the period of 1999-2010. The input maps of temperature, precipitation and evaporation were the maps of average evaporation, of average temperature, and of average rainfall for each 15 years.

Development of a simulation model

A transient groundwater flow model was constructed to assess the impacts of groundwater abstraction to groundwater resources in CMP. The hydrogeological conceptual model consists of seven aquifers separated by seven aquitards. The aquifers and aquitards are heterogeneous and anisotropic. The hydraulic conductivities were divided into parameter zones. The vertical hydraulic conductivities were estimated as one-tenth of the horizontal hydraulic conductivities. The top aquifer is unconfined and the rest aquifers are confined aquifers. Impermeable basement of intrusive and extrusive formations were defined in the north and seashore lines in the west and east were specified head boundaries. The inflow components from the top of the aquifer included direct recharge from precipitation, river and canal leakage. The discharge components included evaporation, seepage to river, canals and abstraction.

The numerical model was constructed using the conceptual model approach (Brigham Young University Environmental Modelling Research laboratory, 2000). The model consists of 14 model layers and calibration time is 11 years from 2000 to 2010. The domain of the model has an area of 16,940km^2. The model grid consists of 134 rows and 114 columns with a uniform grid size of 1500 x 1500 m. The calibration time was divided into seasonally stress period resulting 22 stress periods. The model inputs included model layers elevations and properties, boundary conditions, recharge and discharge and initial groundwater levels. The top elevation of the top layer is land surface elevation defined by 7.779 points with the coordinates andelevations.

More than 268 borehole data were analyzed to create a scatter point file consists of top and bottom elevations of 14 model layers. Layers of 1, 3, 5, 7, 9, 11, and 13 represented for aquitards or impervious layers. Layers of 2, 4, 6, 8, 10, 12, and 14 represented for aquifers qh, qp_3, $qp_{2\text{-}3}$, qp_1, n_2^2, n_2^1 and n_1^3, respectively (Fig. 5).

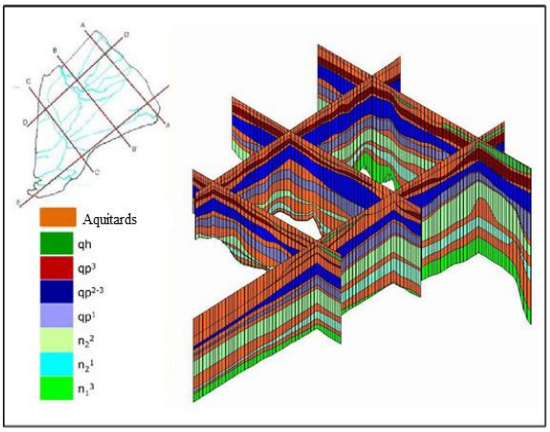


Figure 5. Aquifer system in Ca Mau peninsula

Model layer properties consisting of vertically and horizontally hydraulic conductivities, specific storage, specific yield…were calculated from the pumping data of 234 aquifer tests and assigned to parameter zones. The value of the General Head boundaries assigned for big rivers, seashore were collected from 39 hydrological stations. The inputs for the Specific Head boundaries assigned for the boundaries of aquifer qp_3, qp_{2-3}, qp_1, n_2^2, n_2^1 and n_1^3 are groundwater levels and were interpolated from measured groundwater level at 94 observation wells. The areal recharge was calculated using WetSpass model. The seasonally groundwater abstraction from each aquifer was gained from the investigation carried out in 2011.

The initial groundwater levels were the average groundwater levels in 1999 at 94 observation wells in the National Monitoring Network. The transient model was calibrated with the manually adjustment of hydraulic conductivities, specified head and specific storage values.

The calculated groundwater levels were compared with measured groundwater level in observation wells.

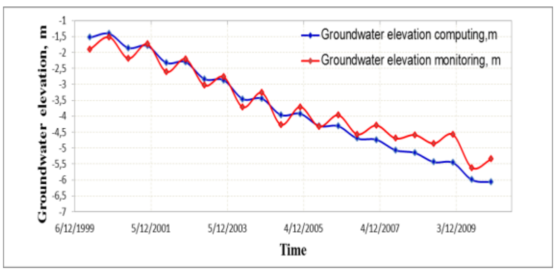


Figure 6. Computed and measured groundwater level at observation well Q40102t

There are 28 long-term groundwater level observation wells with complete observation data from 1999 to 2010; 2 in the first aquifer, 4 in the second, 7 in the third, 4 in the fourth, 5 in the fifth, 5 in the sixth, and 3 in the seventh. Fig. 6 shows an example how calculated groundwater level fitting to the observed groundwater level.

Simulation of the impacts of climate scenarios

The calibrated transient model was used to simulate the impacts of the climate scenario high CO_2 emission-A2. The simulation time was taken 75years from 2015 to 2090andis divided into12stress periods of fifteen years and six months. The calculated groundwater level at October 2010 was used as the initial conditions. The 2010 groundwater abstraction pattern and rate were kept unchanged. Six groundwater models (1 groundwater flow and 1 solute transportation models) were constructed to assess the impacts of the climate scenario A2 on groundwater resources. The groundwater flow model is used to evaluate the impacts of climate change on the quantity of groundwater resources. The indicator for assessment the impacts of climate change on the quantity of groundwater resources are the decrease in groundwater levels and depletion of groundwater storage. The solute transportation model is used to evaluate the impacts of climate change on the quality of groundwater resources. The indicator for assessment the impacts of climate change on the quality of groundwater resources is the increase of area having the total dissolved solid (TDS) greater than 1000 mg/l.

3. RESULTS

Amount of groundwater recharge

The amounts of groundwater recharge during the period of 2000-2010 calculated by WetSpass are shown in Table 2. The amount of groundwater recharge varies from 1,795,546 to 3,574,317m^3/day. The amount of groundwater recharge in the rainy season is greater than that in the dry season from twofold to sevenfold.

The amounts of groundwater recharge during the period of 2020-2100 under three different scenarios of climate calculated by WetSpass are shown in Table 3. The amount of groundwater recharge 3,543,892m^3/day for scenarios A2. In the same year, amount of groundwater recharge in rainy season is greater than that in dry season. In one scenario, amount of groundwater recharge decreases in time. The amount of groundwater recharge decreases from low to high emission scenarios in period of 2050 – 2100. The amount of groundwater recharge in period of 2020-2100 is less than that of 2010. The average reducing rates of the amount of groundwater recharge is 28,050 m^3/day for scenario A2. The trend of groundwater recharge in both dry season and rainy season are decrease.

Table 2. Amount of groundwater recharge during period of 2000 to 2010.

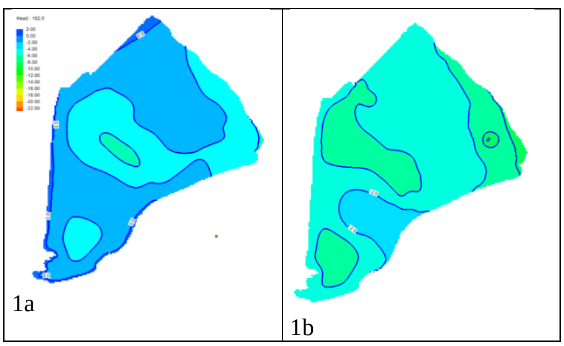
Year	Groundwater recharge, m^3/day		
	In dry season	In rainy season	For the whole year
2000	526,121	2,203,248	2,729,369
2001	390,766	1,900,306	2,291,072
2002	201,959	1,617,982	1,819,941
2003	250,905	2,470,744	2,721,649
2004	176,158	1,619,388	1,795,546
2005	225,511	2,208,206	2,433,717
2006	344,141	2,087,565	2,431,706
2007	325,899	3,248,418	3,574,317
2008	354,552	2,888,677	3,243,229
2009	317,688	2,046,693	2,364,381
2010	185,004	2,492,037	2,677,041

Table 3. Amount of groundwater recharge during period of 2015 to 2090

Year	Groundwater recharge, m^3/day Scenario A2		
	In dry season	In rainy season	For the whole year
2015	1,332,461	2,064,297	3,396,758
2030	1,370,848	2,173,044	3,543,892
2045	1,268,924	1,928,317	3,197,242
2060	1,030,559	1,349,204	2,379,763
2075	934,614	1,119,243	2,053,857
2090	760,415	711,186	1,471,601

Impacts of groundwater abstraction on groundwater resources.

The indicators for assessing the impacts of groundwater abstraction on groundwater resources are the decrease in groundwater levels and depletion of groundwater storage.



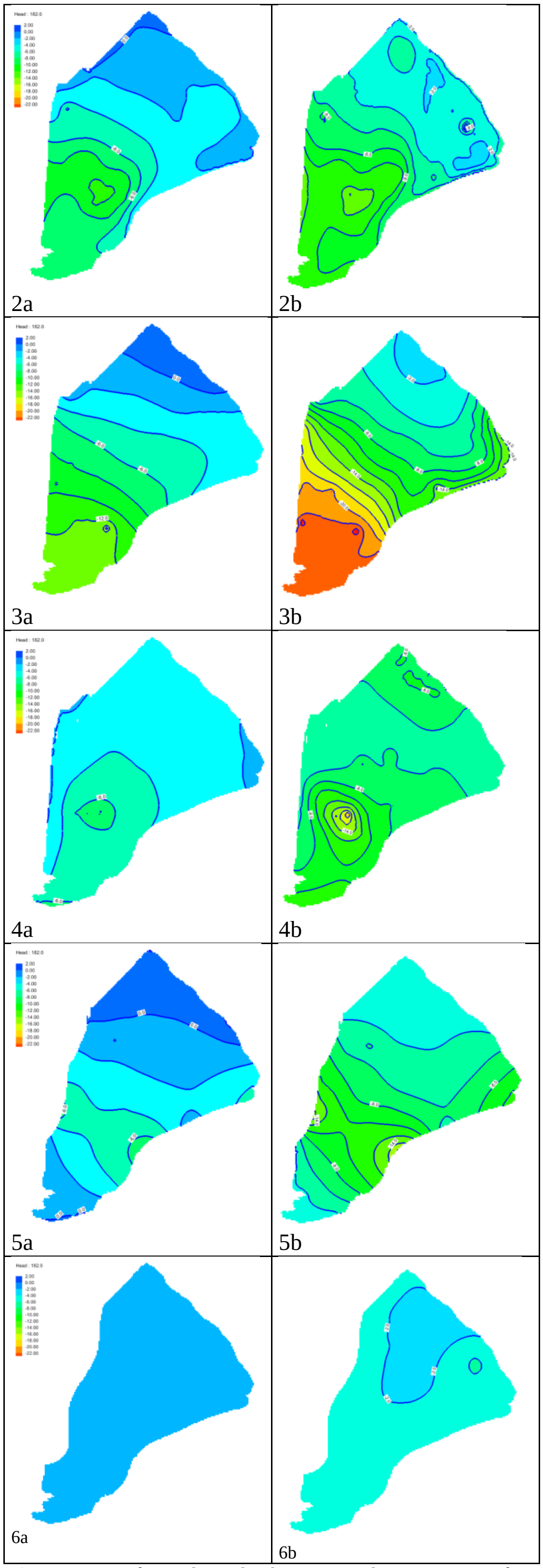


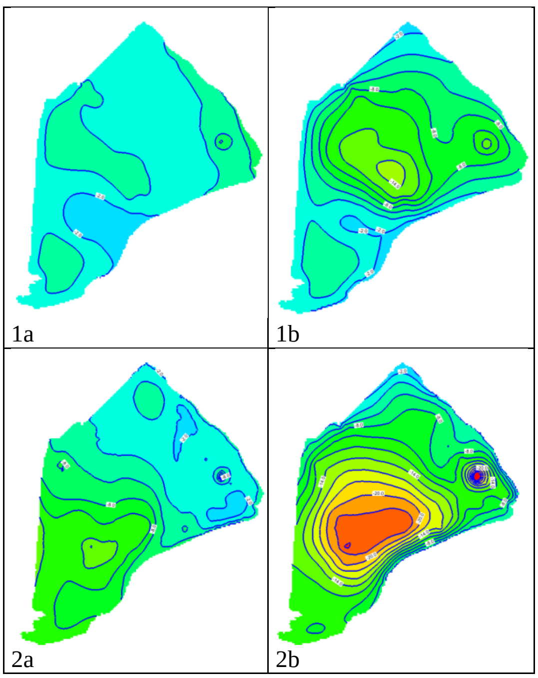
Figure 7. Maps of groundwater levels on 2000 and 2010 in sixs aquifers. The a and b stand for year 2000 and 2010, respectively; 1, 2, 3, 4, 5, and 6 stand for aquifer qp_3, $qp_{2\text{-}3}$, qp_1, n_2^2, n_2^1, and n_1^3, respectively.

Fig.7 shows the decrease in groundwater levels due to groundwater abstraction in all aquifers. It is clear that the groundwater levels decrease dramatically in all six aquifers, several cones of depressions were shaped in the maps of groundwater level in the year of 2010. The rate of groundwater level decrease at the center points of the cones of depression are 2.80, 1.76, 1.24, 1.98, 1.42 and 2.58 m/year for qp_3, qp_{2-3}, qp_1, n_2^2, n_2^1, and n_1^3, respectively.

Impacts of climate changes on groundwater resources.

The indicators for assessing the impacts of climate changes on groundwater resources are i) the decrease in groundwater levels, ii) depletion of groundwater storage and iii) the increase of area having TDS greater than 1000 mg/l.

Fig.8. shows the differences in groundwater level on 2010 and on 2100 under different climate scenarios. It is clear that the cones of depression are enlarged by 2090 in comparison with those of 2010 for scenario of climate A2. The absolute values of the differences in groundwater level between 2015 and 2090 and the rates of decrease in groundwater levels of the scenario at the center of the cones of depression for each aquifer are shown in Table 4.



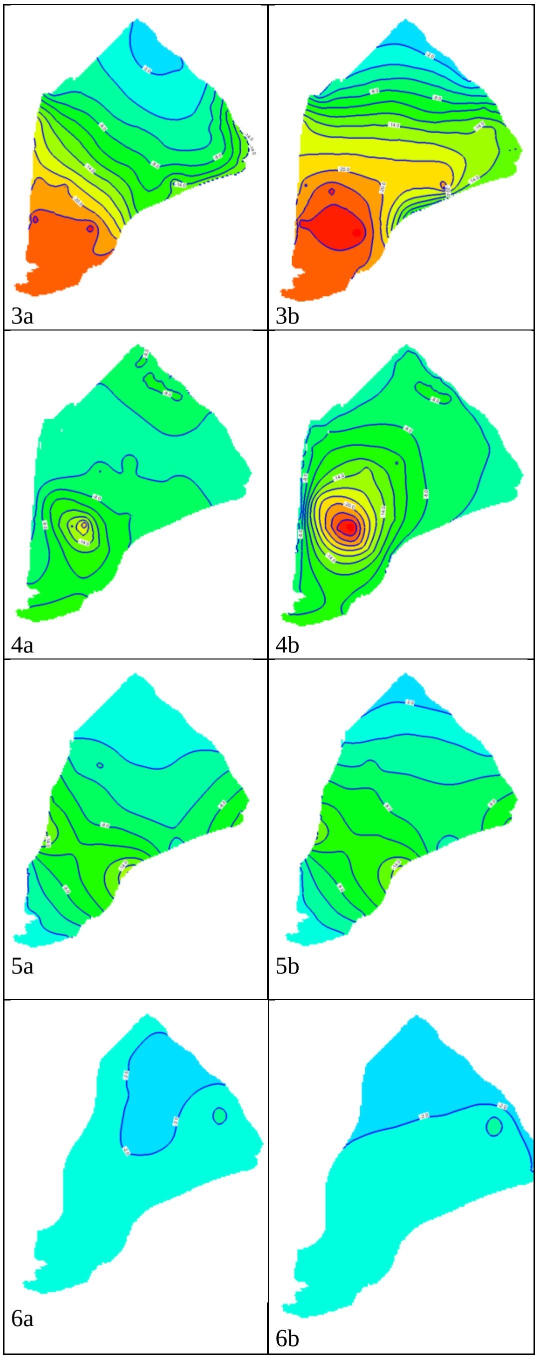


Figure 8. Maps of groundwater level on 2010 and 2090 under the climate scenario A2

The differences between groundwater levels of 2015 and 2090 and the rates of decrease in groundwater levels of aquifer qp_3, qp_{2-3}, n_2^2 and n_1^3 are increase. While these of aquifer $qp_1$and n_2^1 is on the contrary.

Table 4. Decrease in groundwater level under the climate scenario A2

Aquifer	Difference between GW levels in the year of 2015 and 2090	Average rate of decrease in groundwater level, m/year
qp_3	10.28	0.114
qp_{2-3}	17.42	0.194
qp_1	4.77	0.053
n_2^2	44.51	0.495
n_2^1	1.46	0.016
n_1^3	22.35	0.248

The yearly changes in storage of aquifer qh decreases since 2075, while the yearly changes in storage of all the rest aquifer have increase. This means that in the future, the inflow component to whole aquifer system will be less, and it takes a very long time for the aquifer system to be re-balanced status. The area having the total dissolved solid (TDS) in groundwater greater than 1000mg/l is considered to be area having.

Table 5 shows the increase and the average rate of increase in areas having saline groundwater in 2090 in comparison with that of 2015 of all aquifers. These areas increase in all aquifer, except for aquifer qh.

Table 5. Increase in area having saline groundwater in 2090 in comparison with that of 2015

qp_3	qp_{2-3}	qp_1	n_2^2	n_2^1	n_1^3
2538	7174	5818	3188	3156	3429
28.20	79.71	64.64	35.43	35.07	38.10

4. DISCUSSION

The rate of decrease in groundwater levels in periods of 2000-2010 (impacts by groundwater abstraction) is greater than that of the periods 2015-2090 are 0.114m/year; 0.194m/year; 0,061 m/year; 0.495 m/year; 0.018 m/year; 0.248 m/year. It is clear that groundwater abstraction is main reason to make groundwater elevation to decrease dramatically, and impacts of groundwater abstraction is much larger than that of climate changes. The groundwater levels and the yearly changes in storage are decreased and the yearly changes in storage is of negative values, while the areas having TDS values greater than 1000mg/l increase from low emission scenarios to high emission scenario. The reasons for that can be explained by the decrease of groundwater recharge in future under three scenarios of climate.

5. CONCLUSION

Impacts of groundwater abstraction and climate change on groundwater resources in CMP can be quantified by the groundwater flow and transportation models. Among the required inputs for these models, groundwater recharge was calculated by WetSpass package in which all the climate change variables such as rainfall, evaporation, temperature… are included. In order to improve the accuracy of the models, data for calibration and validation of WetSpass model to calculate GW recharge, data of river stages, sea level, surface water saline intrusion, flood…are needed to collect. And groundwater abstraction in future has not yet been included in all scenario simulations to assess more accuracy the impacts of both GW abstraction activities and climate change on GW resources.

The results show that, groundwater abstraction is of much more strong impacts on groundwater resources than the climate changes and in the future groundwater resources of the study area is under depletion. Therefore, the orientation for development of groundwater resources in future should concentrate to reduce the groundwater abstraction, to improve groundwater potential by means of artificial recharge and to use more surface water resources.

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Đánh giá tác động của biến đổi khí hậu đến tài nguyên nước dưới đất bán đảo Cà Mau

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Tóm tắt **-Nghiên cứu đánh giá định lượng tác động của hoạt động khai thác nước dưới đất và biến đổi khí hậu đến tài nguyên nước dưới đất khu vực bán đảo Cà Mau bằng các mô hình dòng chảy và dịch chuyển biên mặn. Việc khai thác nước dưới đất không được kiểm soát và biến đổi khí hậu trong khu vực đã làm suy giảm mực nước và diện tích phân bố mặn nhạt trong các tầng chứa nước. lượng bổ cập trong khu vực được tính toán theo kịch bản biến đổi khí hậu bằng phần mềm WetSpass. Mô hình dòng chảy nước dưới đất và dịch chuyển biên mặn được lập để đánh giá tác động của việc khai thác nước và biến đổi khí hậu đối với tài nguyên nước dưới đất. Kết quả cho thấy, do sự khai thác nước dưới đất giai đoạn 2000-2010, mực nước ngầm giảm với tỷ lệ 0,33; 0,31; 1; 0,91; 0,52 m/năm đối với tầng chứa nước qp_3, qp_{2-3}, qp_1, n_2^2, n_2^1 và n_1^3; và từ năm 2004, việc thay đổi trữ lượng hàng năm là tiêu cực có nghĩa là nguồn nước dưới đất đang cạn kiệt. Theo kịch bản biến đổi khí hậu A2 mực nước dưới đất ở tất cả các tầng nước ngầm giảm ở mức từ 0,016 xuống tối đa là 0,248 m/năm; sự thay đổi trữ lượng toàn bộ bán đảo Cà Mau vào năm 2090 là tiêu cực và nguồn nước dưới đất vẫn còn đang cạn kiệt. Diện tích phân bố nước mặn trong các tầng chứa nước tăng lần lượt là 17,91 đến tối đa là 100,65 km²/năm.**

Từ khóa **- Biến đổi khí hậu, bổ cập nước dưới đất bán đảo Cà Mau, xâm nhập mặn nước dưới đất.**