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Assessment Of Climate Change On Flood Dynamic With Deterministic Hydrological Model. Application To The Vugia-Thubon Catchment - Viet Nam

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ASSESSMENT OF CLIMATE CHANGE ON FLOOD DYNAMIC WITH DETERMINISTIC HYDROLOGICAL MODEL. APPLICATION TO THE VUGIA-THUBON CATCHMENT - VIET NAM

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ABTRACT

In recent years, Climate Change is commonly known as global warming and associated with sea level rise. Such process is one of the most serious challenges facing the human beings in the 21st century. As shown in World Bank studies, Vietnam is among the countries most heavily affected by the consequences of climate change. To get more understanding on the impact of this natural phenomenon to Vietnamese people, a methodology has been elaborated in order to assess different climate scenarios over a large catchment and flood dynamics. The simulations are based on a validated deterministic hydrological model (Mike She model - DHI) calibrating during period 1998-2004 with R, E reach to 0.9, 0.8 respectively and validating during period 2005-2011 with R, E reach to 0.86, 0.72 respectively. The change of hydrological components in the end of 21st century is estimated on the data of CCSM3.0 and MIROC-Merders GCM models under the A2 emission scenario. The simulation allows to analyze the changes in the flood dynamics and to perform the frequency and the return period analysis. The approach allows providing an operational approach for integrating the climate change within the engineering design activities dedicated to flood protection measures and resilience strategies.

KEY WORDS

Climate change, floods, deterministic hydrological modeling, Vugia Thubon catchment.

1. INTRODUCTION

Vietnam is located in the region of the south East Asia monsoon. Most of the population work in agriculture and inhabitants essentially concentrate at the coastal plain, Vietnam is among the countries most heavily affected by the consequences of climate change. According to the assessment of Vietnam government, in late 21st century, Vietnam's yearly mean temperature will increase 2-3°C, the total yearly and seasonal rainfall will increase while the rainfall in dry seasons will decrease, the sea level could rise 0.75 to 1m compared to the 1980-1999 period. About 10-12% of Vietnam's population are directly impacted and country could lose around 10% of GDP [1]. These challenges urge Vietnam to have a plan and suitable policies and

measures to improve public awareness, as well as capacity to respond to climate change. In order to estimate the impact of climate change, the assessment of variation in hydrological regime, river flow within a river basin scale is expected to provide valuable input for decision makers and also give a complete insight for communities to establish better adaptation strategies. This paper presents the long term variation of runoff in the Vugia Thubon river. The simulations are based on a validated deterministic hydrological model (Mike She model-DHI) which uses input data corresponding to a climate change at the period of 2094-2100.

2. CHALLENGES FOR VUGIA THUBON CATCHMENT

The Vugia Thubon, which originates on the eastern side of the Truong Son Mountain range and drains to the ocean near the cities of Da Nang and Hoi An, is the biggest river system of the Coastal province in the central region of Viet Nam. This system has two main rivers, the Vu Gia and Thu Bon rivers, which flow through many complex topographies: the relatively narrow mountainous area with a maximum elevation of 2600 m at Ngoc Linh Mountain which, features a large number of steep tributaries, and the flat coastal zone at the downstream, prone to annual flooding consisting of a complex interconnected coastal river system. This system is located at a tropical monsoon climate region where weather phenomena, such as rain and storm happen complicatedly. With the typical characteristic of the region, the climate pattern in Vu Gia Thu Bon basin is influenced by Truong Son Mountain with a quite high rainfall, with an average annual rainfall of 2612 mm. However, it differs in season, 65 – 80% of the annual rainfall drops during the period of September – December. Moreover, this region is annually attacked by 2-4 typhoons that bring huge rainfall and whirlwind. It makes inundation disaster happen more seriously. On the contrary, drought frequently occurs in the remaining months.

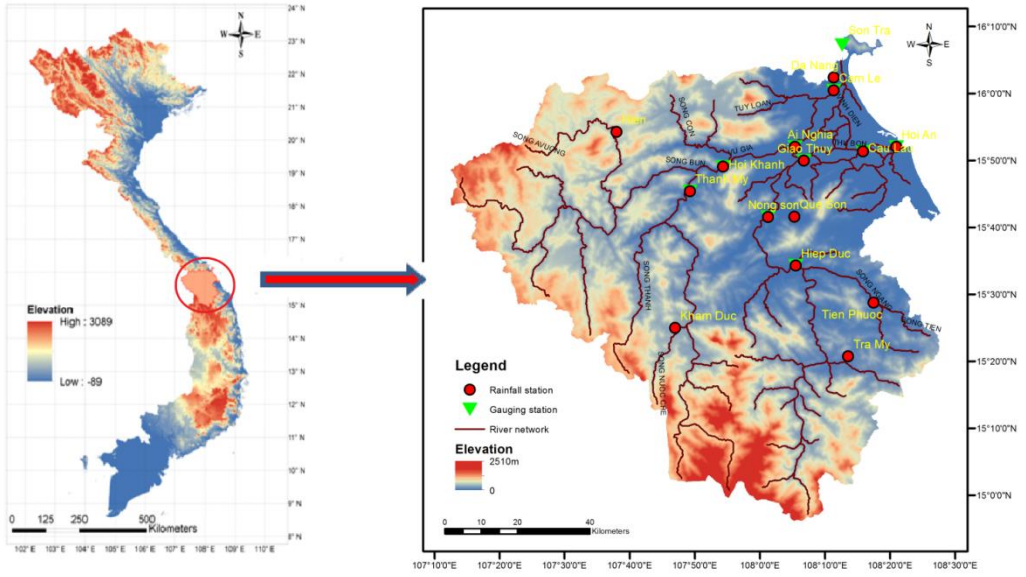

Figure 1. Vu Gia Thu Bon catchment in central Viet Nam, and hydro meteorological network.

Due to the violence of climatological events, the fragile economic condition and the underdeveloped infrastructure, the natural disasters related to river flow deeply affect the population in this region. In addition, the farming habits formed agricultural production also influence negatively on the prevention of inhabitants against natural catastrophes. Furthermore,

although local authorities have made efforts to prepare for these disasters, these works seem still insufficient. They have not yet had a complete strategy to help population avoid the catastrophic effects. Consequently, the population in central Vietnam, especially in Vugia Thubon basin, annually sustains considerable damages to people and property. The statistics from 2003 to 2007 shows that flood and storm disaster loses in Quang Nam province are estimated average up to 6.26% of the GDP (might reach to 18-20% in extreme years). [2] According to the prediction of IPCC's scenario, under the impact of global warming and sea level increase, flood and drought disaster, abnormal phenomena in Vugia Thubon basin will happen more frequently and more extremely. It makes the consequences of natural disasters to people, livelihood, social economic development are more severe.

3. METHODOLOGY

Constructing the prevention plan for natural disasters related to climate change requires accurate assessments in this domain. For the moment, most estimations about climate change at global scale, as well as at regional scale are likely base on scenarios from the Intergovernmental Committee for Climate Change (IPCC – 2007) [3]. From these climate scenarios, the challenge is to derive and generate realistic forecasts for the hydrological processes. This task is challenging and request many steps before to reach the objective which could be the flood frequency changes in order to improve design and mitigation measures. In the case of large catchments, this analysis is an essential tool for the development of master plans and for the development of a real strategy on land use and economic development. The challenge consists in creating a coherent chain of tools, with a sufficient accuracy, able to start from the data produced by the Global Circulation Models (GCM) and to generate hydrographs in the analyzed catchment for the new climate conditions. The proposed approach could be then formulated as follow:

- GCM produce data according to different climate scenarios;
- The data are transformed through downscaling methods in order to fit with the catchment size and the requested scale for hydrological analysis;
- A deterministic distributed hydrological model, validated under actual climate conditions, is then used for future climate simulation;
- The new simulated flood events are analyzed and compared with the frequencies observed for the actual conditions;
- The differences between actual and future conditions allow assessing the potential impact of climate change.

The added value of this approach is on the use of a deterministic distributed hydrological model which offers the possibility to asses in an accurate way the consequences of the future conditions. The main hypothesis, that could be easily accepted, is that the hydrological processes simulated under the actual climate will keep a similar dynamic in the future.

4. APPLICATION TO VUGIA THUBON CATCHMENT

In order to assess the variation of runoff at Vugia Thubon catchment happening in the end of this century, a deterministic hydrological model (Mike She model) has been built. The elevation data using in the model is taken from STRM DEM with the resolution 90 m of NASA (Figure 1) (http://www.cgiar-csi.org). The land use and soil data are provided by researcher of project Land Use and Climate Change Interaction in Central Viet Nam (LUCCI), and project Impacts of Climate Change in Mi-Central Viet Nam (P1-08 VIE). The input rainfall using in this model

is result of redistributing spatially observed rainfall from 15 rainfall stations in this catchment by Krigging method. The groundwater is supplied by Central Vietnam Division of Water Resources Planning and Investigation (http://www.ceviwrpi.gov.vn). The Mike11 model is established for a system with 44 branches (Figure 1). The results are compared with data from 8 gauging stations located on 2 main rivers of this catchment (Figure 1). The assessment of model is performed the correlation coefficient (R), and Nash-Sutcliffe coefficient (E).

$$R = \frac{\sum_{i=1}^{n}(X_{obs,i}-\overline{X}_{obs}).(X_{model,i}-\overline{X}_{model})}{\sqrt{\sum_{i=1}^{n}(X_{obs,i}-\overline{X}_{obs})^2.\sum_{i=1}^{n}(X_{model,i}-\overline{X}_{model})^2}} \quad (1)$$

$$E = 1-\frac{\sum_{i=1}^{n}(X_{obs,i}-X_{model,i})^2}{\sum_{i=1}^{n}(X_{obs,i}-\overline{X}_{obs})^2} \quad (2)$$

where the Xobs is observed value and Xmodel is modelled value at time/ place i.

To assess the most negative consequences of climate change towards the region, the variation of climate factors using in this study are constructed on GCMs with extreme emission scenarios (A2 scenario). The rainfall in the period of 2094-2100 is calculated based on present observation of the period of 1998-2004 using the delta change factors (Table 2). These factors obtain from downscaling processes on CCSM3.0 and MIROC-meders by colleagues in National University of Singapore. The evapo-transpiration and sea levels in future are established by climate change module of Mike Zero model [4]. These simulations take place with hypothesis that there are no changes in land use, soil map and river networks.

Table 2: Averaged rainfall delta change factors apply during the period 2094-2100.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CCSM	21.81	11.07	22.59	11.18	0.07	8.17	17.31	33.79	55.56	91.04	61.5	9.49
MIROC	-2.11	-13.01	6.77	30.09	26.43	6.37	51.36	39.92	70.59	48.23	138.99	32.55

5. RESULTS AND DISCUSSIONS

Calibration and validation

In order to estimate precisely the variation of runoff under the impact of climate change, comparisons are generally realized on hydrological model in long period, e.g 30 years [5]. Unfortunately, this data requirement is not available in Vugia-Thubon Catchment. Hence, in this study, the obtained change only relied on a Mike She model that is calibrated during the period of 1998-2004, and validated during the period of 2005-2011. The model simulates on all of available components of Mike She model, e.g overland flow, river and lake, unsaturated flow, evapotranspiration, saturated flow.

Table 3: Statistical indices of MIKE SHEmodel in Vugia Thubon catchment.

Station	Calibration(1998-2004)		Validation (2005-2011)	
	R	E	R	E
Thanh My	0.89	0.78	0.82	0.63
Nong Son	0.9	0.8	0.86	0.72

Hydrographs in Figure 4 and Figure 5 demonstrate that the model simulates relatively accurately the runoff in Vugia Thubon catchment. Simulated base flow at the two stations Nong Son and Thanh My are similar to the measurements. However, it seems that the peak of sub-main flood is not presented well. This limitation may cause by the quality of observation data. Peak floods are almost the same with observation data. Some peaks are higher than reality but the difference is not very high, it is reasonably acceptable.

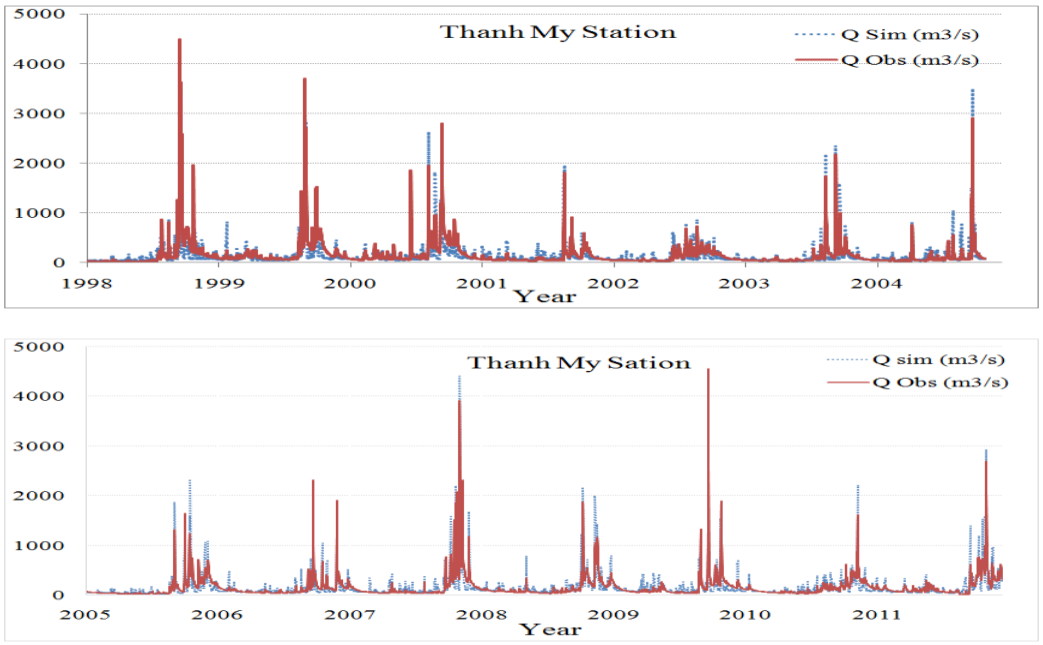

Figure 4. Calibration and validation of Mike She model at Thanh My station

The efficiency of Mike She model is also shown through the statistical coefficients in Table 3. Daily discharges are compared between simulation and observation. The R and E coefficients at Nong Son and Thanh My in the calibration period reach 0.90, 0.89 and 0.8, 0.78, respectively. In the validation period, these factors reduce, but not very low, R and E coefficients at Nong Son station is 0.86 and 0.72 and at Thanh My is 0.82 and 0.63. These results demonstrate the performance of Mike She model when simulating the hydrological process and this model is able to estimate the variability of stream flow under the impact of climate change.

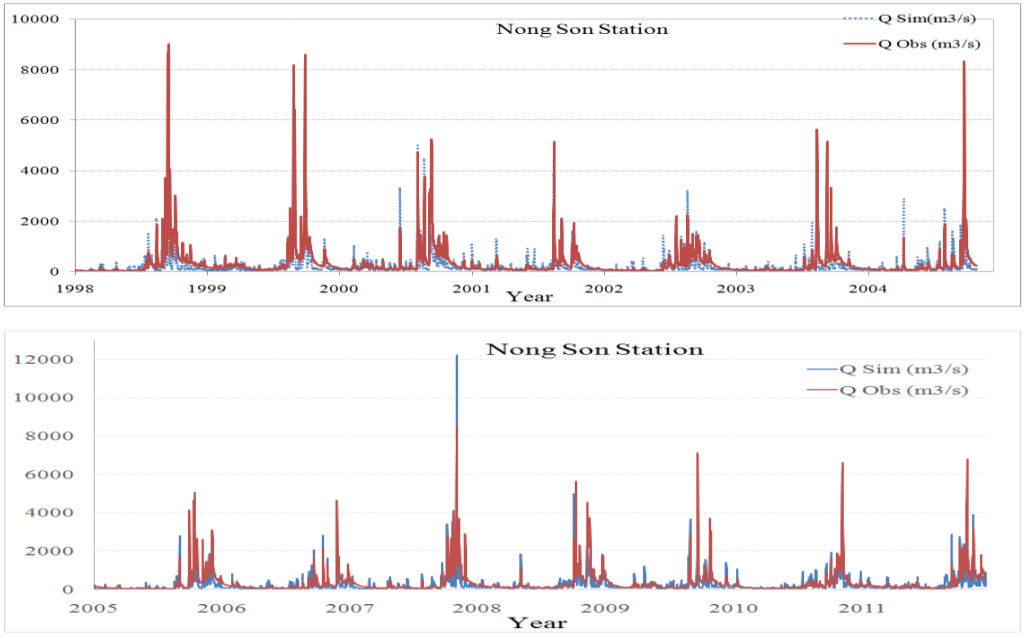

Figure 5. Calibration and validation of Mike She model at Nong Son station.

Responses of stream flow

The global warming assumes to create the increase of precipitation, sea level and impact to evapotranspiration in Vugia Thubon catchment. So it is not surprising that the flow regime in this catchment extremely vary. The results obtained from Mike She model for the end of this century indicate entirely this change. The variation of flood flow in Vugia Thubon river system is presented via the variation of flow measuring at Nong Son, Thanh My Stations (Figure 6).

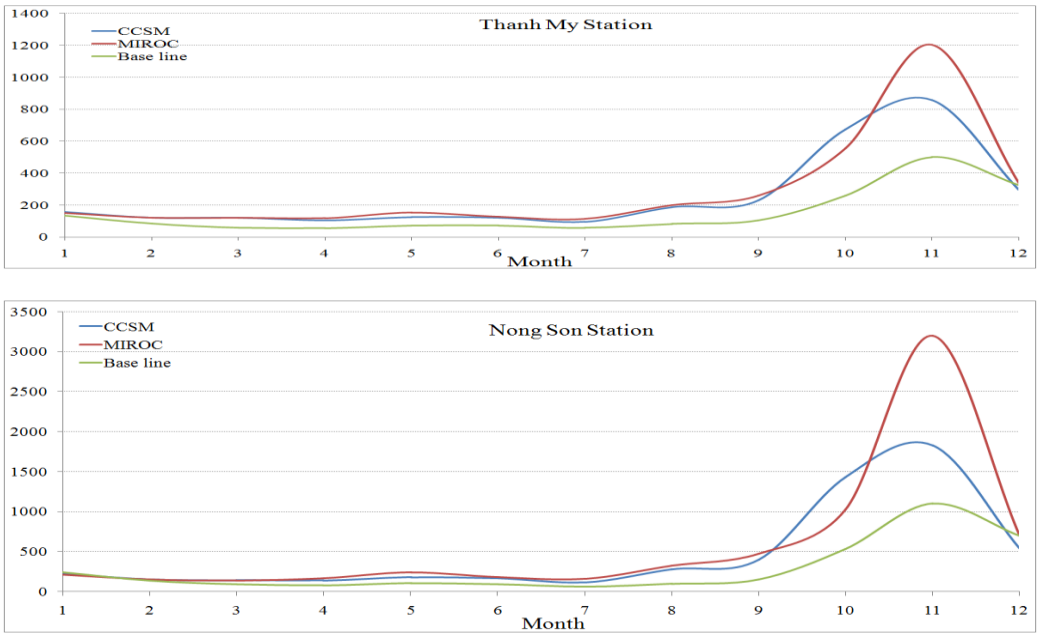

Figure 6. Baseline and future stream flow (m^3/s) at Thanh My station and Nong Son station.

According to hydrographs at two stations, it is easy to realize the considerable changes on the flow in wet season. The increase is at all months in rainy season. This tendency is similar to the conclusion of Bergstrom, et al [6] that changes in extreme values of runoff can be more critical than mean value. This result is the consequence of precipitation raise which concentrates essentially in rainfall season. Among them, the MIROC scenario drives the great variation. With this scenario, the future average monthly flow in wet season could reach 1203.4 m^3/s against the baseline 499.9 m^3/s at Thanh My (in November) and at Nong Son 3201.2 m^3/s compared with baseline 1100.9 m^3/s. The increase is equivalent with the rate 140.7 % and 190.8 % at Thanh My and Nong Son, respectively. The CCSM scenario also gives increasing trends. However, this trend is not as high as MIROC scenario. The result in November of CCSM scenario is only 856.9 m^3/s at Thanh My and 1827.5 m^3/s at Nong Son,which has an equivalent 71.4 % and 66 %, respectively. This difference indicates that MIROC scenario has a more extreme tendency than others. The numbers in Table 4 also prove the complicated and severe characteristics of flood disasters in the end of 21st sentury.

Table 4: The variation in flood frequency between the period 1998-2004 and 2094-2100.

Frequency	Return period (year)	Thanh My (m^3/s)			Nong Son (m^3/s)		
		Actual	CCSM	MIROC	Actual	CCSM	MIROC
0.95	20	4 828	10 603	12 501	11 065	23 872	37 474
0.98	50	5 713	12 598	14 888	13 936	28 378	44 846
0.99	100	6 377	14 092	16 678	14 618	31 754	50 370

Based on hydrographs in Figure 6, it is easy to recognize that the change is not only on the magnitude, but also on the time. According to that, the flow in the future obtained via MIROC output data is likely to greatly augment on November. In other months in wet season, it also increases, but not as high. Conversely, CCSM scenario brings the increase in long time, almost at whole season. The change in CCSM scenario is not very extremely like results of MIROC, but pretty equal over season.

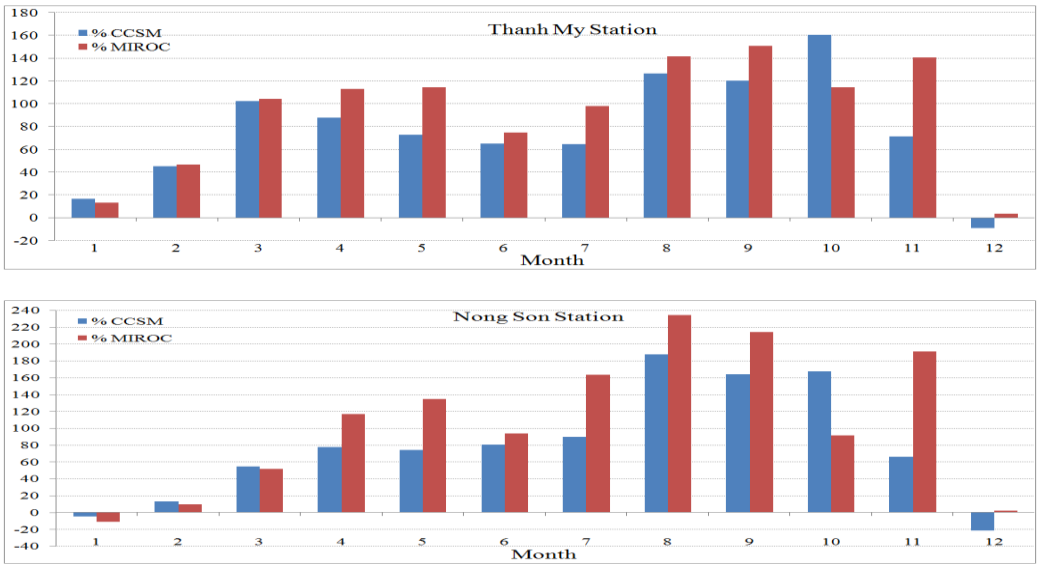

Figure 7. Percentages of future monthly stream flow in comparing with present, Thanh My station and Nong Son station.

The drought and salinity situations occur essentially complicate in this region. Especially, with pressure of high speed in social economic development and population increase, water requirement in dry season becomes more urgent. So that it is necessary to estimate the runoff in dry season for the end of 21st century for this area. Fortunately, the results of this study present that under the change of climate, the low flow in Vugia Thubon river system will almost increase. This is presented in Figure 7. According that, 6 on 8 month (from March to August) of dry season, the runoff on both main branches is predicted to highly rise. The variation is about 50-220 % with all MIROC and CCSM scenario. It leads to the mean flow in this period change from 66.49 m^3/s (baseline) to 124.89 m^3/s (CCSM), 138.82 m^3/s (MIROC) at Thanh My station and from 87.17 m^3/s (baseline) to 170.00 m^3/s (CCSM), 201.98m^3/s (MIROC) at Nong Son station. This augmentation might help to reduce the pressure for water supply, irrigation, and mitigate the salinity. In contrast, on months starting of dry season, the runoff takes reducing trends or does not change. Concretely, the drought in January, February is forecasted happening more seriously. The flow on this two months will maintain or reduce in comparison with present situation.

Hydrological shift

The variation of temporal factor in studying climate change is important. The movement of climate factors and runoff factors will affect widely to decide the harvest schedule, the kind of cultivated crops, product plan and to people activities. Vugia Thubon catchment is a large rice production with 2 main crops, Winter-Spring crop and Summer-Autumn crop which happen

annually during period December to April and May to October. Unfortunately, the results of this study demonstrate that both of these main crops will be impacted by earlier movement of runoff factors. Figure 7 show that possibly, the dry season in the end of 21st century will come earlier than present. Both runoffs at Thanh My station and Nong Son station seem to reduce in December and January. The reductions are more extremely with CCSM scenario. The average monthly runoff on December will loss 8.9% at Thanh My and 21.7% at Nong son, equivalent 29.12 m^3/s and 150.71 m^3/s respectively.

6. CONCLUSIONS

With the aim of estimating the impacts of climate change on runoff of Vugia Thubon river system, a deterministic hydrological model - Mike She model - is built. This model describes hydrological components in this catchment. It is calibrated and validated in the period of 1998-2004 and 2005-2011. The performance of model is affirmed via statistical indices. The change in precipitation, evapotranspiration taking from CCSM and MIROC models under A2 emission scenario is used to assess the variation in future. The analysis demonstrates the serious impacts of climate change with this region. The flow in the month of flood season could be increase until 200% in comparison with present. The flood happens more frequently and extremely. While the discharge on months of beginning of dry season decreases. These cause the natural disaster concerning flood and drought become more complicated. Simultaneously, the change in temporal factors is presented clearly in this region. The dry season is likely to be early. While the flood season extend and maintain longer. This study is seen like a basis for local authorities to make strategies to mitigate the impact of climate change on this area, help the population in Vugia Thubon Catchment prevent actively and adapt better with natural disasters. It also useful to water resource agencies, irrigated management, agricultural departments get an insight on this phenomena. From that they will re organize the product scheme, harvest plan, as well as suitable structure of crop plans. The research is also an evidence to confirm the quality of deterministic hydrological model, especially Mike She model in modeling hydrological phenomena as well to estimate the impact of variation of natural factor on hydrological cycle.

ACKNOWLEDGEMENTS

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