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Methodology for climate change assessment of flood dynamics using deterministic hydrological model - Application to the Vugia-Thubon catchment - Vietnam

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ABSTRACT. – 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. Under the impact of these phenomena, extreme climatic phenomena are expected to be more frequent and serious, leading to natural disasters especially related to water. Flood risk represents a major issue especially for developing countries where the economy as well as the adaptation capacity against disaster is still poor. As shown in World Bank studies, with more than 70% of the population working in agriculture, inhabitants essentially concentrate at the coastal plain, Vietnam is one of 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 which is integrating geology, soil, topography, river systems and climate variables. The validation of this model is obtained through measurements and observations made at different stations within the catchment. The actual climate in the period of 1998-2004 is properly reproduced by the model which provides a clear view about the flood processes. Future climate is obtained from downscaled GCM data that provide a scenario for 2094-2100 of hydrological variables. The new 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 model for integrating the climate change within the engineering design activities dedicated to flood protection measures and resilience strategies.

Key-words: Climate change assessment, floods, deterministic hydrological modeling, long-term simulations, Vugia Thubon catchment, Vietnam

Évaluation de l'impact de l'évolution climatique sur la dynamique des crues à l'aide d'une approche hydrologique déterministe - application au bassin de Vugia Thubon – Vietnam

RÉSUMÉ. – Depuis quelques années l'évolution climatique est au centre des préoccupations en particulier avec le processus de réchauffement et de remontée du niveau marin. Cette dynamique est l'un des plus importants défis à relever pour le 21e siècle. Sous l'effet du réchauffement, les processus extrêmes sont censés être plus intenses et plus fréquents, engendrant ainsi davantage de catastrophes naturelles. Dans ce contexte, le risque inondation constitue un enjeu majeur en particulier pour les pays en voie de développement où la situation économique reste fragile tout comme la capacité d'adaptation. Les récentes analyses de la Banque mondiale ont montré que plus de 70% de la population Vietnamienne se concentrent sur la plaine côtière qui accueille activités agricoles et développement urbain. Cet espace s'avère particulièrement vulnérable vis à vis de l'évolution climatique. Afin d'évaluer l'impact de cette évolution sur la dynamique des crues, une méthodologie originale basée sur une approche hydrologique déterministe et différents scénarios climatiques a été développée. Un modèle hydrologique déterministe distribué intègre la géologie, les sols, la topographie, le réseau hydrographique et bien sur les variables climatiques. La validation de l'approche a été réalisée à partir des données disponibles sur le bassin versant du Vugia Thubon. Le climat sur la période 1998_2004 constitue la référence actuelle et est bien reproduit par le modèle qui simule avec justesse les processus d'inondation. La prise en compte du climat futur est réalisée à partir de simulations issues de plusieurs modèles globaux (GCM) qui fournissent des scénarios pour la période 2094-2100. Les simulations hydrologiques avec ces nouvelles conditions permettent d'analyser les changements dans la dynamique des crues ainsi que dans les fréquences et périodes de retour. Cette méthode permet de produire des résultats qui sont exploitables dans le cadre d'une approche opérationnelle dédiée à élaboration de stratégies de protection et de résilience.

Mots-clés : Evaluation, changement climatique, crues, inondations, modèle hydrologique déterministe distribué, simulations long terme, bassin versant du Vugia-Thubon, Vietnam.

I. INTRODUCTION

Climate change due to increasing greenhouse gas emissions is considered to be one of the major challenges to human beings in 21st century. According to the Fourth Assessment Report of the Intergovernmental Committee for Climate Change (IPCC 2007) [Pachauri and Reisinger, 2007], the average surface temperature of the Earth is likely to increase by 1.1 to 6.4°C by the end of the 21st century, relative to 1980-1999, with a best estimate of 1.8 to 4.0°C. IPCC, (2007) also forecasts global average sea level rise of between 0.18 and 0.59 m in the period 2080 to 2099, relative to the years 1980 to 1999. It will lead to changes in precipitation, atmospheric moisture, increases in evaporation and probably raise the frequency of extreme events. These changes may strongly affect many factors on a global scale. The consequences of these phenomena will influence human society e.g the reduction of agriculture production, increase risk on animals, socio-economic damages, enhanced water conflicts, poverty, war... etc. Particularly at river deltas, coastal regions and developing countries, the impacts of climate change to socio-economic development are more serious. There is a need of having a robust and an accurate estimation of variation of natural factors due to climate change, at least in the hydrological cycle and flooding events to provide a strong basis for mitigating the impacts of climate change, and adapting to these challenges.

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 one of 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 around 0.75 to 1m compared to the 1980-1999 period. About 10-12% of Vietnam's population are directly impacted and the country's economy could lose around 10% of GDP[Vietnam government,2011]. These challenges urge Vietnam to have a plan and suitable policies which help 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 factors in the Vugia Thubon river system.The simulations are based on a validated deterministic hydrological model (Mike She model from DHI) which uses input data corresponding to a climate change at the period of 2094-2100.

II. CHALLENGES FOR VUGIA THUBON CATCHMENT

The Vu Gia Thu Bon, 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 2600m 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 2612mm. However, it differs in season, 65 – 80% of the annual rainfall drops during the period of September – December. The precipitation has shown increasing trends from north to south and from low to high elevation area. 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. Despite these complicated climate conditions, the hydrological infrastructure in the basin is still underdeveloped: the density of measuring stations is sparse, especially the rain and flow gauge stations in tributaries. Although this area covers around 10350 km^2, it has only 15 stations (Figure 1) that record rainfall data.

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. The statistical number in Table 1 express the natural damages to this area in recent years.

The study area is considered the most dynamical economic region in Vietnam central. This region has experienced active changes with an average growth rate of 10 per cent and an economic structure that is in high transformation towards industrialization and modernization [Fowler, *et al.*, 2007]. The socio-economy of the region is strongly affected by natural disasters. According to recent five years statistics from 2003 to 2007, flood and storm disaster loses in Quang Nam province are estimated average up to 6.26% of the GDP. In years with excessive rain & flood, losses can sum up to 18-20% of the GDP and severely crash human lives and property. According to the prediction of IPCC's scenario, under the impact of global warming, sea level increase, the change in hydrological cycle, flood and drought disaster, abnormal phenomena e.g phenomena El Nino and La Nina 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.

III. 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 based on scenarios from the Intergovernmental Committee for Climate Change (IPCC – 2007) [Pachauri and Reisinger, 2007]. 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 reaching 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, 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

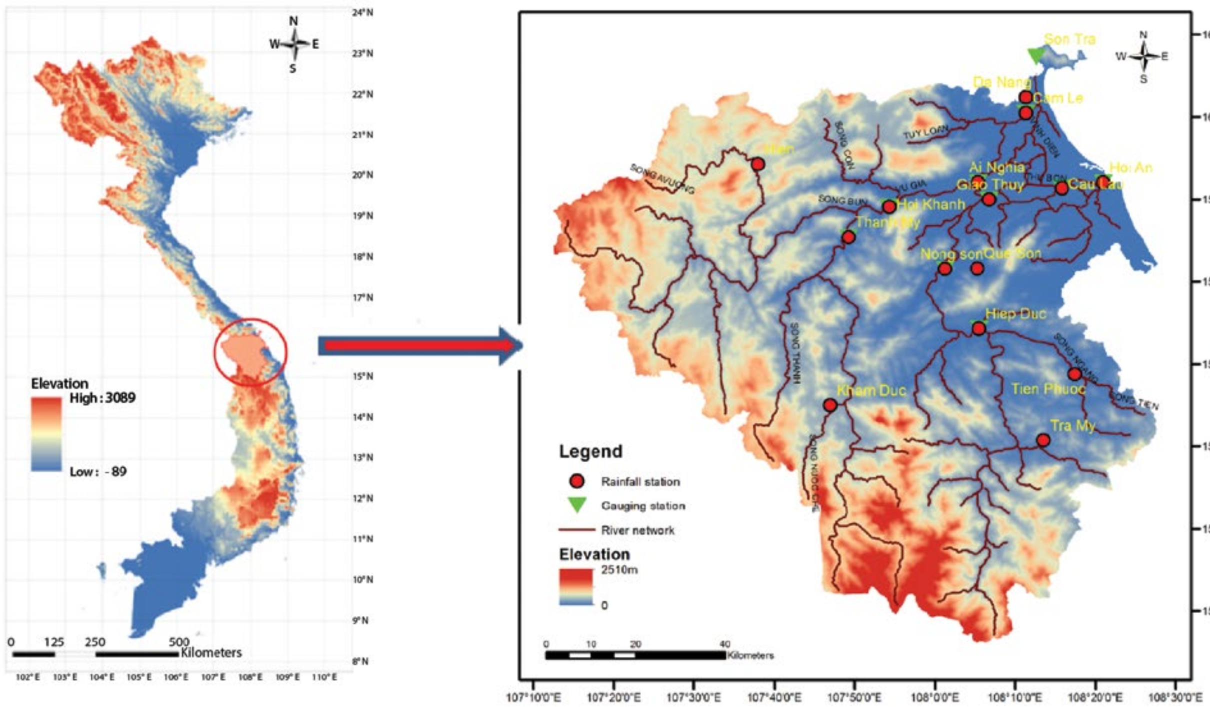

Figure 1: *Vugia Thubon catchment in central Vietnam, and hydro meteorological network.*

Table 1: Statistic of disaster damages in Central Vietnam in recent year.

Year	Dead (Persons)	Injured (Persons)	Missing (Persons)	Domicile	Class room	Hospital	Property (Million USD)
1999	737	476	56	1 043 029	6344	95	350
2004	77	53	33	228 010	635	81	349
2007	47	122	2	32 580	296	68	97.5
2009	303	1308	9	373 740	7423	158	1094

(*Source*: Flood prevention center in Vietnam central region)

generate hydrographs in the analysed 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 analysed 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.

III.1. Global Circulation Models and downscaling methods

The climate change and the response of hydrological factors to climate change have been studied since the middle of 20st century. Most assessments have been based primarily on a coupling approach between global atmospheric general circulation models (GCMs), which are designed to simulate the past and current climates. Then, they are used to predict the future state of global climate based on specific scenarios of green-house gas emission, and hydrological models. GCMs are one of the most widely used analytical tools for estimating the climate change, and this work has been attached special importance to study by research centers and international community. However, GCMs are generally operational with very coarse spatial resolution of the order of hundreds of kilometers because of the complicated characteristics and the limitation of computational capacity [Nam, *et al.*, 2012]. The data with a resolution of about 200-500km, taken from GCMs, might not be suitable to estimate the variation of hydrological factors in the future for regional impact studies. Most of the river basins on the world are smaller than typical resolution of the GCM [Raghavan, *et al.*,2014], hence climate data with large cell size could not represent accurately the happening of future phenomena. In order to overcome this restriction, Regional climate models (RCMs) have been developed. The expectation is that RCMs with the finer resolution could represent better the characteristic of climate at regional scale. The output of RCMs, which describes more accurately the local characteristics, is used as input in the hydrological model.

Downscaling is an important technique that applies regularly to convert the variations of climate change factors in future from large cell size to finer, from available scale to needed scale. Accordingly, the dependence on computational capacities and the complicated problems when calculating the change for small area is partially reduced. As a result, hydrologists could evaluate the impact for more scenarios, as well as could know more confidently the tendency of climate change in the region. A number of approaches have been utilized for this purpose. Most of the methods concentrate in two types, namely dynamical downscaling and statistical downscaling techniques. However, each method has advantages and disadvantages. Flowler, *et al.* (2007) have shown that dynamical method is used to produce regional climate models from large scale data of global climate models. Output data are typically resolved at around 0.5° (50km) latitude and longitude scales, some projects may be reached to 10-20km and parameterize physical atmospheric processes. Thus, they have abilities to more realistically describe regional climate features such as orographic precipitation, extreme events, and regional scale anomalies, or non-linear effects. In contrast, this method still remains several inconveniences concerning to computational ability, limitation in the number of scenarios available and strong dependence on GCM boundary forcing [Fowler, *et al.*, 2007]. While the empirical downscaling technique is likely to be simpler and practical for translating coarse data from GCM to small cell size applied in regional project. This method is based on the differences between the control and future GCM simulations which are applied to baseline observations for each time step. In this method, the adding value is frequently presented by delta change factor that could be derived from observational data using a statistical relationship. Its simplicity leads to cost effectiveness and applied probability for regions with non available data. However, there are also some restrictions concerning to the quality and quantity of observation data, not taking into account the change according to the seasons and regions and ignoring the change in variability [Fowler, *et al.*, 2007].

III.2. Deterministic distributed hydrological model

The main interest of a deterministic distributed hydrological model is to be able to provide hydrological data at any locations within the catchment. This possibility allows to investigate, in depth the hydrological dynamic. Several tools are today available and could be used for such analysis. The chosen model is Mike She developed and extended by DHI Water & Environment since the last decades of the 20st century. Mike She covers the major processes in hydrologic cycle and includes process models for evapotranspiration, overland flow, unsaturated flow, groundwater flow, channel flow, and their interactions. Each of these processes can be represented at different levels of spatial distribution and complexity, according to the goals of the modeling study, the availability of field data and the modeler's choices [Butts, *et al.*, 2004]. The representation of catchment characteristics and input data is provided through the discretization of the catchment horizontally into an orthogonal network of grid squares. In this way, spatial variability in parameters such as elevation, soil type (soil hydraulic parameters), land cover, precipitation and potential evapo-transpiration can be represented. Within each grid square, the vertical variations in soil and hydro geological characteristics are described in a number of horizontal layers with variable depths. Lateral flow between grid squares occurs as either overland flow or subsurface saturated zone flow. The one-dimensional Richards' equation employed for the unsaturated zone assumes that horizontal flow is negligible compared to vertical flow [Thompson, *et al.*, 2004]. Its performance has been demonstrated in past studies.

Andersen, *et al.* (2001) applied the Mike She model to simulate the hydrological process of Senegal River Basin. This model was developed on an area 375000km^2 and included all of hydrologic components. The result was relatively preventative of the characteristic of this catchment with good obtained statistical coefficients. Thomson, *et al.* (2004) used this model to simulate the hydrological system in lowland wet grassland in southeast England. These authors used Mike She coupling with Mike 11 to present the hydrologic factors in Elmley Marshes catchment. This research gave remarkable results in simulating surface flooding, groundwater and flow in the channel. The application of the coupled Mike She/Mike 11 modelling system to the Elmley Marshes has demonstrated its potential to represent complex hydrological systems found within many wetland environments. The model is likely to be preeminent to simulate hydrology in semi-arid area. [McMichael, *et al.*, 2006]

IV. APPLICATION TO VUGIA THUBON CATCHMENT

In order to assess the variation of run off 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 90m 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) (Figure 2,3). The input rainfall using in this model is the result of redistributing spatially observed rainfall from 15 rainfall stations in this catchment by Kriging method. The groundwater is supplied by Central Vietnam Division of Water Resources Planning and Investigation (http://www.ceviwrpi.gov.vn). The Mike 11 model is established for a system with 44 branches (Figure 1). There are only some observed cross sections at downstream so most cross sections using in this project were taken from DEM resolution 10m of P1-08 VIE. 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 with statistical measures of the root mean squared error (RMSE), the correlation coefficient (R), and Nash-Sutcliffe coefficient (E).

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i-1}^{n}\left(X_{obs,i} - X_{model,i}\right)^2}{n}} \qquad (1)$$

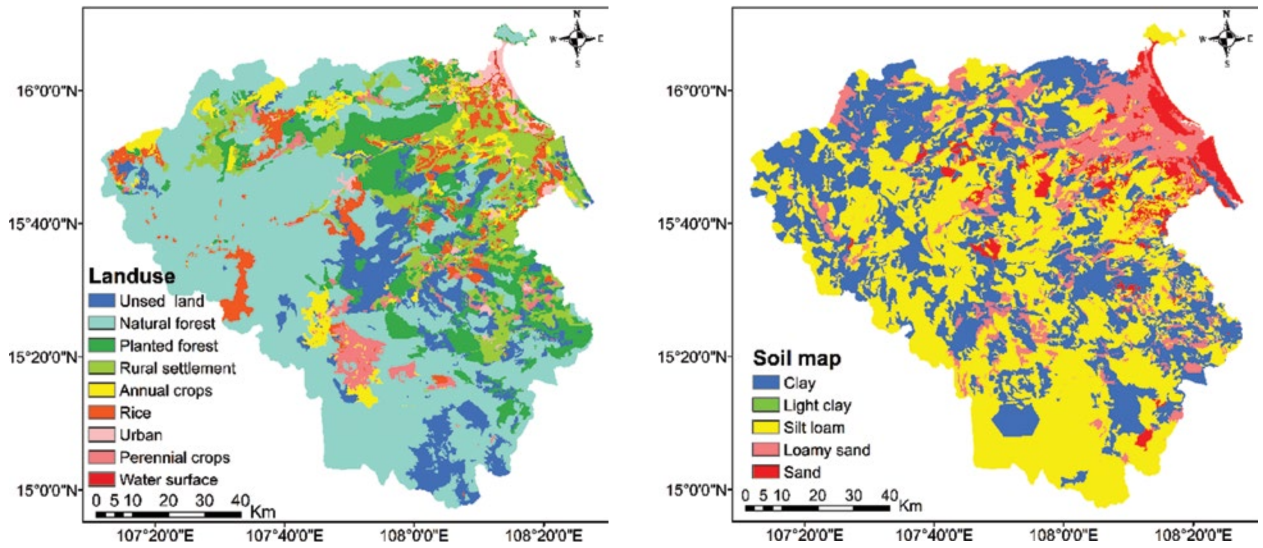

Figure 2, 3: *Land use and soil map of Vugia Thubon river basin.*

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

	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

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

$$E = 1 - \frac{\sum_{i=1}^{n}\left(X_{obs,i} - X_{model,i}\right)^2}{\sum_{i=1}^{n}\left(X_{obs,i} - \bar{X}_{obs}\right)^2} \quad (3)$$

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. Concretely, they are built under A2 scenario which assumes that a very heterogeneous world with continuously increasing global population and generally oriented economic growth that is more fragmented and slower than it other storyline [DHI, 2012]. 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.

These simulations take place with hypothesis that there are no changes in land use, soil map and river networks.

V. RESULTS AND DISCUSSIONS

V.1. 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 [Raghavan, *et al.*, 2014]. 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. This will be able to describe the most accurate hydrological cycle in Vugia Thubon catchment, as well as to reduce the uncertainty when simulating for future scenarios. The sensitivity analysis is manually carried out to determine the response of each parameter on the model. This procedure helps the calibration become more efficient.

Hydrographs in Figure 4 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. The quality of observed data may cause this limitation. In the dry season, the data is only captured once or twice per day, so it could not present concretely the hydrograph. It is really difficult to overcome the

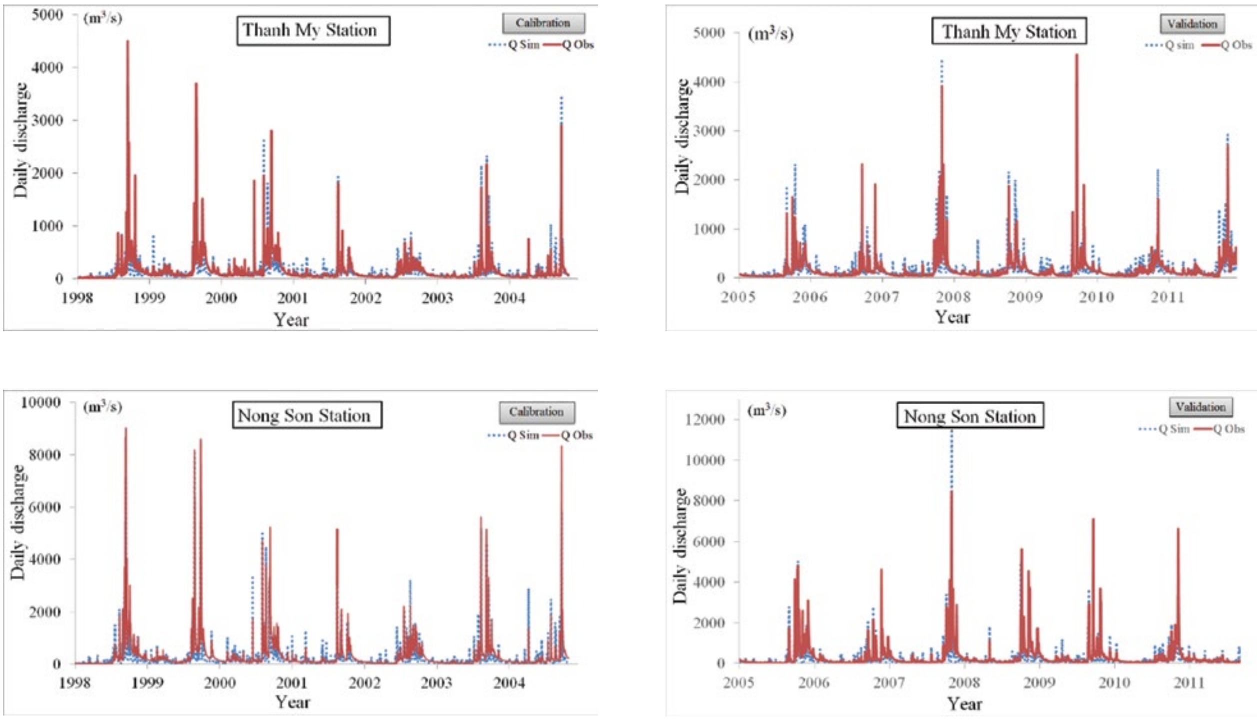

Figure 4: *Calibration and validation of Mike She model at Thanh My station and Nong Son station.*

problem concerning to the missing 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. Moreover, the higher discharge in wet season when simulating the impact of climate change might result in better protections. The validated hydrographs confirm the quality of model. Also, they present that the tendency of simulated peak discharge is higher than measurement.

The efficiency of Mike She model is also shown through the statistical coefficients in Table 3. Daily and monthly discharges are compared between simulation and observation. These numbers prove the accuracy of this model in describing the hydrological process in Vugia Thubon catchment. 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. The RMSE coefficient at Nong Son and Thanh My in the simulated period are relatively small, they are only 124.92m^3/s at Thanh My, and 317.94m^3/s at Nong Son. 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.

V.2. Responses of stream flow

The global warming assumes to create the increase of precipitation, sea level and the impact to evapotranspiration in Vugia Thubon catchment. Thus, 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.

V.2.1. Floods

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 5). 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.* (2001) 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 1203.4m^3/s against the baseline 499.9m^3/s at Thanh My (in November) and at Nong Son 3201.2m^3/s compared with baseline 1100.9m^3/s. The increase is equivalent with the rate 140.7% and 190.8% at Thanh My and Nong

Table 3: Statistical indices of Mike She model in Vugia Thubon catchment.

Station	Calibaration (1998-2004)						Validation (2005-2011)					
	Daily			Monthly			Daily			Monthly		
	RMSE	R	E	RMSE	R	E	RMSE	R	E	RMSE	R	E
Thanh My	124.9	0.89	0.78	162.9	0.93	0.83	150.2	0.82	0.63	156.80	0.95	0.89
Nong Son	317.9	0.90	0.80	411.7	0.95	0.80	341.0	0.86	0.72	425.41	0.95	0.81

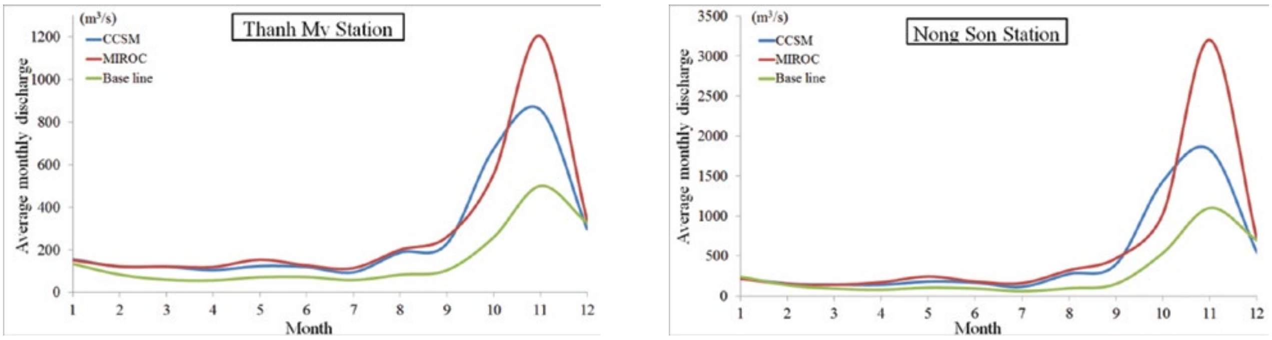

Figure 5: *Baseline and future stream flow at Thanh My station and Nong Son station.*

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 856.9m³/s at Thanh My and 1827.5m³/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.

Based on hydrographs in Figure 5, 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 of wet season, it also increases, but not as high. Conversely, CCSM scenario brings the increase in long time, almost at the whole season. The change in CCSM scenario is not very extreme like the results of MIROC, but pretty equal over season. It is helpful for strategist as well as local authority to prepare plans to response to these changes because the damage caused by flood disaster depends on both, the time and intensity of inundation. This uncertainty helps to get a global point of view to suggest the most reasonable and safe prevention against the future flood catastrophes.

V.2.2. Low flows

The drought and salinity situations occur essentially complicated in this region. Especially, with the pressure of high speed in social economic development and population increase, water requirement in dry season becomes more urgent. Currently, there have been several conflicts between localities concerning on this problem. 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 6. According that, 6 on 8 months (from March to August) of dry season, the run off 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 66.49m³/s (baseline) to 124.89m³/s (CCSM), 138.82m³/s (MIROC) at Thanh My station and from 87.17m³/s (baseline) to 170.00m³/s (CCSM), 201.98m³/s (MIROC). This augmentation might help to reduce the pressure for water supply, irrigation, and mitigate the salinity. In contrast, on starting months 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.

V.2.3. 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 the period of 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 6

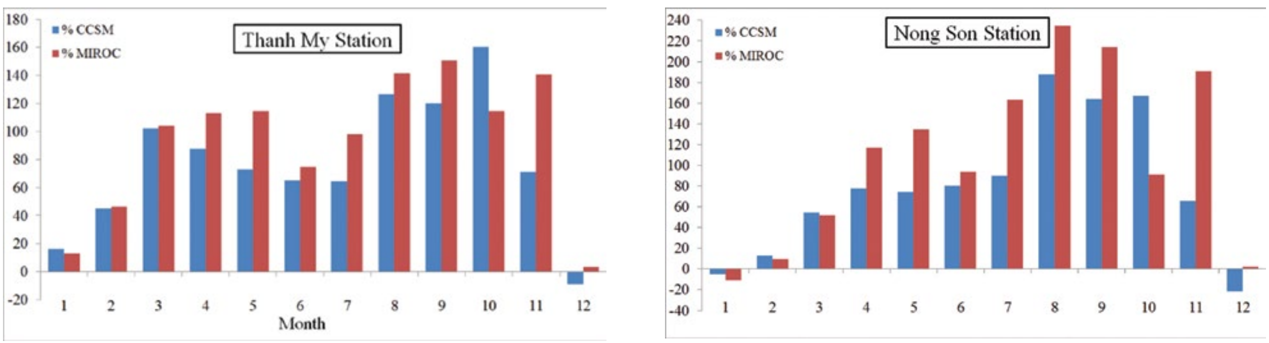

Figure 6: *Change in the percentage of future monthly stream flow in comparing with present, Thanh My station and Nong Son station.*

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shows 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 extreme with CCSM scenario. The average monthly runoff on December will loss 8.9% at Thanh My and 21.7% at Nong son, equivalent 29.12m^3/s and 150.71m^3/s respectively. This influences on the initial growth period of rice in Winter-Spring crop and affects directly on the productivity. On the contrary, the flood season have earlier coming tendency. In present, the peak flow concentrates on the end of October and November but in CCSM scenario, flood runoff moves earlier to September. The early appearance of flood brings a negative impact on harvest quantity, and rice quality.

VI. 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 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. Dry season is likely to be early while flood season extends and maintains longer.

The study also indicates the uncertainty of climate change model. In Vugia Thubon catchment, the increasing magnitude of flow discharge with MIROC scenario is higher than with CCSM scenario. The difference between two scenarios is relatively big. However, MIROC scenario only leads to vary at extreme value, particularly at main flood. The increase of CCSM scenario is not as serious as MIROC scenario, but it happens in almost all flood seasons. The research is 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.

This study is seen like a basis for local authorities to make strategies to mitigate the impact of climate change on this area as well as to help the population in Vugia Thubon Cactment prevent actively and adapt better with natural disasters. It is also useful for water resource agencies, irrigated management, agricultural departments to 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.

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