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Assessment of flood and drought in Pursat Catchment

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Abstract: *Flood and drought have always been the most frequent disaster in the world record. Cambodia, being at rank of 116 of the most vulnerable country, has suffered so much from flood and drought. That's why the main purpose of this study is to identify flood and drought characteristic. This study of flood and drought is based on CAESAR-Lisflood, a combination of CAESAR and LISFLOOD-FP. Study area of this case is Pursat Catchment. Calibration and validation are verified using NSE, RSR and Pbais.DEM of the catchment was generated from ArcSWAT and average rainfall was calculated from rain gauge in the catchment. Then, the simulated discharge was calibrated against discharge in Khum Veal station. After discharge was simulated, flow duration curve was created and analysis and inundation maps were generated. Simulated discharge show only acceptable result in calibration. Flow period changes from ending in October or November to around December or even January of the following year. Though, peak discharge increases from less than 632 m3/day to almost 900m3/day, it still occurs round October or November. Flow duration curve shows a low frequency of high magnitude flow (around 500 m3/day) and the possibility of this river never dried out is high, or in other word, low flow (around or less than 10m3/day) in Stung Pursat exists year round. In flood inundation map, the flow doesn't show a lot of differences but it changes in color which also means it changes in depth. Though, in this study, base scenario is not good enough to create climate change scenario, it also provides the basic understanding of flow in Pursat catchment. Further study should be conducted like the study of flow in water resource infrastructure condition as well as study in climate change scenario.*

Keywords: flow duration curve; flow period; flood inundation

1. INTRODUCTION

Cambodia has very diverse geography (fig.1). Though, being one of the poorest countries in Asia, Cambodia has suffered so many natural disasters, mostly flood, drought and storm. According to US credit ratings agency Standard & Poor (Phnom Penh Post, 2014), Cambodia was assigned as the highest possible overall rank of 116, the most vulnerable to climate change. Food insecurity, reduced agricultural crop yields and restricted labor forces triggered by hanging rainfall conditions, disaster recovery efforts placing increased pressure on government budgets, and civilian deaths are just some of the economic consequences Cambodia faces as global warming worsens (Phnom Penh Post 2014). In 2011, the flood disaster left Cambodia with great damages which cannot be recovered without financial donation from the Asian Development Bank and the World Bank. Though, it was disastrous, it will get worse in the future. As Cambodia is vulnerable to climate change and the fact that natural disaster is getting worse and worse, the damage that Cambodia will face is much greater than it has ever been. As bad as it can get, Pursat province, which located in northwestern Cambodia, is one of the most vulnerable areas in Cambodia. In every major disaster, Pursat has always been on the list. Moreover, Pursat is also under poverty line, which makes the province even harder to recover from any more serious catastrophes.

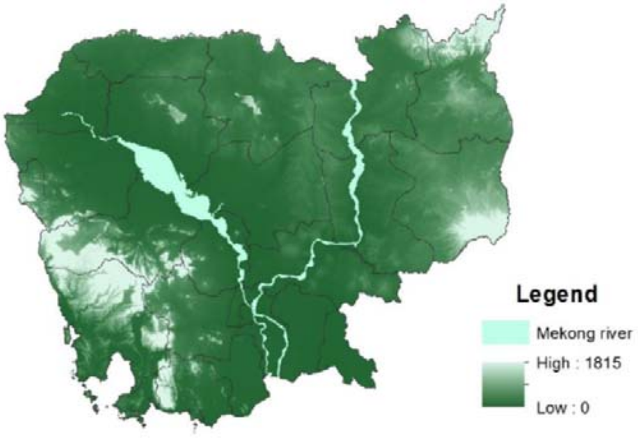

Fig.1. Map of Cambodia

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2. METHODOLOGY

2.1. *Study area*

Pursat Province of 12,692 km2, in the West of Cambodia, is one of the most vulnerable provinces in Cambodia and usually is affected by climate change disasters. The province is divided into six districts, 49 communes and 495 villages with a total population of 357,172. The Stung Pursat river catchment is located in the Pursat province, south of the Tonle Sap Great Lake, and drains an area of 5,955 km2 (Ashwell et.al, 2011). The Stung Pursat river catchment is shared by six districts: Veal Veng, Kravanh, SampovMeas, Krakor, Bakan, and Kandieng (CNMC, 2012).The river originates in the drier eastern slopes of the Cardamom mountains and flows for approximately 150 km, ultimately draining into the Tonle Sap Great Lake. Two main tributaries, the Stung Peam and Stung Santre (Prey Khong) rivers, flow in a northerly direction and meet the Pursat River just aboveBacTrakuon. The drainage area of Stung Pursat at BacTrakuon (just below the confluence of the Pursat and the two tributaries) is 4,245 km2 and drainage area at the Khum Veal gauging station (farther downstream near the town of Pursat) is 4,596 km2 (CNMC, 2012).

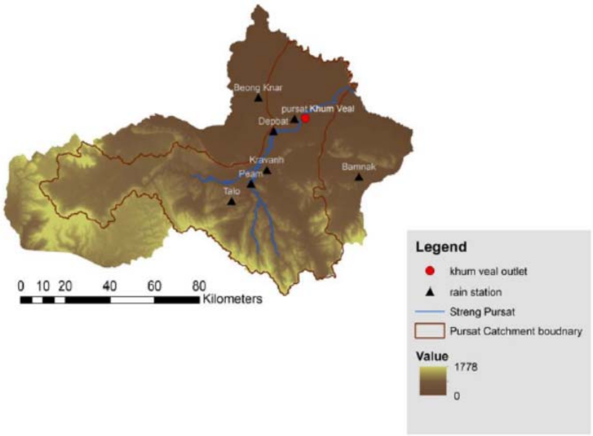


Fig.2. Map of Pursat province

2.2. *Data collection*

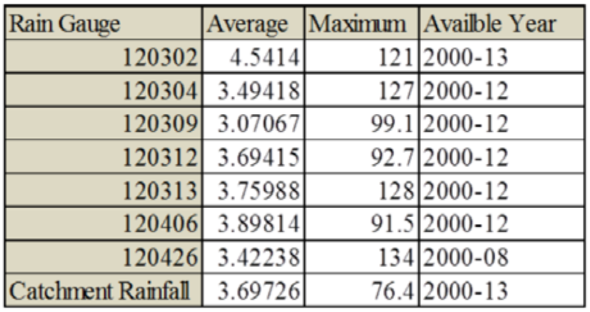
In CAESAR Lisflood catchment mood, the most important data is rainfall and watershed DEM. Watershed can be delineated using ArcSWAT and Cambodia DEM (MORAM, 2010). At least, one data set is needed. In that case, the station in Pursat town (120302), Dap Bat (120304), Talo (120309), Kravanh (120312), Peam (120313), Bamnak(120406), BeoungKhnar (10426) are used to create the average rainfall in the catchment (Table 3.1). Since the discharge data is very broken, the calibration cannot be done with it. Though, the discharge can be generated using rating curve. The selected station is Khum veal, because Khum veal is located near the outlet of the catchment (fig.2.).

The Equation of Khumveal:

$$Q=11.191-11.059H+12.696\,H^2 \qquad \text{(Eq.1)}$$

Where: H = water level in the river (m)

Table 1. Rainfall in Purst catchment



Rain Gauge	Average	Maximum	Availble Year
120302	4.5414	121	2000-13
120304	3.49418	127	2000-12
120309	3.07067	99.1	2000-12
120312	3.69415	92.7	2000-12
120313	3.75988	128	2000-12
120406	3.89814	91.5	2000-12
120426	3.42238	134	2000-08
Catchment Rainfall	3.69726	76.4	2000-13

2.3. *Selected model: CAESAR-Lisflood*

CAESAR-lisflood can be run in two modes; a catchment mode, with no external fluxes or inputs aside from rainfall; and a reach mode with one or more points where water and sediment are inputted. CAESAR-Lisflood can accept any grid cell size in the DEM (though all cells must be the same size) and has been used with DEM's from 1m to 100m cells. CAESAR Lisflood uses a rainfall input to generate runoff over the drainage basin using an adaptation of TOPMODEL just like in CAESAR (Tom J. Coulthard, 2013) which is then routed using the equation from LISFLOOD-FP. The flow sweeping algorithm in CAESAR Lisflood is just like that in the LISFLOOD-FP model. By using Equation 1 to establish the discharge across all four boundaries of a cell, the cell water depth (h) is updated using Equation 2.

$$Q = \left(q - gh_{flow}\Delta t\,\frac{\Delta(h+x)}{\Delta x}\right)\Big/\left(1 + \frac{gh_{flow}\Delta t n^2|q|}{h_{flow}^{\frac{10}{3}}}\right)\Delta X \qquad \text{(Eq. 2)}$$

Where q is the flux between cells from the previous iteration (m2 /s)
G is gravitational acceleration (m/s); N is roughness coefficient ($m^{1/3}$ /s)
H is depth (m); Z is elevation (m); Hflow is the maximum depth of flow between cells
X is the grid cell width (m); T is time (s)

$$\frac{\Delta h^{i-j}}{\Delta t} = \left(Q_x^{i-1,j} - Q_x^{i,j} + Q_y^{i,j-1} - Q_y^{i,j}\right)/\Delta X^2 \qquad \text{(Eq. 3)}$$

Where I and j are cell co-ordinates

$$\Delta t_{max} = \alpha\frac{\Delta X}{\sqrt{gh}} \qquad \text{(Eq. 4)}$$

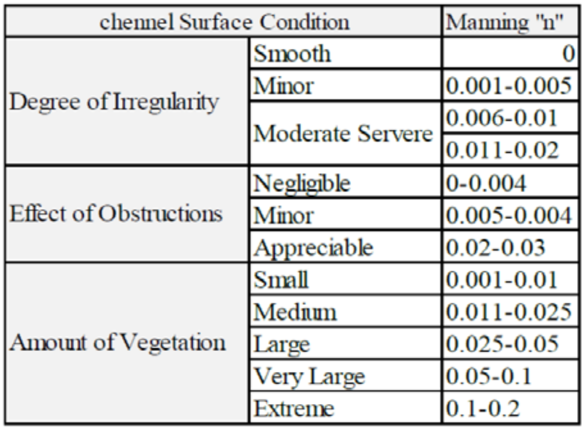
Where α is a coefficient typically defined between 0.3 and 0.7 (Bates et al, 2010).

Caesar Lisflood is a geomorphological / Landscape volution model that combines the Lisflood-FP 2d hydrodynamic flow model with the CAESAR geomorphic model to simulate rosion and deposition in river catchments and reaches over time scales from hours to 1000's of years. CAESAR is a two dimensional flow and sediment transport model. It can imulate geomorphological changes in river catchments or reaches, on a flood by flood basis, over periods up to several thousands of years. CAESAR can be run in two modes; a atchment mode, with no external fluxes or inputs aside from rainfall; and a reach mode with one or more points where water and sediment are inputted to the system.

In CAESAR, flow model uses a “flow-sweeping” algorithm, which calculates a steady state, uniform flow approximation of the flow field. Discharge is distributed to all cells within a 2-5 cell range in front of a cell according to the differences between the water surface elevation of the contributing cell and bed elevations of the receiving cells. If no suitable receiving cells can be identified in the sweep direction, for example if there is an obstruction, then the discharge remains in the contributing cell to be distributed in subsequent sweeps (possibly in different directions) during the same scan. Flow depth and velocity are calculated from these discharges using Manning’s equation.

The calculated cell flow depths and velocities are then used to calculate a shear stress that can then be used to calculate fluvial erosion and deposition. This is carried out using either the Einstein (1950) or Wilcock and Crowe (2003) sediment transport formula. CAESAR also allows up to nine different grain size classes to be modeled, and these grain sizes may be transported as bed-load or suspended load. Deposition of sediment differs between bed-load and suspended load, with bed-load being moved directly from cell to cell, whereas suspended load is dependent upon fall velocities and the concentration of sediment in suspension within a cell. The incorporation of multiple grainsized, selective erosion, transport and deposition of the different size fractions is an important feature of CAESAR, as it allows a spatially variable sediment size distribution to be modeled. Since this grain size variability is expressed vertically as well as horizontally, it requires a method of storing sub-surface sediment data. This is carried out by using a system of active layers comprising a surface active layer representing the stream bad; multiple buried layers (strata); a base layer; and, if required, an immovable bedrock layer (Van de Wiel et al., 2007). Slope processes are also modeled, with mass movement occurring when a critical slope threshold is exceeded and enable material from slopes to slop. These slope processes enable material from slopes to be fed into the fluvial system as well as the input from landslides (both large scale and small-e.g. bank collapse). By changing the flow equation, it also changes the direction of flow. In CAESAR, flow operates in 8 directions, while in LISFLOOD-FP, flow operates in 4 directions. This will allow the model to run faster in a mass conservation but it has some problems with coarse DEM. So the solution is to use high resolution DEM.

Table 2. Manning coefficient of roughness



chennel Surface Condition		Manning "n"
Degree of Irregularity	Smooth	0
	Minor	0.001-0.005
	Moderate Servere	0.006-0.01
		0.011-0.02
Effect of Obstructions	Negligible	0-0.004
	Minor	0.005-0.004
	Appreciable	0.02-0.03
Amount of Vegetation	Small	0.001-0.01
	Medium	0.011-0.025
	Large	0.025-0.05
	Very Large	0.05-0.1
	Extreme	0.1-0.2

Models were calibrated by three quantitative Statistics rather than visual comparison of simulated with observed data. This procedure was recommended by D.N. Moriasi. The three statistics that were used to evaluate the effectiveness of the model are: NSE, RSD and Pbias (D.N. Moriasi et al, 2007). And it can calculated as below:

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}(Q_i^{obs} - Q_i^{sim})^2}{\sum_{i=1}^{n}(Q_i^{obs} - Q^{mean})^2}\right] \qquad \text{(Eq. 5)}$$

$$PBAIS = \left[\frac{\sum_{i=1}^{n}\left(Q_i^{obs} - Q_i^{sim}\right) * 100}{\sum_{i=1}^{n}\left(Q_i^{obs}\right)}\right] \qquad \text{(Eq. 6)}$$

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\sqrt{\sum_{i=1}^{n}(Q_i^{obs} - Q_i^{sim})^2}}{\sqrt{\sum_{i=1}^{n}(Q_i^{obs} - Q^{mean})^2}} \qquad \text{(Eq.7)}$$

In general, stream flow model simulation can be judged as satisfactory if NSE > 0.50 and RSR ≤0.70 and PBIAS = ±25% (D.N. Moriasi et al, 2007)

2.4. Flow duration curve

The basic time unit used in preparing a flow-duration curve will greatly affect its appearance. For most studies, mean daily discharges are used. These will give a steep curve. When the mean flow over a long period is used (such as mean monthly flow), the resulting curve will be flatter due to averaging of short-term peaks with intervening smaller flows during a month. Extreme values are averaged out more and more, as the time period gets larger (e.g., for a flow duration curve based on annual flows at a long-record station).

First, start by sorting discharge from highest to lowest and assign each discharge with a rank of “R”, each discharge has one rank “R” of its own, with total of n discharge. “1” is the rank for the highest discharge. Calculate percentage of time "F" whereF=100*[R/(n+1)].

Where: F = the probability that a given flow will be equaled or exceeded (% of time)

R = the ranked position on the listing (dimensionless)

n = the number of events for period of record (dimensionless)

3. RESULTS AND DISCUSSION

3.1. Simulation discharge

The analysis of discharge generated by the model and the discharge generated by rating curve and water level is done to get the accuracy of watershed simulation. The water level is that from Khum Veal station which is the nearest to the outlet of the basin. Water level is used to calculate the discharge because of the lack of observed discharge data. Moreover, the calibration period is form 2000 to 2004. But the actual result is less than 5 years since CAESAR-Lisflood needs a few hundred days to warm up and fill in the basin. The three main criterions are verified and the parameters are Manning coefficient of roughness "n" and value "m". The correlation between the simulated and the observed discharge is not yet acceptable, even though some of the parameters are already satisfied (Table 3.). The parameter that show good result is the combination between n=0.05 and m=0.01, with NSE=0.46; Pbias=24% and RSR=0.7.

Table 3. Calibration statics

n	m	NSE	Pbais	RSR
0.05	0.005	-1.8053	-9.8258	1.67491
	0.0075	0.12039	48.5031	0.93788
	0.01	0.4677	24.0091	0.72959

m	n	NSE	Pbais	RSR
0.01	0.05	0.4677	24.0091	0.72959
	0.03	-0.0945	-14.567	1.33957

In the validation of year 2005 and year 2006, the simulated discharge and the observed seems to match up better and show better NSE. Even though, both NSE and RSR barly past the satisfied line, 0.510 and 0.69966. Though, the two seem to match (Figure 4.1.), observed discharge seem to match but the peak of simulated discharge is higher than that of observed discharge and the flow of the observed discharge started earlier and lasted longer.

Though, there is one noticeable error in this model simulation. Whenever the simulation discharge equals to 0, the observed discharge is at its lowest point, around 6 to 7 m3/s. Moreover, the possible reason for the simulation and the observation is the infrastructure. The effect of the infrastructure on the discharge is very strong, so because the study did not include the dam or any other structure that's why there are some differences.

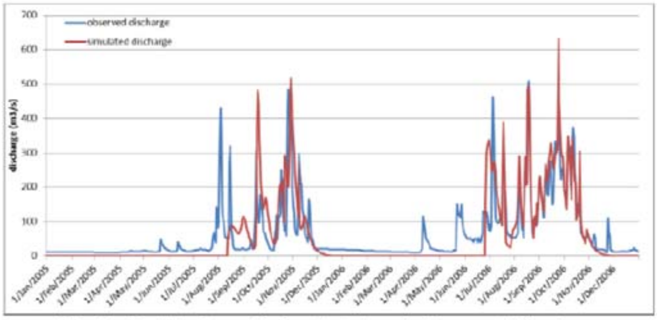


Fig.3. Validation of simulated and observed discharge

As in fig.4., simulated discharge and rainfall seem to match better in the later than in the earlier year. In year 2013, rainfall is very high so does simulated discharge. This shows that this model needs at least several years to get good correlation, but the problem calibration data and the uncertainty of effect of hydrology infrastructure in stung discharge. In the beginning of simulation (year 2000), discharge is lower than any other year, this happened because CAESAR-Lisflood needs time to warm up which results in lower discharge. Plus, there is an error in simulation, the model always generates low flow as 0 rather than generates it as permanent low flow. This shows that the possibility of exiting low flow in stung Pursat year round is high.

In the beginning of simulation, most of the flow starts in June or July, but sometimes it may delay until August. It begins with flow as low as round 40 m3/s or even as high as 322 m3/s. The start flow is very varied and the pattern is very hard to predict. Flow period is round 4-5 months long except in 2002 which has only 2 months flow period. Peak discharge, which normally occurs in September or October, is between 400 m3/s and 638 m3/s. Likewise, rainfall magnitude in the beginning is less than that in the later year (2011, 2012 and 2013). After 2006, flow starts to occur early, in April. Plus, the start flow is more predictable and higher of between 100 m3/s and 200 m3/s. Flow lasts much longer until the end of the year, sometimes even prolong till January of the following year. The peak period doesn't change much, though its magnitude increases from between 400 m^3/s and 638 m^3/s to between 700 m^3/s to nearly 900 m^3/s.

3.2. Flow duration curve

The percentage of time represents the time of which the discharge is equaled or exceeded. This also means that the "100% - F" is the percentage of time lower discharge. Figure 4.3 illustrates the FDC of simulated discharge at Khum Veal from 2000 to 2013.

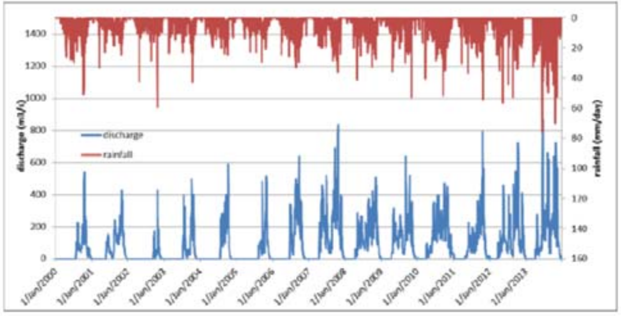


Fig.4. Simulated discharge Vs rainfall

High flow above 300 m$_3$/s has about 5% exceedence which means high flow occurs about 5% of time in 14 years. Although, very high flow (higher than 500) happen only 1% of the time. Flow below 20 m$_3$/s happens around 50% of the time. This shows that flow in this stung is very low. Though, the flow at 0 m^3/s is at about 44%, as mention in section 4.1 flow at 0 m^3/s simulation actually matches flow round 6 to 7 m^3/s in observed discharge. So, the possibility of this river has low flow year-round, despite the result (in fig.5.), is high.

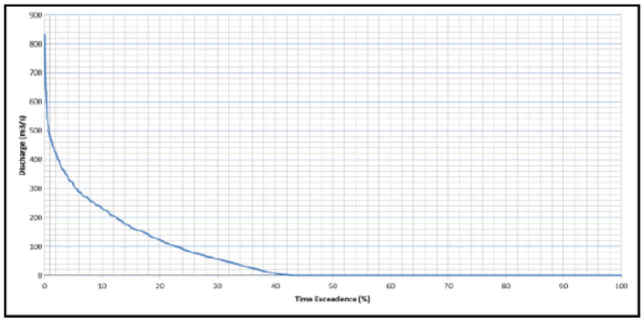


Fig.5. Flow duration curve

4. CONCLUSIONS

Considerable afford in simulating discharge in the catchment was made to predict the flood and drought. Challenge still remains as the paucity of hydro-meteorological data remaining one of the central issues that hindered the development of the applied modeling tools.

After calibration and validation, the result is acceptable though it is not good yet. Both RSR and PBIAS are acceptable but not NSE. Flow of Stung Pursat lasts around 3 to 5 month from June to October or November and the peak discharge is below 632 m$_3$/s. Though, after 2006, the flow period starts to increase by starting April and finishing around January. Moreover, peak is also higher; it can run up to almost 900 m$_3$/s. The only unchanged time is the time of when the peak happens.

High flow above 500 m$_3$/s is rare, it happen only 1 % during 14 years. In fig.4. show that 50% of time is the low below 20 m$_3$/s, though low flow might exist whole year, this shows that this river has never dried out during the study period.

In flood inundation map, water show little different if there exists low flow year round as in Pursat Catchment. Though, if the inundation maps were generated every day, it will be easier to see the differences when they are put together in a time series.

Having done the simulation of discharge in Pursat catchment, we can see that there are many data gap in discharge data as well as water data. Because of time constraint, this study cannot cover all the schematic that should be done. Though, it can be a guide for further study in the area. Some recommended studies are:

- Study about flow with infrastructure conditions
- Creating climate change scenarios
- Projection in flood and drought in both baseline and climate change scenarios
- Create assessment policies for the pre-disaster and post-disaster.

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