論文の内容の要旨

論文題目　Quantitative analysis of droughts in Southeast Asian watersheds
(東南アジア河川流域における干ばつの定量的解析)

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Drought is a regional phenomenon triggered by different climatic and environmental factors. In Southeast Asia, drought is strongly correlated with the El Nino Southern Oscillation (ENSO) phenomenon. The objectives of this study are: 1) to characterize different types of droughts at the watershed scale using WEB-DHM and the Standard Anomaly index for Southeast Asian basins; 2) to identify the effect of ENSO on drought activity in the Southeast Asian region during historically dry years; 3) to determine the effects of SRESa1b future scenario using GCM ensembles for temperature and precipitation on droughts in the selected watersheds; 4) to determine the usability of seasonal climate forecast data to reduce uncertainty in GCMs 5) to quantify the effects of drought on agriculture (crop growth, water requirement and plant stress for rice) using agricultural production data (economics) and the crop model ORYZA2000 (eco-physiological) and 6) to identify watershed management strategies to minimize the impacts of droughts in these basins.

Spatial and temporal quantification of drought resulting from the effect of ENSO were done using the standard anomaly index, a variation of the standardized precipitation index that uses best-fitted distribution patterns to monthly datasets, transforming the fitted distribution to the normal distribution and then standardizing the normalized values. Using the inputs and outputs of the Water and Energy budget distributed hydrological model (WEB-DHM), the frequency and severity of different drought types (meteorological, hydrological and agricultural) can be quantified. This is important in un-gauged or poorly gauged basins with limited data availability. In addition, although some drought types can be identified using satellite data (rainfall and soil moisture), these data have limited temporal and spatial scale (satellites were launched only recently and are still quite coarse and suitable to large scale basins with

some limited accuracy over areas with thick vegetation hence, it has little application to smaller, forested basins that are more common in the Southeast Asian region).

Past and near future Global Circulation Model (GCM) projections (for temperature and precipitation) were used to identify the impacts of climate change on drought. However, the GCM models have several limitations: 1.) coarse grid size that encompasses large areas hence, is prone to underestimations from averaging; 2.) uncertainties between the different models are large and; 3.) frequency of an event is determined probabilistically hence it is not accurate to forecast if a future event will occur on the exact date or not. To address these limitations, simple downscaling to the basin average value was done during bias correction (similar method to Ines and Hansen [2006]) of both parameters for the GCM ensembles to correct the underestimation. For rainfall frequency, only the selection of models with high spatial correlations to satellite information was used and focusing on the no rainfall days, these were determined by truncating the rainfall data at 0.01mm/day. For temperature, linear regression was used to correct past temperature with JRA25 reanalysis data.

Using GCM scenario A1B, the frequency of past hydrological droughts are expected to increase for pilot basins in the Philippines, Thailand, Indonesia but expected to mildly decrease in Malaysia. Meteorological drought was found to increase in Philippines, Thailand, and Malaysia but found to have no change for Indonesia. Most of the severe droughts occurred in the soil moisture for all the basins . For groundwater only 2 basins were considered (Philippines and Indonesia) both of which were found to have moderate increases in near-future droughts. Drought in the Philippines and Indonesia are strongly affected by ENSO hence water resource management strategies such as early warning systems can be done integrated into the ENSO monitoring systems currently in place in these basins. Unfortunately, because of the limitations of GCMs, these trends have limited applicability to watershed management strategies.

To augment these limitations and minimize uncertainty in the GCMs, seasonal climate forecast data was utilized over the Philippine river basin to determine short-term basin-scale responses during drought months. A trial run for 3 ensembles (ENS02 (3-days time lag); ENS05 (5-day time lag) and ENS08 (0 days time lag)) in 1983 drought months June to August (also critical months for agriculture) showed that drought can be forecasted (although slightly more severe than observed). For 1991 from March to May with recorded very mild drought, mild drought was simulated from the SCFs. For

1997 drought months from September to November, results were similar to 1983 simulations where drought was found to be more severe than observed droughts. For 1991, where severe La Nina occurred, it was found that both rainfall and simulated discharge from the SCFs were all overestimated. These preliminary simulations without bias correction using SCF ensembles show that although the effects of ENSO has been accounted for in the new dataset, direct use of this dataset at the basin scale for planning during drought periods will still need to be re-evaluated.

In all the basins, agricultural drought is the most severely affected hence, for this study, its effects on agricultural production and rice physiology are further analyzed using economic production data and the crop model ORYZA2000 to identify the impacts of drought on agriculture and devise appropriate non-structural adaptation strategies to address climate change. The Pampangga river basin in the Philippines was used since the basin is primarily agricultural and it is one of the main rice producing area of the country. The selected drought years 1983, 1987, 1991 and 1998 were simulated during the regular dry season cropping (second cropping: December 16 to May 15) assuming rain-fed rice production (IR72) to estimate rice production on the 2 regular cropping periods in the country. Crop stresses usually occurred during the tillering and flowering stages with the flowering stages being the most crucial since this is when panicle formation that will affect crop yield. Crop stress in 1998 was found to be most severe which corresponded to the very low economic production recorded for that year. Simulated crop yield in 1998 corresponded with recorded crop yield for that year (error=0.14%) indicating that the combined models can simulate crop physiology as affected by environmental factors.

In addition to existing watershed management practices in the different pilot basins, specific practices can be added based on the different functions and current problems of the basins as well as the different projected climate change effects on droughts in these basins. For this study, in addition to drought quantification in the Upper Citarum river basin in Indonesia, estimation of river health in terms of its population equivalent was done to determine the effects of climate change on the water quality fluctuations in the basin as this will severely affect the quality of the water that will be used in the downstream portions of the Citarum river basin. To maintain a dissolved oxygen concentration above 4mg/L, a limit of 25p.e./l/s was used assuming concentrations were similar to those measured by previous studies in 1991. Pollutant flow exceeded the limit 39% of the time for Industrial waste but did not exceed the limit for municipal waste.

Near-future GCM simulations showed a 7% decrease on the frequency that this limit was exceeded for both industrial and municipal use.

Water Management practices based on the results in this study focused mainly on preparing adequate soil moisture in both the surface and root zone since agricultural drought is projected to be intensified in the near future. In addition, proper timing using the basin-specific time delays during ENSO years can be integrated in watershed management planning (irrigation/dam release scheduling, etc). The adaptive capacity of the people can be increased by information dissemination, education and communication, proper implementation of existing water laws and proactive activities both at the local and national level. Resilience can be improved by providing both soft scale (use of drought resistant varieties/crops; supplementary irrigation; multistory cropping, terracing, use of other agricultural practices, etc.) and structural (ponding; digging of wells, impoundments; increase of reservoir capacity, etc.) adaptation strategies that will minimize the effects of drought resulting from changes in climate.