TOWARDS MANAGING DROUGHTS IN A CHANGING CLIMATE: A STUDY OF SOUTHEAST ASIAN WATERSHEDS

Patricia Ann JARANILLA-SANCHEZ, Lei WANG and Toshio KOIKE
University of Tokyo

***ABSTRACT*:** Droughts commonly occur at the regional scale but their effects trickle down to the local level. In Southeast Asia, drought is commonly overshadowed by other pressing issues. However, their effects are economically significant and occur for extended periods of time. They usually affect agriculture—the primary means of livelihood of the most vulnerable stakeholders, the farmers and local folks. The objectives of this study are: 1) to identify drought-prone areas in the pilot watersheds; 2) to identify future trends of climate change on the basins and 3) to determine an integrated drought management strategy at the basin scale to enhance adaptation to climate change in the near future. Using a distributed hydrological model (the Water and Energy Budget-Based Distributed Hydrological Model), drought quantification at the basin scale was done using available historical data from 1982-2007. Future trends were identified using SRESa1b global circulation model ensemble projections from 2046-2064 in four basins in Southeast Asia. These basins are the Pampanga river basin, Philippines; Langat watershed, Malaysia; Upper Citarum river basin, Indonesia and the Ping river basin, Thailand. Results show that historical droughts can be simulated and drought-prone areas can be identified using past data and global datasets. Three drought types were identified using the hydrological parameters in the basins: hydrological, meteorological and agricultural droughts in the future for all the four river basins but they have varying spatial and temporal effects. An integrated drought management system was proposed to minimize drought risk in identified vulnerable areas that will likely be severely affected with increasing future drought trends. From the results of the simulations, appropriate basin-specific water resources management strategies for minimizing the impacts of droughts were identified as adaptation measures to climate change. It is recommended that further studies on the selection, suitability and acceptability of adaptation measures against droughts at the pilot Southeast Asian watersheds be done in coordination with the corresponding stakeholders in the drought-prone areas.

KEYWORDS: droughts, global circulation model, distributed hydrological model

1. INTRODUCTION

Droughts in Southeast Asia are oftentimes overshadowed by other key issues such as poverty alleviation, floods, typhoons, earthquakes and the likes that occur more rapidly and require immediate action from local communities and different sectors of society. Drought effects in the Southeast Asian regions often go unnoticed until its severe effects in water scarcity and economic losses are prevalent. Climate changes are regionally heterogeneous so choice of location is linked to adaptive capacity and vulnerability [Breshears, et al., 2011]. The pilot watersheds in Malaysia, Thailand, Indonesia and the

Philippines are all significant water and energy resources of adjacent capital cities. A report by the World Wildlife fund (WWF) ranked overall vulnerability of the capital cities of Indonesia (Jakarta) and the Philippines (Manila) as having one of the highest overall vulnerability scores while that of Thailand (Bangkok) and Malaysia (Kuala Lumpur) as having lower vulnerability scores. This can be attributed to high environmental exposure for Jakarta and Manila while low environmental exposure for Bangkok and Kuala Lumpur; socio-economic sensitivity of all 4 cities were high except for Kuala Lumpur while inverse adaptive capacity for both Jakarta and Manila were high and very low for Bangkok and Kuala Lumpur. These differences in vulnerability and adaptive capacity of the different pilot watersheds is an important factor in the effectivity of the integrated water resources management (IWRM) strategies developed based on the spatio-temporal effects of drought in the region as well as the projected near future drought trends on the basins.

1.1 Objectives

There are 3 main goals of the study. The first objective is to identify when and where the drought-prone areas are in the 4 pilot watersheds using historical datasets. The second objective is to identify future trends of climate change on the basins given the specific basin morphology and hydrometeorological properties. The last objective is to determine an integrated drought management strategy at the basin scale to enhance adaptation to climate change in the near future.

2. METHODOLOGY

This study utilizes the Water and Energy Budget-based Distributed Hydrological Model to account for datasets that are not readily available in poorly gauged basins as is common in the 4 pilot watersheds selected. Past simulations were used to calibrate the watersheds using historical data. From calibrated past simulation parameters, ensemble GCMs for past and future were simulated and compared using historical data for temperature, precipitation, atmospheric pressure, short wave and long wave radiation, and specific humidity.

2.1 Digital Elevation

A digital elevation model (DEM) was used to define the basin and sub-basins using the Pfafstetter system. ASTER DEM from the USGS LPDAAC was used in 1kmx 1km grid size was used. Each model grid was subdivided into a number of geometrically symmetric hillslopes calculated from finer-resolution DEM (resampled 50m x 50m grid size). This sub-grid scheme was used to simulate lateral water redistributions and to calculate runoff comprised of overland, lateral subsurface and groundwater flows. The flow routing for the river network was calculated using the kinematic wave approach.

2.2 Soil

Two different soil subdivision schemes were used to describe the land surface and hydrological processes [Wang et al., 2009a]. For the land surface processes, the three layer soil structure for the unsaturated zone is the same as in SiB2. Thickness of the soil surface (D1) is set at 5cm; the root zone depth (D1 + D2) depends on vegetation type considered by default in SiB2. The thickness of the deep soil zone (D3) changes with water table fluctuation and is equal to the length of the groundwater level minus the thickness of the root zone depth. Soil hydraulic characteristics were obtained from the Food and Agriculture Organization [FAO, 2003] global dataset with a spatial resolution of 5 arc minutes. The included data are saturated moisture content, residual soil moisture content, saturated hydraulic conductivity for soil surface and van Genuchten parameters (alpha and n) [van Genuchten, 1980].

2.3 Land use

The land use data were from the USGS global land cover (GLCC) dataset (by continent) for Eurasia (for Thailand and Malaysia) and Australia Pacific (for Indonesia and the Philippines).

2.4 LAI and FPAR

To account for the dynamic changes in plant photosynthetic activity, the leaf area index (LAI) and fraction of photosynthetically active radiation absorbed by the green vegetation canopy (FPAR) were obtained from the NOAA AVHRR PAL 16-km LAI and FPAR satellite dataset (Myneni et al., 1997) for the period 1982-2000 and MODIS for 2001-2009.

2.5 Meteorological parameters

Meteorological forcing data used in the simulations were from the Japan Meteorological Agency (JMA) Japan Reanalysis (JRA) data [Onogi et al., 2007] JRA fcst_phy2m dataset for air temperature, specific humidity, air pressure, wind speed, downward solar radiation and long wave radiation.

2.6 Rainfall

Precipitation data were from the Asian precipitation-highly resolved observational data integration towards the evaluation of water resources management (APHRODITE) data. This is a 47-year (1961-2007) gridded (0.25^o x 0.25^o) precipitation dataset for Asia, and utilizes a combination of gauge data and satellite data, the Tropical Rainfall Measuring Mission (TRMM) [Yatagai et al., 2009]. Linear interpolation to downscale the dataset into 1km x 1km grids was conducted for the hydrological simulation 1982-2007).

2.7 Discharge

Discharge for the Philippines was obtained from the National Irrigation Authority (NIA) and the National Water Resources Board (NWRB) for different discharge gauges in the basin to calibrate the model draining out to Manila Bay. For Malaysia, Thailand and Indonesia, the Asian Water Cycle Initiative (AWCI) discharge dataset was used to calibrate the basins.

Table1 the font size and type for each element

Pilot site	Latitude	Longitude
Philippines	14.75^oN to 16.5^oN	119.5^oE to 121.5^oE
Indonesia	6^oS to 8^oS	106^oE to 108^oE
Thailand	17^oN to 20^oN	98^oE to 100^oE
Malaysia	2^oN to 4^oN	100^oE to 102.5^oE

3 Data Analysis

The standard Anomaly Index [Jaranilla-Sanchez, et al., 2011] was utilized to categorize the hydrological parameters into the range of conditions to quantify agricultural, hydrological and meteorological droughts.

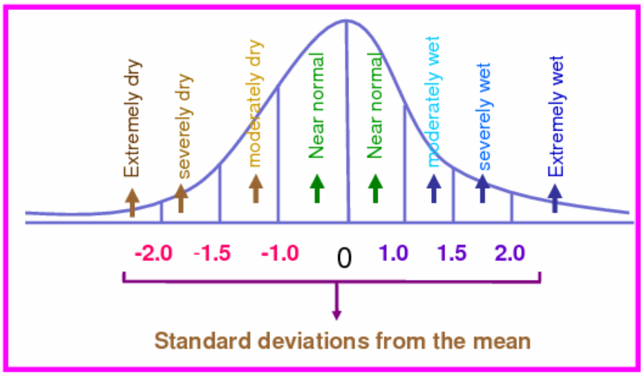

Figure 1. SA categories used to quantify droughts.

3.1 Calibration

The pilot watersheds were calibrated using historical dam inflows and discharge gauges for different time periods. The Nash-Sutcliffe model efficiency coefficient (Nash) [Nash and Sutcliffe, 1970] and relative error (RE) was used for model calibration.

These are defined in the equations below.

$$Nash = 1 - \left[\sum_{i=1}^{n} \left(Q_{oi} - Q_{si} \right)^2 \Big/ \sum_{i=1}^{n} \left(Q_{oi} - \overline{Q}_o \right)^2 \right] \qquad \text{(eq. 1)}$$

$$RE = \left[\sum_{i=1}^{n} \left(Q_{si} - Q_{oi} \right) \Big/ \sum_{i=1}^{n} Q_{oi} \right] * 100\% \qquad \text{(eq. 2)}$$

3.2 Quantification of ENSO effects

Since the Southeast Asian region is commonly affected by ENSO, its effects on the basins were statistically identified using 2-tailed student t-test on 2-year ENSO composites to determine the significant years on the hydrological parameters (rainfall, discharge, soil moistures and groundwater level) simulated by the model on each basin. Results from the t-tests determined when the average values differed significantly for SA during El Niño and La Niña years.

3.2 GCM ensemble selection and Bias correction

GCM ensemble selection was done for all suitable models with R2 above the overall average value of R2 for all the models of each parameter. Selected global circulation models are based on comparing spatial correlation values in the following areas for each of the selected pilot watersheds. The parameters considered are: precipitation, outgoing long wave radiation (OLR), sea level pressure, air temperature, geopotential height, specific humidity, zonal wind and meridional wind.

The model ensemble selection that was used for bias correction included 7 models for the Philippines (*bccr_bcm2_0, mpi_echam5, miub_echo_g, cccma_cgcm3_1_t63, cnrm_cm3, ingv_echam4 and iap_fgoals1_0_g*); 3 models for Malaysia (*cccma_cgcm3_1_t63, iap_fgoals1_0_g, ingv_echam4*); 7 models for Indonesia (*miub_echo_g, miroc3_2_medres, cnrm_cm3, iap_fgoals1_0_g, csiro_mk3_5, bccr_bcm2_0, cccma_cgcm3_1*) and 4 models for Thailand (*miub_echo_g, iap_fgoals1_0_g, cccma_cgcm3_1_t63, mpi_echam5*).

These models were used as ensemble members that were bias corrected using simple linear regression for other parameters and a modified version of the procedure by Ines and Hansen [2006] to correct both rainfall frequency and intensity.

4. RESULTS

Past drought events were quantified using the standard anomaly index for the different drought parameters (rainfall, discharge, soil moistures and groundwater level). Results showed that these past drought events were clearly simulated by the model.

Results on the t-tests showed that for the Pampangga river basin, the most significant effects occurred on the wet season of the second year with the time delay of around 1 to 7 months. Spatially, the most severe drought effects were mostly on the central and southewestern portion of the basin.

For the Ping river basin, t-test showed no significant difference for the 2-year composites during El Niño and La Niña events. Spatially, the drought effects on this basin was very mild and quick recovery period on drought events were observed.

For the Upper Citarum river basin, t-test showed that the significant months were during the dry season of the second year. Spatially, mild to severe agricultural droughts were observed to occur on the entire basin while only mild to moderate meteorological and hydrological droughts were observed.

For the Langat Watershed, t-test showed that the significant months of the 2-year composites occurred on the dry season of the first year. Spatially, during drought months, the entire basin is simultaneously affected by the 3 drought types.

The impacts of future climate change on extreme events especially on droughts are one of the main focuses of this study. However, as Kelly and Adger [2000] noted, it is the short-term hazards and extreme climate events on the seasonal and inter-annual timescale that the bulk of any population experiences and reacts to, rather than long-term trends, and it is through varying character of these events that any long-term change in climate will first be manifest. Hence, historical droughts were used as baseline information on identifying trends in future

Using the same basin parameters from past drought events, future drought events were quantified and identified. Since the GCMs were stochastically determined, only the trends (increase or decrease) in drought events were identified for the near future simulations.

For the Philippines, it was found that a large increase in severe drought conditions at the root zone in the near future is expected. This translates to more severe agricultural drought in the watershed. Figure 1 show past and near future

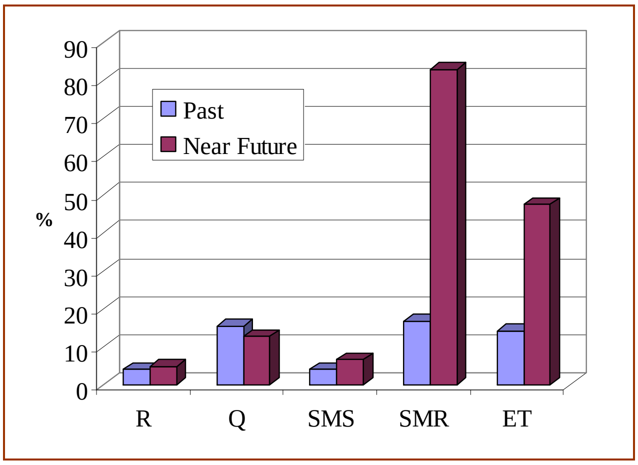

Figure 2. Philippines past and near future drought projections

The same is true for projections in the Ping river basin, Thailand. Severe drought conditions at the root zone are also expected indicating that the deeper soil moisture will be severely affected. Agricultural drought is expected to increase.

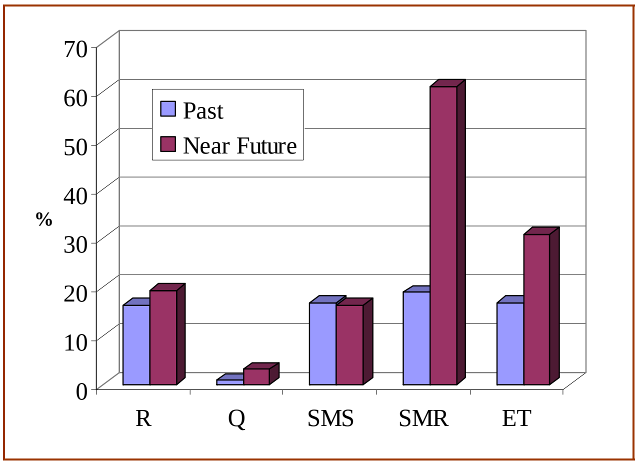

Figure 3. Thailand past and near future drought projections

For Malaysia, both the surface and root zone soil moisture will be severely affected. This indicates that severe agricultural drought is also expected. It is interesting to note that unlike the first 2 watersheds, evapotranspiration is not expected to increase.

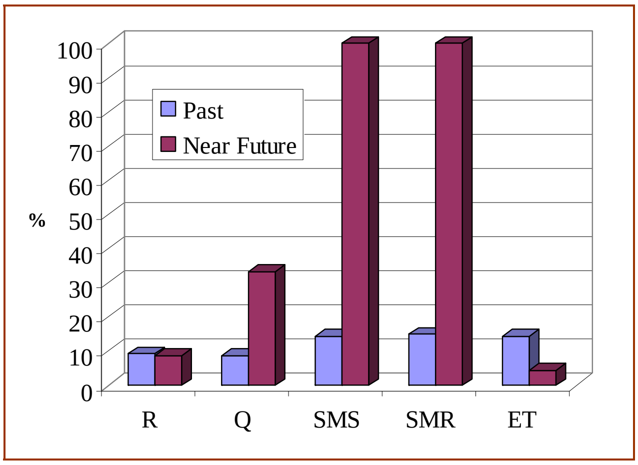

Figure 4. Malaysia past and near future drought projections.

The case is completely different for the Upper Citarum River Basin in Indonesia. Rainfall and soil moisture conditions are expected to increase in drought conditions but discharge was found to decrease significantly. This indicates that rainfall will decrease in overall average but the extreme conditions are more frequent hence, resulting to increased discharge.

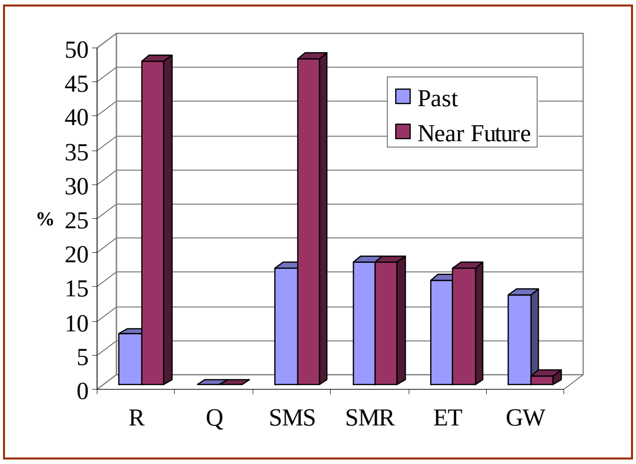

Figure 5. Indonesia past and near future drought projections

From the results in both the observed historical data and future projections of the different drought-related parameters in each watershed, basin-specific water resources management strategies were determined that can be used to assist the stakeholders in the different watersheds to adapt to changes in climate and the effects of drought.

For the Pampangga river basin, previous studies list the following as possible adaptation strategies (mostly focusing on agricultural practices since effects on this is expected in the future): water reuse by recycling of drainage water and groundwater (Maraseni, et al., 2010); water use planning; optimizing irrigation practices; supplemental or micro-irrigation (Rockstrom, et al., 2002); crop substitution during dry years (e.g. maize or other more droug-tolerant high yielding crops) or abandoning the second and third cropping altogether (Roberts et al., 2009). The latter is commonly practiced in the basin especially since results from the 2-year ENSO composite shows that El Niño worsens in the second year wet season making it futile to proceed with the second or third cropping season. However, the time delay observed prior to the occurrence of the other drought types indicate that some of the hydrological parameters that are unaffected for the given time period can be used as viable alternatives to supplement the water deficit in the drought-affected parameters.

For the Ping river basin, previous strategies were mostly geared towards flood adaptation and improving the lives of the people. These can be modified to include preparation for the soil moisture deficit expected in the near future. Analysis of the historical droughts has shown that although mild hydrological and meteorological droughts were observed, mild to severe agricultural droughts have been observed. In addition, the current soil moisture condition is slightly lower than field capacity indicating that the water at the root zone is not always readily available for plant uptake. It is expected that root zone soil moisture will be severely affected in the future. A strategy to remedy root zone soil moisture deficit is to target this deficit by using sub-surface irrigation systems. The advantage of this strategy aide from water savings (not lost by evapotranspiration) is it targets the layer directly so that crops can readily uptake the water. This procedure is commonly practiced in large farms in the area. The quick recovery time of droughts is an additional advantage in this basin especially since the significant deficits occurred right before the wet season. With proper scheduling of agricultural activities, moisture deficit effects can be minimized. With proper management of water resources, (e.g. systematic water distribution, water impoundment, crop irrigation scheduling, etc.), the severe effects of these short-term droughts can be avoided.

For the upper Citarum river basin, ENSO effects on the second year during the dry season allows for some crop scheduling and preliminary preparation for the severe effects on agriculture in this region. Adaptation strategies can be: cropping pattern changes, crop substitution during dry years and alternative sources of livelihood especially on the second year. Near future simulations show increasing agricultural drought trends but decreasing hydrological droughts. This indicates that in some periods, this basin may be exposed to floods but at the same time, in other periods, soil moisture deficits may occur especially during the dry season. Hence modification in agricultural practices such as crop scheduling, proper crop selection, and alternative sources of livelihood need to be implemented in the future. If properly managed, the excess water in the surface water may be advantageous to the basin's agricultural activities but if neglected may lead to hazardous flooding especially in the low elevation areas. The central plains of the basin are prone to both flooding and drought hence, possible adaptation strategies are: continuance of flood control practices, water management planning, use of available discharge when rainfall is not available (water impoundments, increase of dam capacity, etc).

For the Langat watershed, since Malaysia has a uniform climate throughout the year, most of the available watershed management practices are focused on pollution reduction, environmental protection, management of the quality of life, public health and socio-economy of the people, and ecosystem health management. Land use is rapidly being converted to more industrial uses which might be beneficial to the impending increase in agricultural drought in the future. In addition, the cropping pattern has already shifted to more drought tolerant plantation crops such as palms (for oil). Water management strategies such as contour embankments to address soil acidity by limiting erosion, crop and irrigation scheduling based on the significantly different effects of ENSO during the first year on the dry season (wetter conditions during El Niño and drier conditions during La Niña) which can be an advantage to prepare for the drier El Niño and wetter La Niña that succeeds it during the wet season when most crops are planted. The basin had a very quick biophysical response to drought and so all the drought types occurred almost simultaneously in the entire basin. Hence, ample preparations (water impoundments and other supplementary water storage, surface and subsurface irrigation schemes, irrigation scheduling, water routing, dam operation regulation etc.) are needed to combat drought effects in the future since both hydrological and agricultural droughts are expected to increase in frequency and severity.

Water along with other commodities such as food, energy, health and the ecosystem are interconnected hence this vulnerability of one is linked with the others. This paper focuses on the biophysical assessment through hydrological modeling of the water and energy interactions at the selected basins.

4.1 Integration of Biophysical Assessment into a comprehensive water resource management plan

We propose an interactive triadic approach that allows direct feedback of the various sectors (socio-economic, biophysical and stakeholder experiences) in coming up with an integrated water resource management plan that is capable of consensus building based on quantitative assessments of the actual impacts of drought at the same time consider the socio-economic conditions to ensure that the adaptation strategies are feasible given the current situation of the basin at the same time allow the experiences of the local people to be the guide to better adapt to changes in climate especially on the projected increases in drought severity in the near future.

Coupled social-ecological systems adjust to changing conditions often at locally (Kelly and Adger, 2002; Yohe and Tol 2002; Breshears et al., 2011). This means that specific conditions have to be determined to ensure that local adaptation strategies identified are appropriate. There are several factors that determine if the adaptation strategies are appropriate. The social dimensions of adaptive capacity can be influenced by different factors (e.g. access to resources (financial and technological), and institutional arrangements, including networks of political influence, economic ties, and kinship) (Smit and Wandel, 2006;.Breshears et al., 2011) hence, further studies are needed to ensure that the findings in this study and the suggested strategies based on the simulations are doable and appropriate to the basin since the social scenarios were not explored in the strategy formulation. Additional priorities Kelly and Adger, 2002) that should be integrated in the adaptation strategies to improve the situation of the communities in drought prone areas are: 1) poverty reduction, 2) risk-spreading througth income diversification, 3) respecting common property management rights and 4) promoting collective security.

5. CONCLUSIONS

Droughts may be regional in nature but its effects on the basin scale are different depending on the basin characteristics of the watershed. The standard anomaly index was able to identify different drought types at the basin scale in Southeast Asia.

The most effective scheme in enhancing adaptive capacity during climate change is those that address the sustainability of triadic socio-economic, biophysical and local knowledge integrated into the water resources management strategy focusing at the local level but is nested in an effective cross-scale dynamics (Turner et al., 2003; Breshears, et al., 2011) that is adaptive, flexible and addresses governance at multiple levels (Folke et al., 2002; Breshears et al., 2011) and is not restricted to geographical boundaries.

Further studies are needed to assess the interactions of basin scale vulnerability to drought of the other important resources and identify possible links that can reinforce adaptation while minimizing the vulnerability of one resource.

REFERENCES

Breshears, D., L. Lopez-Hoffman and L. Graumlich, 2011. When Ecosystem Services Crash: Preparing for Big, Fast, Patchy Climate Change, *AMBIO*, 40, 256-263, doi:10.1007/s13280-010-0106-4.

FAO, 2003. Digital soil map of the world and derived soil properties, Land and Water Digital Media Series Rev. 1, United Nations Food and Agriculture Organization, available in CD-ROM.

Folke, C.., Carpenter, S., Emqvist, T., Gunderson, L., Holling, C.S. and Walker, B. 2002. Resilience and sustainable development: Building adaptive capacity in a world of transformations. Ambio 31, 437-440.

Ines, A.V.M. and J.W. Hansen, 2006. Bias correction of daily GCM rainfall for crop simulation studies, *Agr. Forest Meteorol.,* 138, 44-53, doi:10.1016/j.agrformet.2006.03.009.

Jaranilla-Sanchez, P.A., L. Wang and T. Koike, 2011. Modelling the Hydrologic responses of the Pampangga River Basin, Philippines: A quantitative approach for identifying droughts, *Water Resour. Res.*, 47, doi:10.1029/2010WR00972.

Kelly, P.M. and W.D. Adger, 2000. Theory and Practice in Assessing Vulnerability to Climate Change and Facilitating Adaptation, *Climatic Change,* 47, 325-352.

Kelly, P.M. and W.M. Adger 2002. Theory and practice in assessing vulnerability to climate change and facilitating adaptation. *Climate Change*, 47, 325-352.

Maraseni, T. N., Mushtaq, S., Hafeez, M., and J. Maroulis, 2010. Greenhouse gas implications of water reuse in the Upper Pampangga River Integrated Irrigation System, Philippines, *Agr. Water Manage.,* 97, 382-388.

Myneni, R.B., R.R. Nemani, and S.W. Running, 1997. Estimation of global leaf area index and absorped par using radiative transfer models, *IEEE T. Geosci Remote*, 35, 1380-1393.

Onogi, K., J. Tsutsui, H. Koide, M. Sakamoto, S. Kobayashi, H. Hatsushika, T. Matsumoto, N. Yamazaki, H. Kamahori, K. Takahashi, S. Kodokura, K. Wada, K. Kato, R. Oyama, T. Ose, N. Mannoji and R. Taira, 2007. The JRA-25 Reanalysis, *J. Meteor. Soc. Japan*, 85(3), 369-432.

Roberts, M., Dawe, D., Falcon, W.P. and R. L. Naylor (2009), Notes and Correspondence El Niño-Southern Oscillation Impacts on Rice Production in Luzon, the Philippines, *J. Appl. Meteorol.Clim.*48,doi:10.1175/2008JAMC1628.1.

Smit, B., and J. Wandel. 2006. Adaptation, adaptive capacity and vulnerability. Global Environmental Change – Human and Policy Dimensions, 16, 282-292.

Turner, B.L., Kasperson, R.E., Matson, P., McCarthy, J.J., Corell, R.J., Christensen, L., Eckley, N., Kasperson, J.L., et al., 2003. A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences USA* 100, 8074-8079.

van Genuchten, M.Th., 1980. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils, *Soil Sci. Soc.*

Am. J., 44, 892-898.

Wang, L., T. Koike, K. Yang, T. Jackson, R. Bindlish and D. Yang, 2009a. Development of a distributed biosphere hydrological model and its evaluation with the Southern Great Plains Experiments (SGP97 and SGP99), *J. Geophys. Res.*, D08107, doi:10.1029/2008JD010800.

WWF, 2010. Mega-Stress for Mega-Cities: A Climate Vulnerability Ranking of Major Coastal Cities in Asia, www.panda.org, Switzerland.

Yatagai, A., O. Arakawa, K. Kamiguchi, H. Kawamoto, M.I. Nodzu, and A. Hamada, 2009. A 44-Year Daily Gridded Precipitation Dataset for Asia Based on a Dense Network of Raingauges, *SOLA*, 5, 137-140, doi:10.2151/sola.2009035.

Yohe, G. and R.S. Tol. 2002. Indicators for social and economic coping capacity – moving toward a working definition of adaptive capacity. *Global Environmental Change-Human and Policy Dimensions,* 12, 25-40.