APN Science Bulletin
Issue 4, March 2014
ISSN 2185-761x

ARCP2011-05CMY-BAE

Past Trends and Future Projections of Climate and Hydrology over Asia including 18 Demonstration Basins in Asian Water Cycle Initiative (AWCI) Countries

Deg-Hyo Bae[1], Toshio Koike, Moon-Hwan Lee, Kyung-Hwan Son and Jehangir Ashraf Awan
[1]Corresponding author
Sejong University, Republic of Korea
Email: dhbae@sejong.ac.kr

ABSTRACT: The present study analysed historical climate and hydrology trends of future climate change impacts over 18 demonstration basins in Asian Water Cycle Initiative (AWCI) countries. The Mann-Kendall test was employed for past trend analyses. The analysis showed an increasing trend for average temperature and a decreasing trend for average precipitation and runoff over Asia in the past 30 years (1977–2006). To analyse future climate change impacts, three Global Circulation Models (GCMs), i.e., CGCM3_T47, CGCM2_3_2 and CM4 were selected using criteria based on probabilistic uncertainty analysis, correlation coefficient and RMSE. The analysis projected increases in average temperature, precipitation and runoff over Asia in 2020s, 2050s and 2080s. By 2080s, the average temperature, precipitation and runoff over Asia were projected to increase by 3.7°C, 10.7% and 11.1%, respectively.

KEYWORDS: *climate change, trends analysis, Mann-Kendall, GCM*

Introduction

Climate change impact assessments are necessary to mitigate and prepare for climate change-induced disasters in the future. The Asian monsoon region is highly susceptible to natural hazards and the monsoon plays an important role in global water circulation, providing substantial precipitation and water resources to the people living within the region. While the Asia monsoon can provide substantial benefits, such as for power generation and foodgrain production, etc., it can also contribute to flood and drought problems.

Many factors contribute to water-related problems, but climate change complicates the issues in Asia, thus rendering difficult-to-manage scenarios during the monsoon period. Presently, policy decisions in the water sector are often made with uncertain information regarding the future state of climate and available water resources. Thus, prediction of future climate trends could be a key factor that affects further development of the Asian region. The main objectives of the present study are to analyse historical trends of climate and hydrology over Asia as a whole and in eighteen individual basins, one selected from each of the countries that participate in the Asian Water Cycle Initiative (AWCI), using the Mann-Kendall test, and to project future change in climate and hydrology using suitable GCMs.

Study Area and Data

The present study analysed both historical trends and future projections of climate and hydrology in the Asian monsoon region. The study area covered all eighteen countries involved in the AWCI, i.e., Bangladesh, Cambodia, India, Indonesia, Japan, Laos, Malaysia, Mongolia, Nepal, Pakistan, Philippines, South Korea, Sri Lanka, Thailand, Uzbekistan, Bhutan, Myanmar and Viet Nam as shown in Figure 1. The analysis first addressed climate and hydrology trends in Asia overall and then in eighteen specific hydrologic basin (one in each country). The basins were selected based on their importance from the viewpoint of socio-economic benefits and availability of hydrological data including precipitation, maximum and minimum temperature, streamflow and wind speed data. Table 1 identifies basins that were selected.

Precipitation and temperature data at 0.5 degree horizontal grid resolution was obtained from the APHRODITE data set (Asian Precipitation-Highly-Resolved Observational Data Integration Towards Evaluation of Water Resources). This data set is based primarily on data obtained from a rain-gauge-observation network (Yasutomi et al., 2011 and Yatagai et al., 2012) that covers all eighteen countries. To run the Variable Infiltration Capacity (VIC) macroscale hydrologic model, the Digital Elevation Model (DEM), Soil and Land use datasets were obtained from U.S. Geological Survey (USGS, 1996) (http://eros.usgs.gov), Food Agriculture Organization (FAO, 1998) and University of Maryland (Hansen et al. 1998), respectively at different available resolutions and converted to 0.5 degree grid resolution to comply with resolution of other datasets used in the study. In addition, we used 0.5 degree gridded meteorological forcing dataset (Adam & Lettenmaier, 2003; Adam et al. 2006) as input for VIC model. For analysis of historical trends, we used temperature, precipitation and runoff data for 30-year period from 1977 to 2006.

Figure 1. The study area.

No.	Country	Basin name	Area (Km²)	Climate regime
1	Bangladesh	Meghna	61,021	Humid
2	Bhutan	Punat-sangchhu	13,263	Temperate
3	Cambodia	Sangker	2,961	Very Humid
4	India	Seonath	30,760	Humid
5	Indonesia	Mamberamo	78,992	Humid
6	Japan	Tone	3,300	Humid
7	Korea	Upper Chungju-dam	6,662	Temperate
8	Lao PDR	Sebangfai	8,560	Very Humid
9	Malaysia	Langat	2,350	Very Humid
10	Mongolia	Selbe	303	Semi-arid
11	Myanmar	Shwegyin	1,747	Very Humid
12	Nepal	Bagmati	3,700	Humid
13	Pakistan	Gilgit	12,800	Humid
14	Philippines	Pampanga	10,540	Humid
15	Sri Lanka	Kalu Ganga	2,720	Very Humid
16	Thailand	Mae Wang	600	Humid
17	Uzbekistan	Chirchik-Okhangaran	20,160	Humid
18	Viet Nam	Huong	2,830	Very Humid

Table 1. General description of 18 demonstration basins.

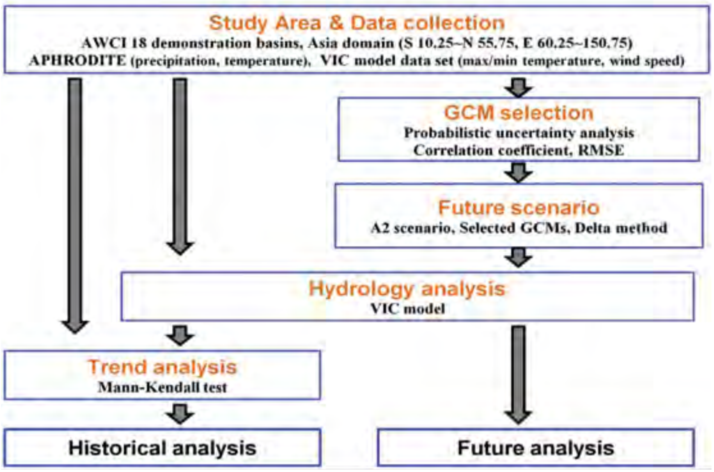

Figure 2. Methodology.

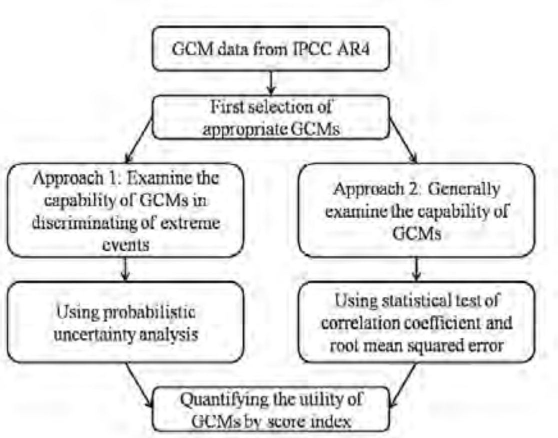

Figure 3. Procedure for evaluating the utility of IPCC AR4 GCMs.

Methodology

The methodology adopted to analyse the historical and future trends is illustrated in Figure 2. Primarily, the past climatology (precipitation, max/min/mean temperature, wind speed) data was collected from APHRODITE and VIC model dataset. The selection of appropriate GCM is an important step for projection of future climate and hydrology. In this study, nine GCMs (as shown in Table 2) available for use in Asia were compared and evaluated. The optimum GCMs were selected based on methods of probabilistic uncertainty analysis, correlation coefficient, and root mean square error (RMSE) as shown in Figure 3. The overall ranking of each GCM was computed based on the scores of all three statistical tests and the three highest-ranked GCMs, i.e., CGCM3_T47, CGCM2_3_2 and CM4 were selected in this study. For further details on GCMs selection procedure the reader may refer (Le & Bae, 2013). The future scenarios (A2) of three selected GCMs were disaggregated to daily time scale using delta method.

The VIC model was employed for analysis of hydrology data. A regionalisation method was used for parameter estimation of the VIC model at ungauged basins using runoff data from the Global Runoff Data Centre (GRDC). The regionalisation method employed was based on climate zones obtained from Köppen climate classification for Asia (Nijessen et al. 2001).

The Mann-Kendall test was used to analyse past trends. It is a non-parametric test for detecting trends in time series data which has the ability to cope with missing values and values below a specified detection limit. The test is widely used for analysing trends in environmental data (Kahya & Partal, 2007; Liu & Zheng, 2004).

Results and Discussion

Past Trends of Climate and Hydrology over Asia

The Mann-Kendall test was applied to 30-years (1977–2006) of temperature, precipitation and runoff data in Asia as a whole and at selected basins. The Mann-Kendall test statistics were computed for each grid point and the spatial distribution of trends was obtained as shown in Figure 4. The results show increasing and decreasing trends with 90% and 95% significance levels. The arrows (↑) and (↓) denote the increase and decrease trends, respectively. Results indicate that over the past 30 years, the average temperature over Asia increased approximately by 0.27°C/decade. This estimated increase is substantially high compared to global temperature increase of 0.13°C/decade by 4th assessment report of the Intergovernmental Panel on Climate Change (IPCC, 2007).

Most regions show increasing temperature trends except Bangladesh, Thailand and Sri Lanka. Especially distinct increasing trends (95% confidence level) are observed over Indonesia, Malaysia, Tibetan Plateau,

HIGHLIGHTS

- » Decreasing trends in precipitation and runoff, and increasing trends in temperature over most regions in Asia over the past 30 years.
- » Temperature is projected to increase in all areas in Asia.
- » Precipitation is projected to significantly increase over southwestern parts of South Asia and decrease over bordering regions of South Asia and East Asia.

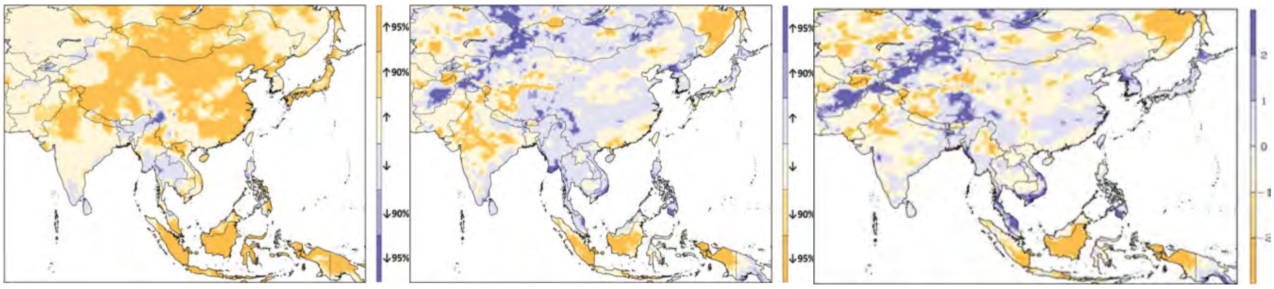

Figure 4. Mann-Kendall test results of annual historical temperature, precipitation and runoff over Asia region.

northwest India, Mongolia, China, Korea and Japan. Some other regions also show increasing trends, although with less significant confidence levels.

The average annual precipitation was observed to decrease by 86.5 mm over Asia as a whole over the 30-year period. Especially significant decreasing trends of precipitation (with a 95% confidence level) appeared over the Tibetan Plateau, Indonesia, inland India and southern Far East Russia, while increasing trends were observed over northwest China, north Pakistan, eastern Afghanistan and Korea. The average annual runoff over Asia overall decreased by approximately 41.8mm over the same time period. The spatial distribution of runoff trends was similar to that of precipitation trends.

No.	Country	Basin	Trend analysis		
			TMP	PPT	RNF
1	Bangladesh	Meghna	△	△	△
2	Bhutan	Punat-sangchhu	△	△	▽
3	Cambodia	Sangker	▲	▽	▽
4	India	Seonath	△	▽	▽
5	Indonesia	Mamberamo	▲	▼	▼
6	Japan	Tone	▲	△	△
7	Korea	Chungju-dam	△	△	▲
8	Lao PDR	Sebangfai	▲	▽	▽
9	Malaysia	Langat	▲	▲	▲
10	Mongolia	Selbe	▲	▽	▽
11	Myanmar	Shwegylin	△	△	△
12	Nepal	Bagmati	▲	△	△
13	Pakistan	Gilgit	▲	▲	▲
14	Philippines	Pampanga	△	△	△
15	Sri Lanka	Kalu Ganga	△	△	△
16	Thailand	Mae Wang	△	△	△
17	Uzbekistan	Chirchik-Okhangaran	▲	△	△
18	Viet Nam	Huong	▲	▲	▲

Table 2. Trend analysis of temperature (TMP), precipitation (PPT) and runoff (RNF) using the Mann-Kendall test at 18 demonstration basins. The filled triangle indicate statistically significant trend at 95% confidence level.

The basin-scale trend analysis was also conducted for eighteen selected basins applying the Mann-Kendall test for the 30 years. The results for annual temperature, precipitation and runoff for these basins are shown in Table 3. All eighteen basins demonstrated an increasing trend in annual temperature. The trend in temperature increase at ten basins was statistically significant at 95% confidence level.

The Mann-Kendall test revealed a decreasing trend for annual precipitation at Mamberamo basin, and increasing trends at Langat, Gilgit, and Huong basins with statistical significance at 95% confidence level. All remaining basins showed increasing trends for annual precipitation at a lower confidence level except Sangker, Seonath, Sebangfai and Selbe basins. The trend analysis of runoff showed decrease in the annual runoff at Mamberamo basin and increase at Chungju-dam, Langat and Gilgit basins with statistical significance at 95% confidence level. All remaining basins showed increasing trends for annual runoff except Punatsangchuu, Sangker, Seonath, Sebangfai and Selbe basins at a lower confidence level.

The results of basin-scale analysis should be used with care to deduce the general trend over a particular region as these results may sometimes be misleading due to uncertainty in data for a single grid point or a single station. For instance, the basin-scale analysis at Kalu Ganga basin in Sri Lanka showed an increasing trend in temperature even though Sri Lanka has an overall decreasing temperature trend over the past 30 years, as shown in Figure 4.

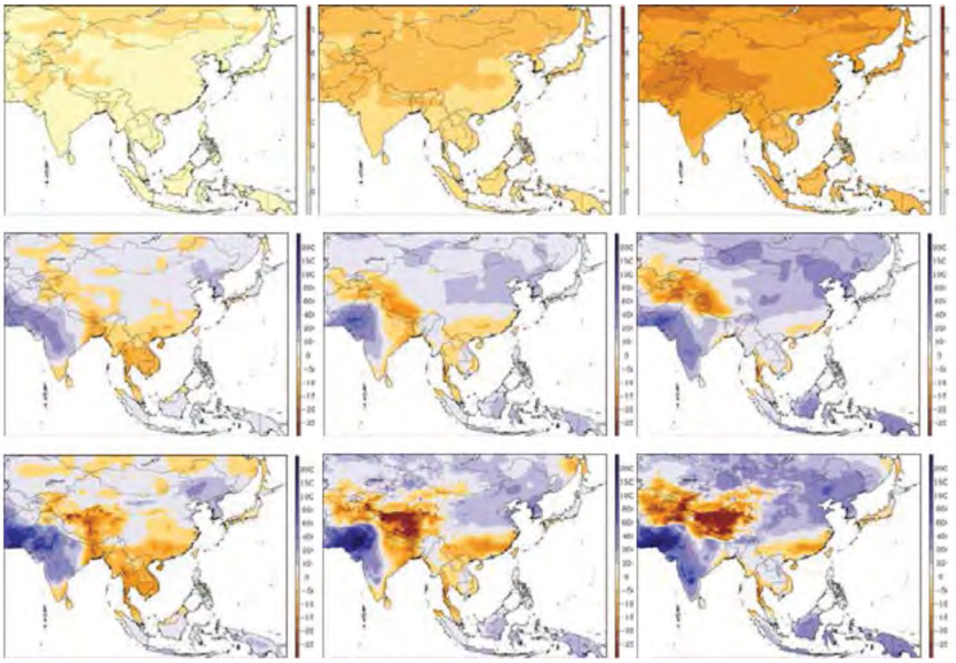

Figure 5. Relative change of temperature (top), precipitation (middle) and runoff (bottom) by 2020s (left), 2050s (centre), 2080s (right).

Future Projections of Climate and Hydrology over Asia using CGCM3_T47, CGCM2_3_2 and CM4

In this study nine GCMs were compared and evaluated for Asia region and three best GCMs i.e. CGCM3_T47, CGCM2_3_2 and CM4 were selected. For future climate and hydrology impact, the ensemble mean values of selected GCMs were used. To assess the uncertainty of selected GCMs for future projections, we analysed the results of each GCM. The results showed increased uncertainty toward future periods. By the end of 21st century, the projections results of temperature showed the uncertainty of about 1.1°C with average annual temperature increase of 3.0°C, 3.6°C and 4.1°C over Asia as a whole by CGCM2_3_2, CGCM3_T47 and CM4, respectively. The projection results for average annual precipitation over Asia as a whole showed comparatively low uncertainty with difference of about 3.3%. The increase of 14.5%, 14.3% and 11.2% average annual precipitation was projected by CGCM2_3_2, CGCM3_T47 and CM4, respectively.

Figure 5 shows the changes projected in temperature, precipitation, and runoff at future periods (2020s:2011-2040, 2050s:2041-2070, 2080s:2071-2100) relative to the reference period (1977-2006). The projections showed increase of average temperature over Asia during all future periods. The average temperature over Asia was expected to increase by 0.9°C, 2.1°C and 3.7°C in 2020s, 2050s and 2080s, respectively. The projection results showed 1.8%, 4.6% and 10.7% increase in annual mean precipitation over Asia by 2020s, 2050s and 2080s, respectively. The precipitation was projected to significantly increase over the southwest region of South Asia and decrease over the bordering regions of South Asia and East Asia. The projection results showed 1.5%, 3.9% and 11.1% increase in annual mean runoff over Asia by 2020s, 2050s and 2080s, respectively. The projected spatial distribution of future runoff change was similar to that of precipitation over Asia.

The results of future change in the eighteen specific basins are summarised in Table 4 showing change rates of temperature, precipitation and runoff in the 2020s and 2080s. Temperature was projected to increase at all the basins in both future periods. The highest increase of 5°C was projected in the Gilgit basin and lowest increase of 2.6°C was projected in the Pampanga basin by 2080s. For precipitation, nine basins showed decreasing trends by the 2020s and subsequently increasing trends by the 2080s.

Precipitation was projected to increase in all of the remaining basins for both future periods of the 2020s and the 2080s except Chirchik Okhangaran basin which showed an increasing trend by the 2020s followed by a decreasing trend by the 2080s. By 2080s the highest increase of 21.1% and highest decrease of 16.4% precipitation was projected at Mamberamo and Giglit basins, respectively. The projected features of runoff at most selected basins were similar to that of precipitation for future periods. By 2080s the highest increase of 28% and highest decrease of 19.9% runoff

Demonstration basins		Temperature		Precipitation		Runoff	
		2080s	2020s	2080s	2020s	2080s	2020s
1	Meghna	1.3	4.0	-6.4	6.6	-9.7	6.1
2	Punatsangchhu	0.7	4.0	-7.1	4.8	-11.0	3.8
3	Sanker	0.6	3.0	-8.7	0.4	-12.8	-0.6
4	Seonath	0.8	4.0	11.8	14.9	18.8	19.5
5	Mamberamo	0.6	2.8	6.8	21.1	9.2	28.0
6	Tone	0.6	3.3	1.0	4.1	0.5	1.2
7	Chungju-Dam	0.9	3.8	11.6	17.7	15.4	21.2
8	Sebanfai	0.8	3.1	-8.2	7.2	-11.3	8.8
9	Langat	0.6	2.8	-0.9	5.7	-1.2	6.2
10	Selbe	1.2	4.4	1.9	17.6	-0.1	16.7
11	Shwegyin	1.0	3.5	-5.4	1.6	-7.1	0.4
12	Bagmati	0.4	3.8	-1.9	7.9	-0.8	10.8
13	Gilgit	1.1	5.0	-3.0	-16.4	-3.5	-19.9
14	Pampanga	0.6	2.6	0.6	6.2	0.6	6.5
15	Kalu Ganga	0.7	2.7	0.1	9.3	0.0	10.3
16	Mae Wang	0.8	3.5	-7.6	3.6	-11.7	4.3
17	Chirchik Okhangaran	0.7	4.0	2.7	-1.5	3.1	-3.9
18	Huong	0.7	2.9	-8.3	-1.3	-10.9	-2.7
	Max.	1.3	5.0	11.8	21.1	18.8	28.0
	Min.	0.4	2.6	-8.7	-16.4	-12.8	-19.9
	Ave.	0.8	3.5	-1.2	6.1	-1.8	6.5

Table 3. **Change rates of annual temperature, precipitation and runoff at 18 demonstration basins.**

was projected at Mamberamo and Giglit basins, respectively.

Conclusions

In the present study, the past and future trends of climate and hydrology were analysed for the Asia monsoon region and for eighteen specific basins in AWCI countries. The average temperature was observed to increase by 0.27°./decade over Asia during past 30 years (1977-2006). The trend analysis showed increase in temperature over whole Asia except some regions i.e. Bangladesh, Thailand and Sri Lanka. The basin-scale analysis showed increasing temperature trend for all the basins. The trend over Asia during the past thirty years revealed decrease of 86.5 mm and 41.8 mm in average precipitation and runoff, respectively. Trend analysis of precipitation in specific basins showed a statistically significant decreasing trend in Mamberamo basin, and an increasing trend in the Langat, Gilgit and Huong basins.

To analyse future climate change impact, three optimum GCMs (CGCM3_T47, CGCM2_3_2, and CM4) were selected using probabilistic uncertainty analysis, correlation coefficient and RMSE methods. The uncertainty analysis of the selected GCMs showed increased uncertainty toward future periods which was higher for temperature compared to precipitation. Significant increase of average temperature (0.9°C, 2.1°C, 3.7°C), precipitation (1.8%, 4.6%, 10.7%) and runoff (1.5%, 3.9%, 11.1%) was projected for Asia overall for three future periods (2020s, 2050s, 2080s). Temperature was projected to increase in all regions. The precipitation was projected to significantly increase over southwest parts of South Asia and decrease over the bordering regions of South Asia and East Asia. Basin-scale analysis revealed significant increase of precipitation at Memberano basin and decrease at Gilgit basin by 2080s. The temperature was projected to increase for all the basins.

The results demonstrated in this study showed change with high spatial variation such as increase in precipitation and runoff over some regions/basins and decrease over others regions/basins of Asia. Further research needs to be carried out to identify the deriving factors of these variations. Moreover, the projected change may result in positive or negative impacts over different regions that urges the need of detailed regional impact assessment and adaptation studies over vulnerable areas to alleviate future climate-induced disasters.

Acknowledgement

This work was jointly supported by the APN and the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No.2011-0030040).

References

Adam, J.C. & D.P. Lettenmaier, (2003). Adjustment of global gridded precipitation for systematic bias, J. Geophys. Res., 108(D9), 1-14, doi:10.1029/2002JD002499.

Adam, J.C., E.A. Clark, D.P. Lettenmaier, & E.F. Wood, (2006). Correction of Global Precipitation Products for Orographic Effects, J. Clim., 19(1), 15-38, doi: 10.1175/JCLI3604.1.

FAO. (1998). FRA 2000 term and definitions: FRA Working Paper No.1 Rome. Retrieved from: www.fao.org/forestry/fo/fra/index.jsp

Hansen, M., R. DeFries, J.R.G. Townshend, & R. Sohlberg (1998), UMD Global Land Cover Classification, 1 Kilometer, 1.0, Department of Geography, University of Maryland, College Park, Maryland, 1981-1994.

Intergovernmental Panel on Climate Change (2007). Climate Change 2007: The Scientific Basis, available at www.grida.no/climate/ipcc_tar/wg1/index.htm.

Kahya, E., & Partal, T. (2007). Is seasonal precipitation decreasing or increasing in Turkey? Online Journal of Earth Sciences, 1(1), 43–46.

Le, T., & Bae, D.-H. (2013). Evaluating the utility of IPCC AR4 GCMs for hydrological application in South Korea. Water Resources Management, 27(9), 3227–3246. doi:10.1007/s11269-013-0338-8

Liu, C., & Zheng, H. (2004). Changes in components of the hydrological cycle in the Yellow River basin during the second half of the 20th century. Hydrological Processes, 18(12), 2337–2345. doi:10.1002/hyp.5534

Nijssen, B., Schnur, R., & Lettenmaier, P. (2001). Global Retrospective Estimation of Soil Moisture Using the Variable Infiltration Capacity Land Surface Model, 1980-93. Journal of Climate, 14(8), pp. 1790-1808.

Yasutomi, N., Hamada, A., & Yatagai, A. (2011). Development of a long-term daily gridded temperature dataset and its application to rain/snow discrimination of daily precipitation. Global Environmental Research, 15(2), 165–172.

Yatagai, A., Kamiguchi, K., Arakawa, O., Hamada, A., Yasutomi, N., & Kitoh, A. (2012). APHRODITE: Constructing a long-term daily gridded precipitation dataset for Asia based on a dense network of rain gauges. Bulletin of the American Meteorological Society, 93(9), 1401–1415. doi:10.1175/BAMS-D-11-00122.1

ARCP2011-05CMY-BAE

PROJECT TITLE

Climate Change Impact Assessment on the Asia-Pacific Water Resources under AWCI/GEOSS

COUNTRIES INVOLVED

All APN member countries

PROJECT DURATION

Two-year project

APN FUNDING

US$ 84,000

PROJECT LEADER

Prof. Deg-Hyo BAE
Department of Civil and Environmental Engineering, Sejong University, 209, Neungdong-ro,Gwangjin-gu, Seoul, REPUBLIC OF KOREA

Tel: +82 2 3408 3814

Email: dhbae@sejong.ac.kr

Website: http://dasan.sejong.ac.kr/~dbae/