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River management system development in Asia based on Data Integration and Analysis System (DIAS) under GEOSS

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This paper introduces the process of development and practical use implementation of an advanced river management system for supporting integrated water resources management practices in Asian river basins under the framework of GEOSS Asia water cycle initiative (AWCI). The system is based on integration of data from earth observation satellites and *in-situ* networks with other types of data, including numerical weather prediction model outputs, climate model outputs, geographical information, and socio-economic data. The system builds on the water and energy budget distributed hydrological model (WEB-DHM) that was adapted for specific conditions of studied basins, in particular snow and glacier phenomena and equipped with other functions such as dam operation optimization scheme and a set of tools for climate change impact assessment to be able to generate relevant information for policy and decision makers. In situ data were archived for 18 selected basins at the Data Integration and Analysis System (DIAS) of Japan and demonstration projects were carried out showing potential of the new system. It included climate change impact assessment on hydrological regimes, which is presently a critical step for sound management decisions. Results of such three case studies in Pakistan, Philippines, and Vietnam are provided here.

integrated water resources management tools, climate change impact assessment, Asian river basins, Asian Water Cycle Initiative

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The global Earth observation system of systems (GEOSS) Asian water cycle initiative (AWCI) was established in 2007 as a response to the recognized needs for accurate, timely, and long-term water cycle information to implement integrated water resources management (IWRM) practices and with regards to the commonality in the water-related issues and socio-economic needs in the Asia-Pacific region. Implementing IWRM at the river basin level, while respecting the physical, social and political context, is an essential element to managing water resources in a more sustainable way, leading to long-term social, economic and environmental benefits (GWP, 2009). It requires a wide range of disparate data from multiple disciplines and various sources and appropriate tools for processing these data and integrating and translating them into relevant information for water resources practitioners and policy decision makers. A system for supporting IWRM practices thus must be able to simulate and predict a wide range of flows from droughts to floods and to be applicable for long-term, cli-

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mate time-scale periods. However, at the time of AWCI inception, most of the member countries reported a lack of such capabilities. Accordingly, AWCI developed a plan for building an advanced river management system (System, hereinafter) in the member countries, starting from one demonstration basin per country (GEOSS/AWCI implementation plan, 2008). The System is based on the water and energy budget distributed hydrological model (WEB-DHM) that has been validated in various climatic and hydrological conditions (Wang et al., 2009) and that is suitable for simulating all range of flows and provides spatial information on water budget within a watershed including soil moisture and groundwater.

By considering GEOSS efforts enabling relatively easy access to available earth observation (EO) data and the utmost importance of these data for water resources analyses, the System was designed to allow for maximum exploitation of EO data and integrating them with local observation. It was therefore a prerequisite to develop an adequate database of local observations that would comply with GEOSS interoperability standards and to prototype an approach for integrating data from various global and local sources. *In-situ* data from 18 selected demonstration basins have been collected, quality controlled, equipped with appropriate metadata, and archived at the Data Integration and Analysis System (DIAS), Japan, which was launched in 2006 and by 2009 it had begun its application phase and been ready to support IWRM practices in the AWCI countries. To assure applicability to a wide range of natural conditions, the original WEB-DHM model has been augmented with an energy balance-based snow and glacier phenomena scheme and supported with an improved algorithm for snowcover estimation using satellite observation. With incorporation of a dam operation optimization scheme and a comprehensive drought assessment methodology, the System has become a suitable and effective tool for supporting IWRM practices.

Moreover, in recognition of non-stationary nature of water cycle variability (Milly et al., 2008) and considering growing evidence of climate change impacts on water resources in Asia, it is necessary to develop a clear consensus on how to best utilize model projections of climate and hydrology in conducting frequency analysis of future hydrological hazards. Hydrological regime shifts and changes in extreme events, including floods and droughts, are now fundamental threats (Alexander et al., 2006). It is therefore essential to properly asses these changes as a basis for identifying effective responses and developing adequate adaptation strategies. Reflecting on these needs, the presented System has been equipped with climate change assessment capability that enables an easy access to GCM climate projection output of the world climate research programme's (WCRP's) coupled model intercomparison project phase 3 (CMIP3; Mehl et al., 2007) and phase 5 (CMIP5; Taylor et al., 2012), which are being stored at DIAS. With all its components, as described in Section 1, the System is a rather robust tool suitable for long-term simulations of watershed water and energy budget and a wide range of flows from low to high in various climatic regions and capable of providing information to stakeholders from various disciplines for sound water resources management decisions.

Technical advancement and versatile applicability and robustness of the System is a prerequisite for its implementation into operational use; however, it would not be possible without a strong commitment from decision and policy makers of the countries. To assure such a commitment, AWCI has been making efforts to demonstrate capabilities of the System and the benefits resulting from its use to relevant representatives of the member countries including representatives of water-related ministries and agencies and academia. Establishment of the AWCI collaborative framework among member countries and collaborating organizations including GEO Secretariat, Japan Aerospace Exploration Agency (JAXA), the University of Tokyo (UT), united nations university (UNU) and the UNESCO international centre for water hazard and risk management (ICHARM) and the framework recognition by the international community has been playing a key role in this process. In addition, training sessions on the System are being organized and consulting and advisory service is being provided with no-cost to countries by the System developer, the University of Tokyo.

1 Methodology

1.1 Overall approach

The AWCI activity implementation has been taking advantage of the well coordinated AWCI framework of 18 countries including Bangladesh, Bhutan, Cambodia, India, Indonesia, Japan, Korea, Lao PDR, Malaysia, Mongolia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand, Uzbekistan and Vietnam. The network has been maintained through a series of regular international coordination group (ICG) meeting events and conference calls. ICG consists of representatives of water-related ministries and agencies as well as academia of the participating countries and experts in specific focus areas including data integration, hydrological modeling, flood, drought, water quality, climate change, and capacity building. These meetings have been also attended by representatives of main strategic partners as specified above in Introduction section.

Each country had nominated one demonstration basin for which the main water management related issue (or issues) had been identified (e.g. early flood warning using weather forecast data, drought analysis using long-term historical data, dam operation optimization, etc.) and *in-situ* data had been archived at the DIAS system. Given the basin conditions and main issues, a demonstration project (DP) was designed and necessary tools and data were specified. The strategy was to develop the WEB-DHM model for each basin, calibrate and validate it using the local *in-situ* data and then run it in applications tailored for each basin specifically reflecting identified issues and needs. Forcing and other data were taken from most suitable sources, usually global or regional products as mentioned in the data section below. By using WEB-DHM, the available observation data and information were integrated into complex information on watershed water budged over the simulation time including the desired output of flood early warning, drought seasonal forecast or suggestions for optimized dam operation. These activities were carried out by a country team in cooperation with other member countries and experts from the AWCI collaborating organizations and programmes.

The second step was a preliminary assessment of possible climate change impacts on hydrological regimes in the demonstration (or other) basins followed by a more complex study using either the AWCI developed methods or designed and carried out individually in some countries. The schematic framework of the climate change assessment and adaptation (CCAA) study and the data used are shown in Figure 1 and the employed methods are explained in following sub-sections. The approach is to use the general circulation model (GCM) future climate projections as atmospheric forcing for hydrological models (WEB-DHM in case of AWCI study) to elucidate the impact of climate change on hydrological regime in the basin through comparison with historical simulations. Some countries nominated another basin for this study, while the others used the DP basin. Additional *in-situ* data-in particular precipitation-covering a baseline historical period (1981–2000) were collected.

The results were presented and discussed at various meeting events to assure demonstration of developed capabilities to policy and decision makers with an intention to advocate for incorporating these capabilities into operational applications. AWCI has also been pursuing capacity building activities and organized several training courses for researchers and practitioners to familiarize with the new tools and techniques. The preliminary CCAA study was undertaken during such two training courses.

1.2 Models, tools, and techniques development

The AWCI countries represent a wide variety of geographical, climatic and hydrological conditions and thus various tools and methods have been required to implement the demonstration projects in individual basins although the overall approach is common among the countries.

1.2.1 WEB-DHM and WEB-DHM-S

A core tool of the developed system is the water and energy

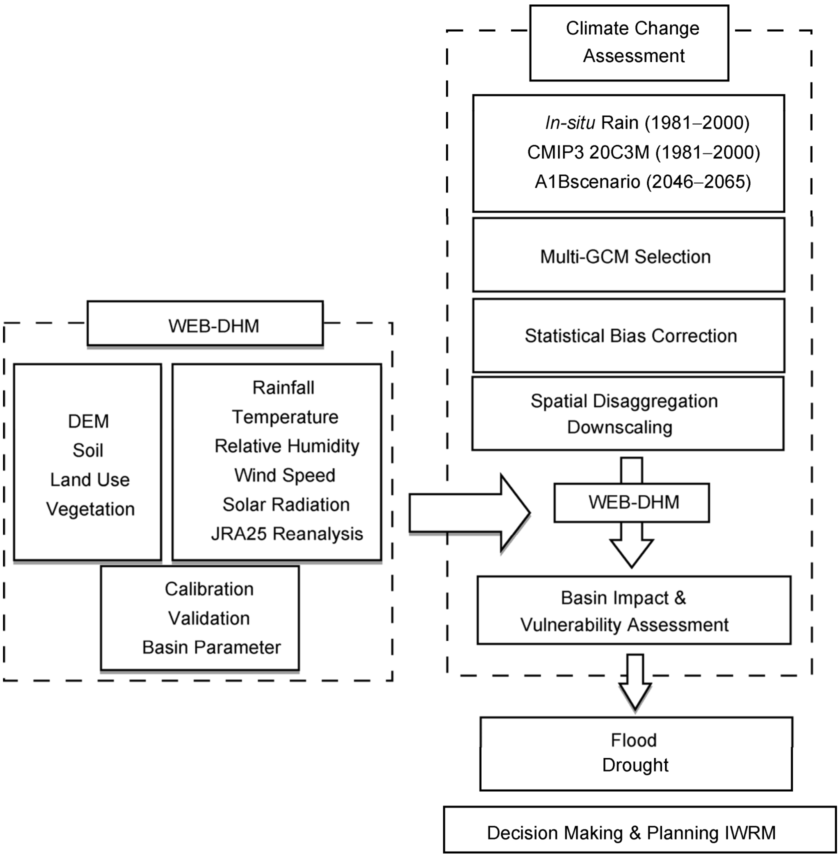

Figure 1 Climate Change Assessment framework, where CMIP3 is the World Climate Research Programme's Coupled Model Intercomparison Project phase-3, 20C3M is the 20th Century Numerical Reproductive Experiment.

budget hydrological model (WEB-DHM) that was developed at the University of Tokyo and verified in various basins. It was developed by fully coupling a land-surface model, the Simple Biosphere scheme (SiB2; Sellers et al., 1996) with a geomorphology-based hydrological model (GBHM; Yang et al., 2004). The WEB-DHM model enables consistent descriptions of water, energy and CO_2 fluxes at the basin scale. It physically describes evapotranspiration using a biophysical land surface scheme for simultaneously simulating heat, moisture, and CO_2 fluxes in the soil-vegetation-atmosphere transfer (SVAT) processes (Wang et al., 2009; Wang and Koike, 2009; Wang et al., 2010a). The basin and subbasins are delineated employing the Pfafstetter scheme, and subbasins are divided into a number of flow intervals based on the time of concentration. All external parameters (e.g., land use, soil type, hillslope and vegetation parameters) and a meteorological forcing dataset including precipitation are attributed to each model grid, in which water, energy, and CO_2 fluxes are calculated. A hillslope-driven runoff scheme employing a kinematic wave flow routing method is adopted in calculating runoff.

Seasonal snow cover and glacier phenomena are an important component of the environment in a number of AWCI countries, in particular (but not limited to) those in the Himalayan region. From a hydrological point of view, the temporal and spatial variability of the snow distribution on a basin scale plays a key role in determining the timing and magnitude of snowmelt runoff. Considering the effect of snow on land and atmospheric processes, it is essential that hydrological models accurately describe seasonal snow evolution (Liston, 1999). For applications in the AWCI basins such a model was developed by coupling the three-layer energy balance snow physics of the Simplified Simple Biosphere model, version 3 (SSiB3; Sun and Xue, 2001; Xue et al., 2003) and the prognostic albedo scheme of the Biosphere-Atmosphere Transfer Scheme (BATS; Dickinson et al., 1993, Yang et al., 1997) into WEB-DHM. The resulting WEB-DHM with improved snow physics (WEB-DHM-S; Shrestha et al., 2010, 2012) adds more features to the WEB-DHM for simulating the spatial distribution of snow variables such as the snow depth, snow water equivalent, snow density, liquid water and ice contents in each snow layer, snow albedo, snow surface temperature, and snowmelt runoff. For snow-covered model grids, a three-layer energy-balance-based snow accumulation and melting algorithm is used when the simulated snow depth is greater than 5 cm; otherwise, a one-bulk-layer snow algorithm is used. Each model grid maintains its own prognostic snow properties (temperature, density, and ice/water content) and/or land surface temperature and soil moisture content. The model was validated in the Dudhkoshi region of the Koshi basin, located in the northeast Nepal Himalayas (Shrestha et al., 2012).

1.2.2 Snow depth distribution estimation method for mountain regions using remote sensing

Monitoring of snow cover areas and snow amount distribution is essential for reliable hydrological modeling in snow and glacier areas. In vast snow areas like the Himalayas, however, adequate field survey is almost impossible and *in-situ* measurements provide limited regional information (Negi and Kokhanovsky, 2011). Presently, with the use of remote sensing instruments, snow cover information and many other parameters can be determined on real-time, year-round over vast, rugged and remote areas. A new approach was developed by Duran-Ballen et al. (2012b) to estimate snow amount using a microwave radiative transfer model (RTM) and the Advanced Microwave Scanning Radiometer for EOS (AMSR-E) data in mountain region, which takes into account local terrain slope and incidence angle of the radiometer (AMSR-E) scanner (Figure 2). The snow algorithm used to derive the snow depth and temperature spatial distribution was validated in a flat region using *in-situ* recorded snow depth data (Tsutsui and Koike, 2009a, 2009b). However, remote sensing instruments are sensitive to the effects of the terrain slope, where the local incidence angle is different from that of a flat surface (which is 55° for AMSR-E). In the developed method, the terrain digital elevation model (DEM; resolution 1 km×1 km to express appropriately the terrain) is used to calculate the slope and aspect of each grid and the local incidence angle is computed with the geolocation of the satellite as it passes over. To overcome the difference of spatial resolution between the AMSR-E data (25 km×25 km) and DEM, brightness temperature, Tb for the two frequencies, namely 18.7 and 36.5 GHz, is estimated with the local incidence angle for each terrain grid and then averaged for the larger satellite

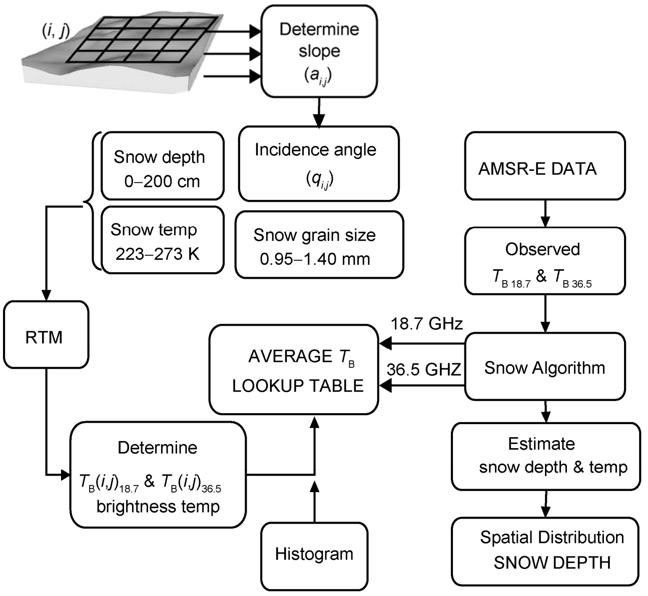

Figure 2 Framework overview of the snow depth distribution estimation method for mountain regions.

footprint grid using a weighted average based on the occurrence of the same local incidence angle. The lookup tables are generated by inputting the snow depth and temperature into the RTM model for a range of local incidence angles (25°–80°), snow depths (1–200 cm), and snow temperatures (223–273 K). One 18.7 GHz Tb and one 36.5 GHz Tb are calculated for each combination of snow depth and temperature and for each terrain grid. Then, the observed Tb is compared to the calculated average Tb in the lookup tables and corresponding snow depth and temperature of each footprint grid is estimated. The algorithm was validated at the Punatsangchhu River Basin in Bhutan (Duran-Ballen et al., 2012b).

1.2.3 Statistical bias correction method and downscaling for climate change impact assessment

The AWCI activities include climate change impact assessment on water resources that use General Circulation Models (GCMs) projection output as forcing data for hydrological models. However, there is substantial bias in GCMs precipitation output including the entire intensity spectrum (insufficient extreme events, biased mean intensity, extensive light intensity drizzle and too few dry days) and thus cannot be used to force hydrological or other impact models without some form of prior bias correction (Piani et al., 2010). Therefore a comprehensive statistical bias correction method on the catchment scale was developed for applications in the AWCI basins. The method, developed by Nyunt et al. (2013a, 2013b), uses an ensemble of available GCM outputs (daily values) and begins with selection of suitable GCMs for a given region based on comparison of historical GCM simulation results with reference data (observation-based global products or reanalyses). Then the daily precipitation output is corrected in three steps including extreme rainfall correction, correction of frequency of wet days (no-rain-day), and the bias of the inter-annual climatology monthly precipitation by using historical *in-situ* rainfall observation. The correction of extreme values is based on partial duration series (PDS), which are constructed using values above a threshold regardless of their year of occurrence, and permit inclusion of more than one event per year (Hershfield, 1973). The generalized Pareto distribution (GPD), which is the limit distribution of excess over a threshold series, is used to model PDS (Bobee and Rasmussen, 1995).

The frequency of low-intensity rainfall wet days is corrected by using the ranking order statistics of entire time series. The total frequency of wet days in the observed dataset is attained and applied to the GCM output to find the threshold rank and rainfall value, below which the GCM output is then considered as no rain day. Finally, rainfall intensities between the extreme and no-rain-day thresholds are classified as normal rainfall in both observed data and GCM output. It is assumed that the cumulative distribution function (CDF) of monthly normal rainfall at a certain grid point follows the gamma distribution function. The daily GCM and observed rainfall data are fitted to a two-parameter gamma distribution for 12 months and the CDF of daily GCM rainfall is mapped to the CDF of observed data for each month. In addition to the intensity and frequency bias, spatial downscaling of GCMs output is essential for regional and local impact studies. A statistical downscaling method was developed and employed in some demonstration basin cases (Nyunt et al., 2013b). It utilizes the Global Satellite Mapping of Precipitation (GSMaP; Kubota et al., 2007) product providing spatial rainfall pattern information (with resolution of 0.1°) and a corresponding rain gauge gridded dataset for correcting the GSMaP rainfall bias. A ratio of each GSMaP grid rainfall total at monthly scale with respect to the total over an area of a corresponding GCM grid is then used to downscale the bias corrected GCM rainfall output.

1.2.4 Drought assessment

A number of AWCI participating countries have identified droughts as a significant issue, which may be worsened due to climate change. A method for temporal and spatial drought classifications was developed by Jaranilla-Sanchez et al. (2011) based on a standardized anomaly index (SA), a variation of the standardized precipitation index (SPI; McKee et al., 1993). The SA index fits a distribution pattern to the monthly hydrological parameter values from the inputs and outputs of hydrological model (WEB-DHM in case of this AWCI study) simulations. This is transformed to the normal distribution and then standardized by taking the anomaly (calculated as the difference of the parameter value from its climatic mean (long-term monthly mean)), divided by the standard deviation of the transformed parameter. The effects of monthly and seasonal differences can be identified by SA, and the quantitative effects of evapotranspiration are integrated into calculations of other parameters using the physically consistent model WEB-DHM. Another advantage of the SA is the ease with which it can be combined with different parameters in spatially identifying the average effects contributing to drought at the basin scale.

1.2.5 Dam operation optimization

Another developed advanced tool is a dam release support system (DRESS) intended for reservoir operators that is based on real-time observations and weather forecast data. The system was developed by Saavedra et al. (2010) and validated at the Tone river basin (AWCI demonstration basin in Japan). Main purpose of the system is optimal dam operation during heavy rainfall to reduce flood peaks downstream and at the same time, to maintain maximum possible storage in reservoirs for designed purposes (e.g. power generation, water supply, irrigation) during lower-flow periods. The DRESS employs the WEB-DHM with an embedded dam operation module coupled to a heuristic algorithm for supporting release instructions. The WEB-DHM runs in normal mode forced by observed precipitation data until a heavy precipitation event is detected in a forecast. At that point, the forecast error is evaluated. Recent observed precipitation and quantitative precipitation forecasts (QPFs) are compared over the previous time step window in terms of location, intensity, and extent and QPF perturbations are calculated to ensemble precipitation members over the total lead time. Then the WEB-DHM model is run using the forecast forcing data to obtain the ensemble streamflow forecast. For special dam operations, *a priori* dam release is calculated for each ensemble member. Once the suggested optimal dam release schedule is determined using the QPF signal, the efficiency is evaluated using the observed precipitation.

2 Data

The AWCI activities are built upon integration of data coming from various sources including observation-based data (local *in-situ* and global satellite-borne observations) and model outputs (GCMs, regional climate models (RCMs), mesoscale atmospheric models) providing reanalyses, forecasts and climate historical simulations and future projections. Particular satellite and model datasets were selected as necessary and available for individual demonstration projects. Usually these include digital elevation model (DEM) data (Shuttle Radar Topographic Mission, SRTM); Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model, ASTER GDEM)), land use (U.S. Geological Survey (USGS) and soil maps (Food and Agriculture Organization, FAO)), leaf area index (MODIS), meteorological variables (JRA25, GLDAS) if not available/usable from *in-situ* observations or in case of future projections and historical simulation evaluations, and others. A large amount of these data is available through the DIAS system or it has been gathered from the original sites.

Local *in-situ* data for demonstration basins were provided by participating countries. As agreed at the initial planning meeting of AWCI, the period of 2003-01-01–2004-12-31 was the basic period for demonstration projects and the countries committed to provide *in-situ* data at least for this period or longer based on the data availability and each country's possibilities. Being quality controlled, equipped with adequate metadata and relatively complex within each basin, the AWCI *in-situ* data represent top-quality datasets for multiple research activities related to water cycle. The *in-situ* data in demonstration basins are summarized in Table 1 and are open and accessible through the DIAS data portal (see References). For the purpose of the CCAA study, additional data have been collected covering the baseline historical period 1980–2000 also mentioned in Table 1. These additional datasets have not been opened for public sharing though discussion on such possibility has been initiated.

3 Results

3.1 Overall demonstration project activities

The results of the demonstration project activities with appropriate references are summarized in Table 2. Details can be found in the mentioned references and also the Final project report by Koike et al. (2013). The preliminary CCAA study undertaken during the AWCI training courses employed the methodology introduced above and shown in Figure 1. However, due to significant simplification in the study design to meet the purposes of training course, the obtained results could not be used to derive any firm conclusions. Subsequently, the preliminary effort was followed by a full extent study in several countries, namely Indonesia, Korea, Pakistan, Philippines, Sri Lanka, Thailand, and Vietnam. The results for Indonesia, Sri Lanka, and Thailand are briefly summarized in the Table 2 with references to original publications. The study in Korea was carried out by Bae et al. (2013) and had a different design in terms of used bias correction, uncertainty assessment, hydrological modeling, and data analysis methods. The three case studies in Pakistan, Philippines, and Vietnam are described in the Section 3.2 below.

3.2 Climate change assessment case studies

The three case studies presented here were carried out in the Soan basin, Pakistan, the Angat basin, Philippines and the Huong basin, Vietnam with an aim to delineate the impact of climate change on hydrological responses of investigated basins. These basins represent three different types of climate patterns in South Asia, namely tropical (Philippines), subtropical (Vietnam) and semi-arid (Pakistan). Being done in various climate regions in Asia these studies provide certain overview of similarities as well as differences in climate change impacts between these regions. Nevertheless, to confirm specific trends for specific regions, several studies in each region need to be carried out and analyzed for various climatologic features, which are an on-going AWCI effort. The presented studies had similar design and used the same methods including: (1) the WEB-DHM development in a targeted basin and its calibration and validation using local *in-situ* data; (2) the GCM model selection from the suite of 24 models participating in the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3, Mehl et al., 2007), (3) the GCM rainfall bias correction and downscaling using available *in-situ* precipitation observation data, (4) the incorporation of GCM meteorological parameters into the hydrological model for past (baseline period 1981–2000) and future (2046–2065; climate scenario SRESA1B) and, (5) the analysis of climate change trends for floods and droughts.

Table 1 List of AWCI demonstration basins and overview of collected *in-situ* data[a)]

	Country	Basin name	Location	Basin area (km^2)	Data period	# of stations (Rec. interval *{Daily if not mentioned otherwise}*)	Observed elements*
1	Bangladesh	Meghna	90.5°–92.5°E, 23.2°–25.3°N	61021	2003/01–2008/12	9	Ta, Pr, Dis, WL
					1980–2000	8	Pr
2	Bhutan	Punatsangchhu	89.3°–90.3°E, 26.6°–28.3°N	13263	1989/01–2008/12	16	Pr, Discharge
					1985–2010	14	Pr
3	Cambodia	Sangker	102.5°–104.0°E, 12.5°–13.5°N	2961	2003/12–2010/01	5 (Hourly)	Pr, WL
					1981–2008	5	Pr
4	India	Seonath	80.5°–82.5°E, 20.0°–23.0°N	30760	2000/06–2004/12	30	Pr
		Upper Bhima	73.3°–75.3°E, 18.0°–19.3°N	14712	1970–2006	36	Pr
					1973–2001	17	Dis
					1985–2002	10	Ta
5	Indonesia	Mamberamo	136.3°–140.8°E, 1.4°–4.5°S	78992	1958/01–2007/12	3 (Monthly)	Ta, RH, Pr, sun, ET
		Citarum	107.2°–108.0°E, 6.7°–7.4°S		1991–2009	37	Pr
6	Japan	Upper Tone	138.2°–139.6°E, 36.2°– 37.2°N	3300	2002/12–2004/12	16 (Hourly)	Ta, WS, WD, Pr, sun, Dis.
					1901–2000	4	Pr
7	Korea	Upper Chungju-dam	127.9°– 129.0°E, 36.8°–37.8°N	6662	2003/01–2004/12	68	Ta, RH, WD, Pr, sun, Dis.
					1980–2000	8	Pr
8	Lao PDR	Sebangfai	105.0°–106.5°E, 17.0°–18.0°N	2300	2003/01–2007/12	6	Pr, WL, AWS
					1988–2013	5	Pr
9	Malaysia	Langat	101.2°–101.9°E, 2.6°–3.1°N	2350	2003/01–2004/12	24	Pr, Dis, Ta
					1980–2000	19	Pr
10	Mongolia	Selbe	106.8°–107.0°E, 47.9°–48.3°N	303	2004/01–2006/12	4	Ta, WL, Dis, Pr
		Tuul	102.5°–108.7°E, 46.0°–49.2°N		1980–2000	8	Pr
11	Myanmar	Shwegyin	96.7°–97.2°E, 17.5°–18.5°N	1747	2003/01–2004/12	1	WL, Dis, Pr
					1980–2000	3	Pr
12	Nepal	Bagmati	85.0°–86.0°E, 27.8°–26.8°N	3700	2003/01–2004/12	22	Ta, RH, Pr, WS
		Narayani	82.8°–85.8°E, 27.5°–29.4°N		1978–2007	1	Pr
13	Pakistan	Gilgit	72.4°–74.8°E, 35.7°–36.7°N	14304	2000/01–2008/12	17	Ta, RH, WD, Pr, Dis
		Soan	72.4°–73.5°E, 32.6°–33.9°N	6487	1999–2008	2	Pr
14	Philippines	Pampanga	120.5°–121.5°E, 14.7°–16.3°N	10540	1961/10–2005/12	4 (Daily, monthly)	Pr, Dis, WL
					1961–2000	3	Pr
					1961–2011	6	AWS
15	Sri Lanka	Kalu Ganga	80.0°–80.7°E, 6.4°–6.8°N	2720	2003/01–2004/12	12	Pr, Dis
					1980–2010	8	Pr
16	Thailand	Mae Wang	98.5°– 98.8°E, 18.6°–18.8°N	600	2006/05–2008/12	14 (10 min)	Ta, Pr, WL
					1979–1992	1	Pr
17	Uzbekistan	Chirchik-Okhangaran	69.3°–71.3°E, 40.2°– 42.3°N	20160	2003/01–2004/12	18	Ta, RH, WS, Pr, SkinT, sun, Dis
					1979–2005	11	Pr
18	Vietnam	Huong	107.0°–108°E, 16.0°–17°N	2830	2003/12–2008/12	8 (Hourly, every event)	WL, Pr
					1976–2009	9	Pr

a) Shaded rows indicate data for the CCAA study. Pr–precipitation, Ta–air temperature, Dis–discharge, WL–water level, RH–relative humidity, WS–wind speed, WD–wind direction, sun–sunshine duration, SkinT–surface temperature, AWS–automated weather station data.

In the presented studies, a set of suitable GCM models for the investigated area were selected for the analysis rather than using the full ensemble of 24 GCMs of the CMIP3 project because some of the models cannot reproduce essential climatology of the subject region and their bias is too large to be correctible making their future projections irrelevant for this region. The selection method is based on model ability to represent regional climate during the baseline period. The key climatologic parameters (precipitation, air temperature, outgoing longwave radiation, meridional and zonal wind, sea surface temperature, and sea level pressure) produced by GCMs were compared with corre-

Table 2 AWCI basins and completed tasks

Country	Basin name	Accomplishments and results	Reference
Bangladesh	Meghna	Hydrological model based on data integration and downscaling techniques was developed employing WEB-DHM. The system was run for the period 2001–2004 using global rainfall forecasts (grid point value, GPV, 24 h lead time issued every 12 h, 1.25°) and global satellite TRMM data (3 h, 0.25°) as observed rainfall, which was corrected by *in-situ* data. It was possible to forecast flood peaks though with certain overestimation, which was mainly attributed to the usage of global forecast.	Saavedra and Koike (2008)
Bhutan	Punatsangchhu	Snow cover modeling using WEB-DHM-S was evaluated for the Punatsangchhu River Basin using JRA25 reanalysis data for meteorological input, *in-situ* precipitation data (10 stations) and *in-situ* discharge (4 stations). The model successfully simulated the seasonal and interannual variability of the snow processes and accurately resembled the observed snow cover area (MODIS) for the time series from 2006 to 2008. JRA25 air temperature bias from the interpolation of the forcing data was analyzed and corrected depending on the ground elevation and interpolated according to the lapse rate. The discharge simulation was greatly improved by taking into account the snow melt contribution.	Duran-Ballen et al. (2012a)
		Subsequently, the new algorithm to estimate snow depth spatial distribution using a microwave radiative transfer model (RTM) in mountain region (introduced in Section 1.2) was applied to the basin and the results showed good agreement with MODIS and WEB-DHM-S snow depth results from previous study.	Duran-Ballen et al. (2012b)
Cambodia	Sangker	Using the precipitation gauge and AWS data, satellite TRMM data and numerical simulations by atmospheric models, a comprehensive study on precipitation patterns in western Cambodia has been carried out that clarified the mechanism of post-monsoon rainfall and suggested three requisite conditions for these rainfall events: (1) abundance of precipitable water, (2) development of a land breeze from the southwest of the Tonle Sap Lake, and (3) large-scale northeasterly wind of moderate strength.	Tsujimoto and Koike (2012)
		In addition, a study was carried out with coupled WEB-DHM and the rice growth model SIMRIW-rainfed to grasp the required hydro-meteorological information for rain-fed agriculture. The results were validated by the LAI and soil moisture in the Sangker River Basin. The sensitivity analysis showed that planting time has relatively higher sensitivity on crop yield than 10-day dry spell during the growing period. Irrigation or small rainfall (2 mm/day) after heading until maturity was shown to increase yield. The sensitivity analysis showed that rainfall prediction at the beginning of the dry season is very important.	Tsujimoto et al. (2013)
		Furthermore, future rice yields were also simulated by using GCMs outputs. In addition, a simple irrigation model was introduced into the coupled model and rice yields in consideration of climate change and irrigation were assessed. The study indicated impact of future precipitation variation on rice production that, however, can effectively be mitigated by constructing irrigation facilities in this area.	Ohta et al. (2014)
Indonesia	Citarum	A climate change assessment study was carried out using the technique of Ines and Hansen (2006). The results indicated increasing agricultural drought but decreasing hydrological drought. Flood peaks are likely to increase and be more frequent in some seasons but soil moisture deficit may be more severe during droughts. Flood-prone lower parts of basin.	Jaranilla-Sanchez et al. (2012); Ines and Hansen (2006)
		Another study was carried out using the technique describes in this paper. The results suggested increasing drought intensity during dry seasons and increasing heavy rainfall events with subsequent flooding, especially in lower parts of the basin.	Nyunt (2013b)
Japan	Tone	A dam release support system (DRESS) introduced in Section 1.2 that is based on real-time observations and weather forecast data was validated at the Upper Tone river basin using the worst heavy rainfall in 2002, 2003, and 2004. The efficiency of the system was demonstrated for all events, with some differences depending on the accuracy of the mesoscale model forecast. The objective function successfully minimized the flood volume at a control point and the free volume of the reservoirs, taking into account different release scenarios. The results indicated that DRESS was feasible for real-life dam operation.	Saavedra et al. (2010)
		The system has been integrated with a real-time data-archive and tested for three typhoon cases (2011 No.12; 2011 No.15; 2013 No.18), showing promising performance. The authors have concluded that the system is operationally applicable to Tone as well as other river basins.	Shibuo et al. (2014)
		A combined dynamical/statistical downscaling approach was proposed that is based on the Pseudo Global Warming Downscaling (PGW-DS) method, which combines climatology differences of GCM ensembles with reanalysis dataset to overcome strong biases in GCMs. A study was carried out over the Tone basin that merged dynamically downscaled precipitation derived from reanalysis and GCM precipitation outputs with three statistical bias correction (SBC) methods to obtain a comprehensive outlook on biases and the most appropriate SBC. In addition, WEB-DHM model was applied using the corrected rainfall dataset to evaluate hydrological responses and thus basin scale integrated validity of this value added dataset.	Rasmy et al. (2014a)
Pakistan	Soan	Study described in Section 3.2	Bhatti et al. (2014)

(*To be continued on the next page*)

(*Continued*)

Country	Basin Name	Accomplishments and Results	Reference
Philippines	Pampanga, Angat, Kaliwa	A climate change assessment study in three basins supplying water for Metro Manila carried out as a part of "The study of Water Security Master Plan for Metro Manila and its adjoining areas". Larger floods were found to increase in the future in all the basins. Severe droughts are likely to occur in the Pampanga basin, while as likely as not in other two basins with local conditions of land cover playing important role.	Jaranilla-Sanchez et al. (2013)
		The Angat basin study is described in Section 3.2	JICA Final Report (2013)
Sri Lanka	Kalu Ganga	A climate change assessment study was carried out using the technique describes in this paper. The results suggested that heavy rainfall was likely to increase during summer monsoon and to decrease during winter season with subsequent risk of flooding/drought, respectively.	Nyunt et al. (2012)
Thailand	Mae Wang	A climate change assessment study was carried out using the technique of Ines and Hansen (2006). The results indicated that agricultural drought might be expected to increase, but rather short-term and very likely replenished during following wet seasons. Suggestions for crop cultivation adaptation based on local situation were mentioned.	Jaranilla-Sanchez et al. (2012); Ines and Hansen (2006)
Vietnam	Huong	The possibility of simulating flooding in the Huong River basin, was examined using quantitative precipitation forecasts at regional and global scales. Raingauge and satellite products were used for observed rainfall. WEB-DHM model was employed and validated against *in-situ* observation (streamflow). During an extreme flood peak, the use of regional forecasts and satellite data gave results in close agreement with results using raingauge data. Using the simulated overflow volumes recorded at the control point downstream, inundation areas were then estimated using topographic characteristics. This study was the first step in developing early warning system and evacuation strategy.	Saavedra et al. (2009)
		A climate change assessment study described in Section 3.2	Unpublished

sponding reference observation-based or reanalysis data. A simple index counter was used for identifying the models, which has above average spatial correlation and below average root mean square error (RMSE) prioritizing models with good rainfall patterns and seasonality. Ability of GCMs to reproduce precipitation patterns is illustrated in Figure 3. The output of selected models was subsequently corrected and downscaled using the *in-situ* observation following the method of Nyunt et al. (2013a, 2013b) described in Section 1.2. An example of bias correction output is shown in Figure 4.

The corrected GCM outputs for the baseline period and the future analysis period were used as forcing data for the WEB-DHM, which produced hydrological response of the target basins. These studies considered natural flow in the basins to elucidate the impacts on natural hydrological regime. The investigated reaches of the basins do not contain significant flow regulation structures (dams). The peak flow trends were estimated by performing an extreme value analysis based on yearly maxima of 20 years daily discharge resulting from the selected GCM forcing datasets. With the assumption that the future climatology would be similar to the past the future projection peak flows could be good indicators of future floods. On the other hand, base flow trends were used to determine drought trends from climate change. The 355th rank of the past climatologically averaged daily discharge simulation was used as the basis of drought discharge (DDavg) and the longest number of days per year when the base flow was less than the past DDavg was identified for both the past and the future simulations. In addition, an average daily discharge was calculated for each year and then average of these averages over the past and the future periods was derived for each GCM output. The values are equipped with standard deviations and tabulated. Specifics of individual studies and result discussions are provided in the each study sub-section below.

3.2.1 Pakistan

(i) Summary description

The Soan River is a tributary of the Indus River, which originates in the foothills of Muree, east of Islamabad, and flows from east to west through the Pothohar area. The area drained down to the Dhok Pathan, a control discharge gauge of this study, comprises 6487 km^2 (Figure 5). The basin is semi-arid with annual total rainfall of 750–1400 mm and its climate is driven by the Indian monsoon with a wet season from July to September. To support agriculture, numerous multipurpose rainwater storage ponds have been constructed. Accordingly, the pond function was introduced in the WEB-DHM model to account for water stored in these ponds. The model was calibrated against observed discharge at the Dhok Pathan gauge for the year 1997 and validated for the year 1998 (Figure 6). In addition, the model performance was evaluated for soil moisture by using surface soil moisture data produced by Land Data Assimilation System of the University of Tokyo (LDAS-UT; Yang et al., 2007). The model grid size was 1000 m. The input data are summarized in Table 3. The APHRODITE rainfall data were used for baseline simulation in 1981–2000 because of limitations of local observation network.

(ii) Results

Four GCMs were selected as suitable for the region of the Soan River, namely gfdl_cm2_0, gfdl_cm2_1 (both by US Dept of Commerce/NOAA/Geophysical Fluid Dynamics Laboratory, USA), miroc3_2_medres, and miroc3_2_hires (both by Center for Climate System Research, University of

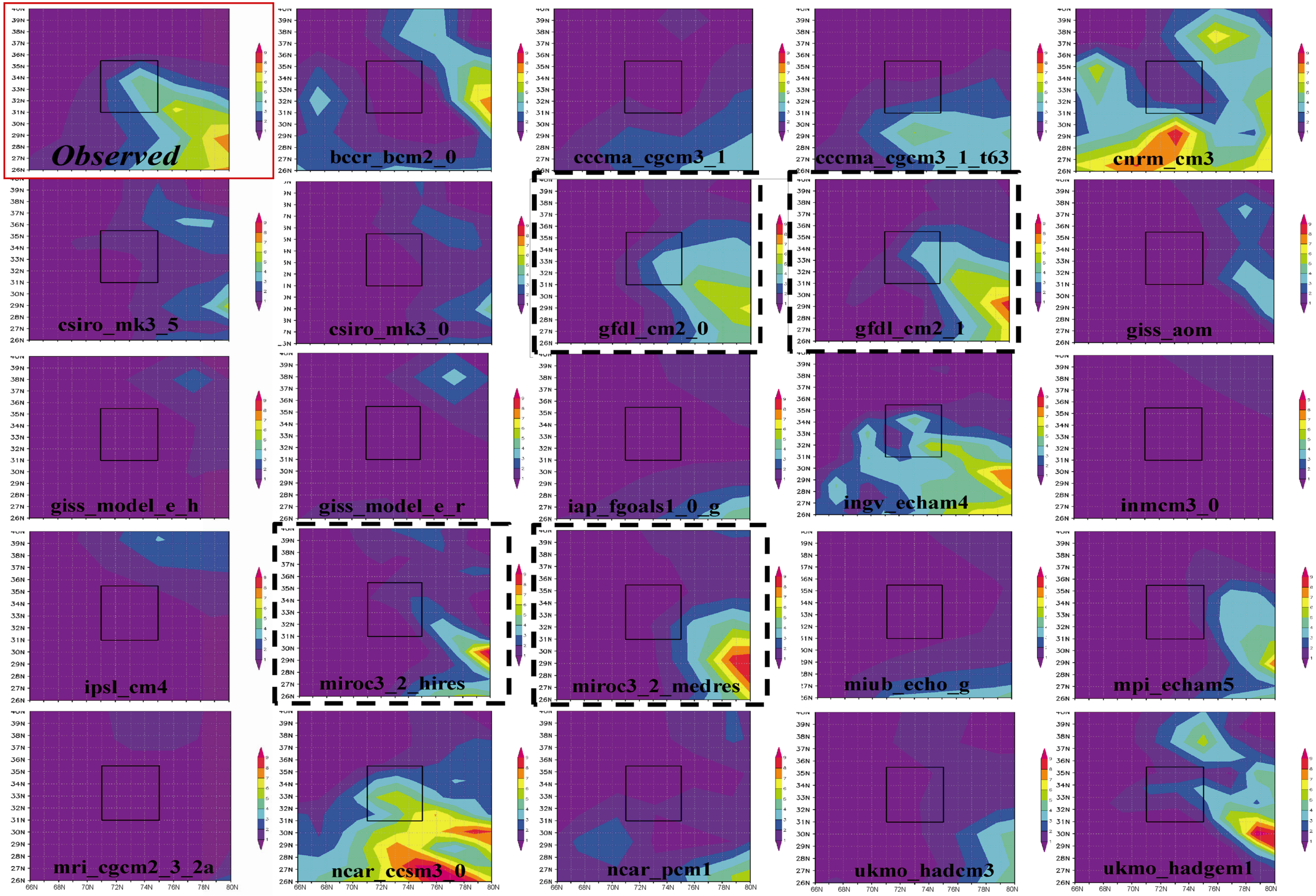

Figure 3 Comparison of observation-based precipitation pattern (Global Precipitation Climatology Project, GPCP; top-left figure) and corresponding 24 model outputs over the region relevant for the Soan basin, Pakistan. Shown is climatologic average precipitation during monsoon season July to September for 1981–2000 (small black box indicates local area considered for precipitation comparison; models boxed in black indicate selected models).

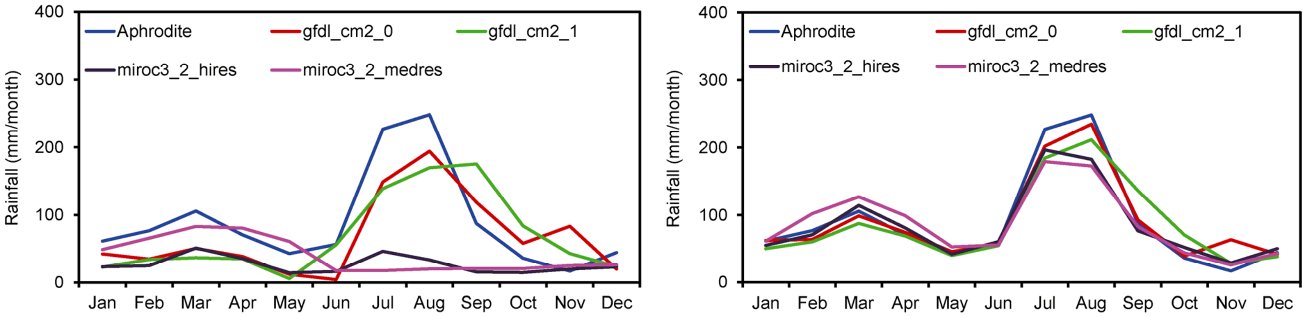

Figure 4 Seasonal cycle of precipitation during 1981–2000. (a) Before bias correction; (b) after the bias correction. Soan River Basin, Pakistan.

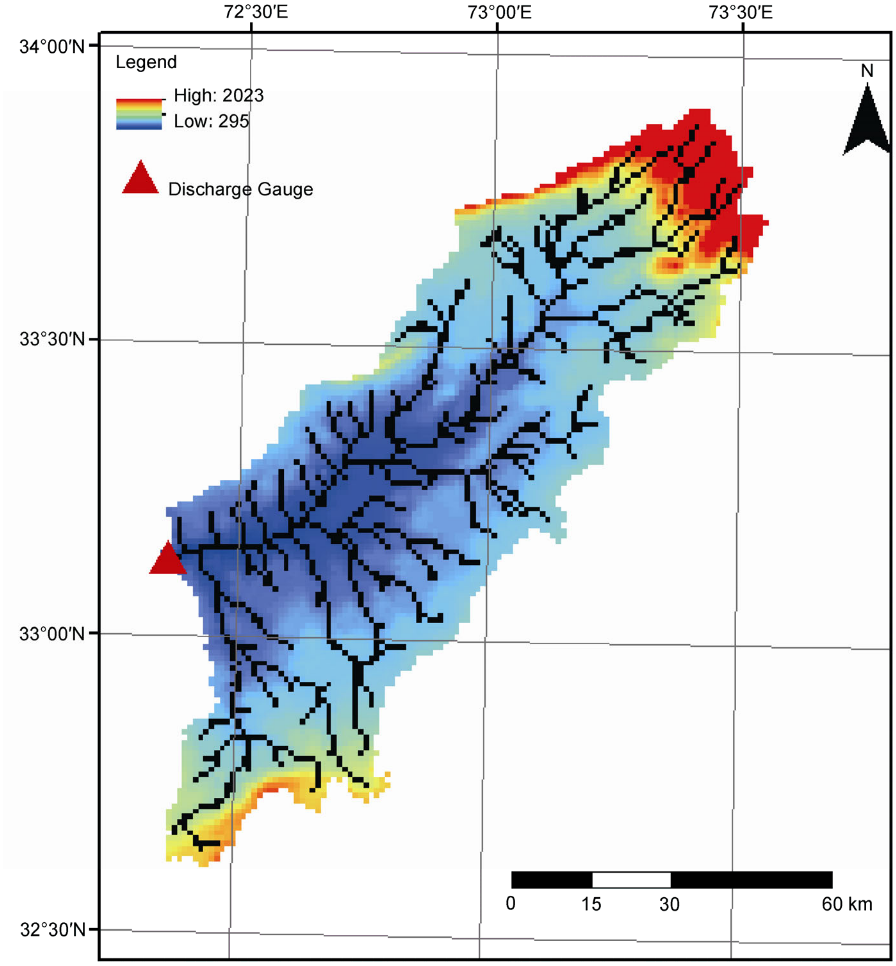

Figure 5 Soan River Basin, Pakistan: river network and elevation.

Tokyo (CCSR UT)/National Institute for Environmental Studies (NIES)/Frontier Research Center for Global Change, Japan Agency for Marine-Earth Science and Technology (FGCGC JAMSTEC), Japan). The analysis of peak flows trends is shown in Figure 7. Three of the four selected GCMs (gfdl_cm2_0, miroc3_2_medres, and miroc3_2_hires) showed similar trends with a substantial increase in magnitude of peak discharges in the future, while the gfdl_cm2_1 model showed decrease in peak discharge in the future. This indicates that it is likely that floods will increase in the future.

The results of drought analysis were not consistent for selected GCMs as it is summarized in Table 4. Outputs of two GCMs (gfdl_cm2_0 and miroc3_2_hires) resulted into slightly higher average daily discharge (ADavg) with higher standard deviation (larger discharge fluctuation) in the future, while the other two models (gfdl_cm2_1 and miroc3_2_medres) indicated a rather significant decrease in ADavg

Table 3 Input data of the Pakistan study

Data	Spatial resolution	Temporal res.	Source
DEM	50 m	Static	SRTM
Land Use	1000 m	Static	Global, USGS
Soil type/local	1000 m	Static	FAO
Discharge	Point (Dhok Pathan gauge)	Daily	Pakistan Meteorological Department (PMD)
Precipitation	Gridded (0.25°)	Daily	APHRODITE (provided by Japan Meteorological Agency (JMA))
Meteorological data (shortwave and longwave radiation, wind speed, humidity, air pressure, air temperature)	Gridded	6-hourly	Japan Reanalysis JRA-25, JMA
Vegetation indices: LAI, FPAR	Gridded (1 km)	8-day average	MODIS Terra

Table 4 Summary of drought trends in the Soan River Basin, Pakistan[a)]

Models	Average Daily Discharge, ADavg (m^3/s) (Average of average daily discharge for 20 years)		Drought Discharge, DDavg (m^3/s) (Average of 355th Rank for twenty years)		Longest no. of days/year below DDavg	
	Past	Future	Past	Future	Past	Future
gfdl_cm2_0	29.13±12.52	30.51±12.98	8.18±6.06	5.44±2.13	272	177
gfdl_cm2_1	32.32±20.00	22.08±11.29	8.25±5.75	7.65±6.14	357	354
miroc3_2_medres	37.88±15.74	28.37±14.30	8.77±7.08	7.63±5.88	319	348
miroc3_2_hires	22.19±9.83	23.11±12.57	7.13±5.89	7.34±6.02	288	307

a) Average values calculated over the 20 years of baseline period (past) and future projection period (future) and mentioned with standard deviation.

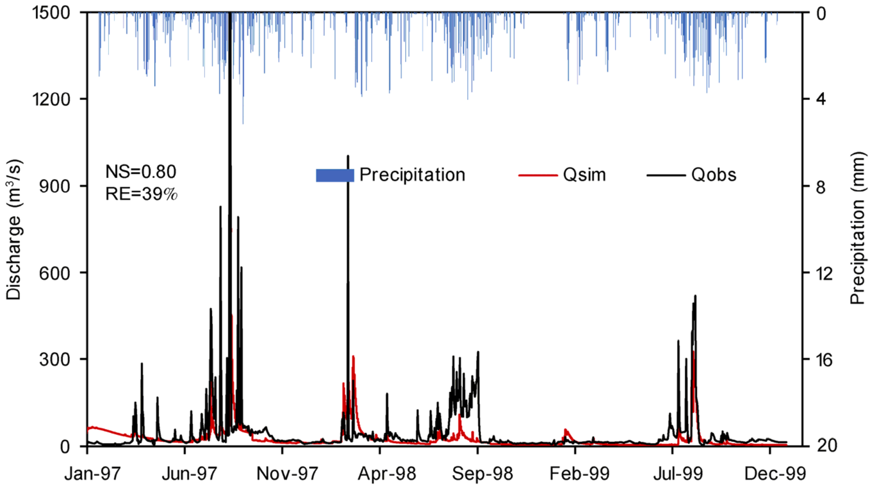

Figure 6 WEB-DHM calibration (1997) and validation in the Soan basin, Pakistan. Qsim is simulated discharge, Qobs is observed discharge, NS is Nash coefficient, and Re is relative error of the calibration.

with smaller standard deviation (less fluctuation) in the future. In case of drought discharge, three models (gfdl_cm2_0, gfdl_cm2_1 and miroc3_2_medres) predicted a slight decrease in DDavg in the future showing more intense drought in the future as compared to past. The standard deviations of these values have a similar range of values for both the past and the future indicating that there is little difference in the fluctuations of the DDavg. Moreover, two models have shown a decrease (gfdl_cm2_0 and gfdl_cm2_1) and two models (miroc3_2_medres and miroc3_2_hires) have predicted an increase in the longest number of days per year below DDavg. The results are thus rather inconclusive in terms of future droughts.

3.2.2 Philippines

(i) Summary description

The Angat river basin (1085 km^2), lies on the Luzon island, along the Cordillera Mountain ranges north-east of the Metro Manila city. It is covered mostly by dense secondary forests (broadleaf deciduous trees) and clay and clay loam soils. The total area considered for simulation delineated by

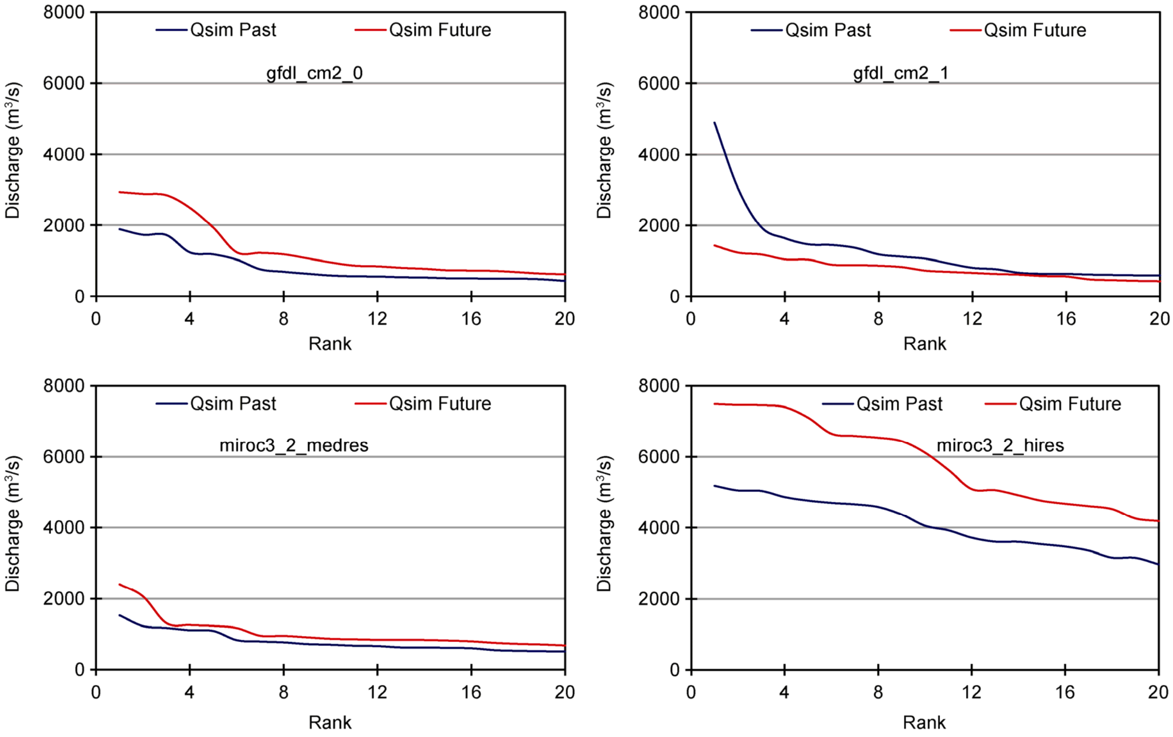

Figure 7 Climate trends of the top 20 peak discharges during 20 years for past and future. The Soan river basin, Pakistan.

using the DEM (to reduce errors that very flat areas may cause during simulation) was 888 km^2. From the Shuttle Radar Topography Mission (SRTM) DEM, minimum elevation is 17 m amsl in the Bulacan area while maximum elevation is 1219 m in the Cordillera Mountain Ranges (Figure 8). The Angat dam reservoir is the main domestic water source of Metro Manila. Additionally water from the dam is used for irrigation of agricultural areas in Bulacan and utilized for hydropower generation. Hence, this river basin is one of the most important water resources in the country. Hydrological simulation considers static and dynamic parameters that would closely represent the present conditions of this basin. There is the Umiray-Angat conveyance tunnel in the basin bringing in waters from the Umiray basin located eastward. The conveyance tunnel data were available from 2001 through 2010 and were incorporated into the WEB-DHM calibration (2002) and validation (2001–2009) (Figure 9). In addition, the model performance was evaluated for soil moisture by using surface soil moisture data produced by LDAS-UT. The model grid size was 500 m. The input data are summarized in Table 5.

(ii) Results

For this study, 6 models were selected using the scoring method described above: gfdl_cm2_0, gfdl_cm2_1, ipsl_cm4 (Institut Pierre Simon Laplace (IPSL), France), ingv_echam4 (National Institute of Geophysics and Volcanology (INGV), Italy), csiro_mk3_0 (Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia), miroc_3_2_medres. Peak flow results are depicted in Figure 10 and show that all models predicted an increase in possible floods, with a great increase of the highest peak discharge within the investigated 20-year period (1.5x–6x higher in the future than in the past), while other 19 peak flows increased only moderately. The results suggest that very probably the intensity of more frequent lower floods will increase moderately but the extreme floods may become significantly more severe in the future.

The results of drought analysis are summarized in Table 6. Three out of six selected models (miroc3_2_medres, gfdl_cm2_0, and gfdl_cm2_1) predicted slight decrease in the average daily discharge ADavg, while the other three (ingv_echam4, ipsl_cm4 , and csiro_mk3_0) indicated an increasing trend with ipsl_cm4 predicting almost double value. However, results of all the models showed a larger standard deviation of ADavg, suggesting much higher fluctuation of daily discharge in the future. Further, five models showed very little difference in DDavg between the past and the future (a slight increase of DDavg in the future) and also, the standard deviations of these outputs had similar range of values, indicating the little difference in drought between the past and the future. Only in case of the ipsl_cm4 model the future DDavg was significantly higher indicating less severe drought with corresponding significant decrease in the longest number of days with discharge below DDavg (zero days predicted in the future). In addition, the longest number of drought days decreased for the ingv_echam4 and gfdl_cm2_1 models, while increasing trend was

Table 5 Input data of the Philippines study

Data	Spatial resolution	Temporal Res.	Source
DEM	500 m	Static	Hydrosheds (http://hydrosheds.cr.usgs.gov/index.php) (90 m-SRTM; reprocessed by the CTGIAR Consortium for Spatial Information)
Land Use	500 m	Static	Global, USGS
Soil type/local	500 m	Static	FAO
Discharge	Point (Angat gauge)	Daily	National Irrigation Agency (NIA), PAGASA
Precipitation	Local Gauge Data, 46 stations (within and around the basin); spatially interpolated by Inverse Distance (IDW) method)	Daily	Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA)
Meteorological data (Shortwave and longwave radiation, wind speed, humidity, air pressure, air temperature)	Local Gauge Data, 46 stations (within and around the basin); spatially interpolated by IDW	Daily	PAGASA
Vegetation indices: LAI, FPAR	Gridded (1 km)	8-day average	MODIS Terra

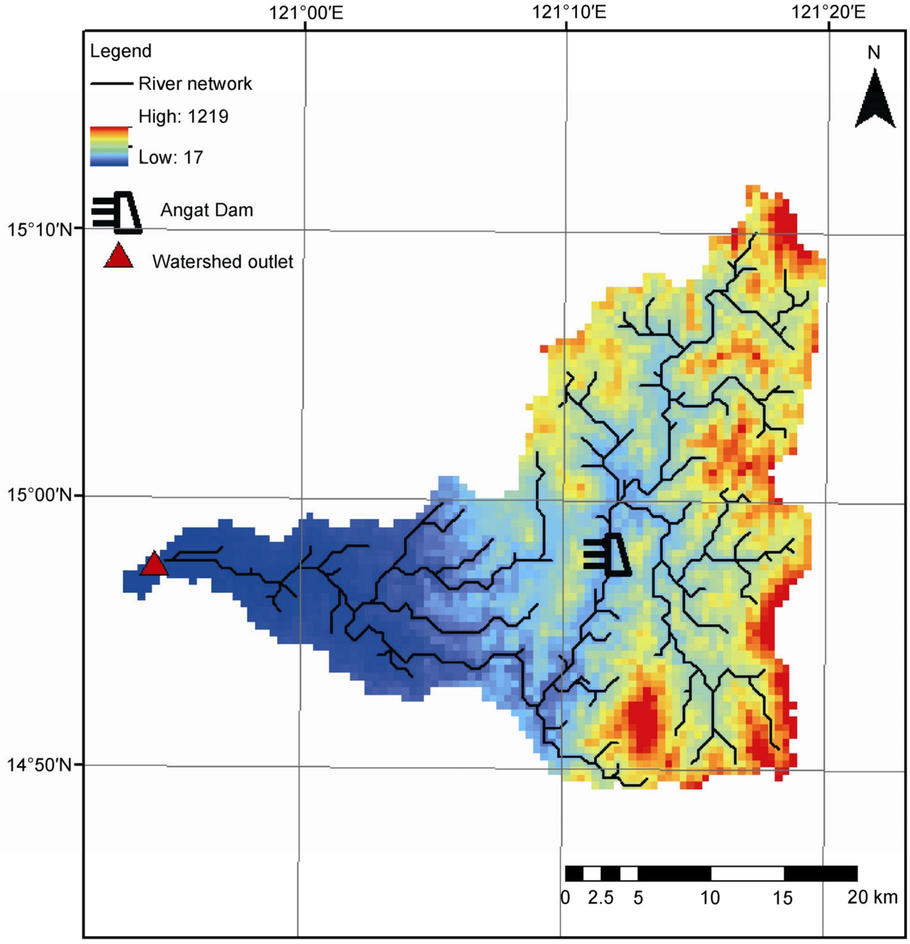

Figure 8 Angat River Basin, Philippines: river network and elevation.

observed for the remaining three models (miroc3_2_medres, gfdl_ cm2_0, csiro_mk3_0). The results are rather inconclusive in terms of drought frequencies and durations but indicate that intensities may not be significantly increasing. In this context, Jaranilla-Sanchez et al. (2013) observed that the dense forest of the Angat basin is essential for lowering the effect of climate change on drought intensification.

3.2.3 Vietnam

(i) Summary description

The Huong River basin is a major source of water for irrigated agriculture and aquaculture, and for industry and energy generation in the coastal area of the Thua Thien Hue Province, central Vietnam. More than 80% of the area is mountainous and hilly terrain with the average basin altitude of 330 m and the average basin slope of 28.5%. The topography changes rapidly from the upper stream down to the plain, without a transition area, which results in a high runoff in the rainy season with large floods and inundation across wide areas. The main river channel runs south-north, passing the city of Hue then flowing into the Tam Giang-Cau Hai lagoon system. The basin has recorded the highest rainfall in Vietnam, with more than 5000 mm per year in the mountainous part and 3000 mm per year in Hue (Saavedra et al., 2009), with the rainy season lasting from September through November when also main typhoon activity occurs. The present study focused on the 1600 km^2 basin drained down to the Kim Long station (Figure 11). The WEB-DHM model was developed with 500 m grid size and calibrated and validated for the rainy seasons in the years 2006 and 2007 against the observed discharge at the Kim Long station (Figure 12). The input data are summarized in Table 7.

(ii) Results

Five GCMs were selected as suitable for the region of the Huong basin, namely: gfdl_cm2_1, giss_aom (by NASA/ Goddard Institute for Space Studies), miroc3_2_hires, miroc3_2_medres, and miub_echo_g (by Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA, and Model and Data group). All the models predicted an increase in the extreme peak flow intensity in the future, however intensities of lower floods (lower ranks of peak discharge) did not change (Figure 13). Also, all the models predicted an increase in the average daily discharge ADavg and in case of five of them the standard deviation of ADavg also increased, suggesting larger variation in daily discharges in the future (Table 8). At the same time, all the models indicated a decreasing trend in DDavg. The standard deviations have a similar range of values for both the past and the future indicating also similar fluctuations of the DDavg. The longest numbers of days per year with discharge below DDavg were predicted to increase by four models while the giss_aom model suggested decrease of this value. The results indicate that higher extreme peak flows may be expected in the future but at the same time, the low flows will decrease, intensifying the droughts during dry seasons. Therefore, appropriate adaptation measures should be sought to store the likely excess water during wet season for supplementing it during

Table 6 Summary of drought trends in the Angat River Basin, Philippines[a)]

Models	Average Daily Discharge, ADavg (m^3/s) (Average of average daily discharge for 20 years)		Drought Discharge, DDavg (m^3/s) (Average of 355th rank for twenty years)		Longest no. of days/year below DDavg	
	Past	Future	Past	Future	Past	Future
miroc3_2_medres	28.28±7.59	27.78±13.54	0.14±0.02	0.15±0.04	100	135
ipsl_cm4	35.32±9.03	63.71±13.83	1.85±0.24	6.5±0.57	57	0
ingv_echam4	32.86±5.45	35.40±6.97	0.17±0.02	0.19±0.04	104	74
gfdl_cm2_1	32.63±10.64	31.28±12.34	0.16±0.02	0.17±0.04	134	88
gfdl_cm2_0	35.02±10.97	34.19±11.97	0.17±0.42	0.18±0.47	166	254
csiro_mk3_0	28.54±7.89	30.34±13.84	0.15±0.28	0.15±0.05	99	102

a) Average values calculated over the 20 years of baseline period (past) and future projection period (future) and mentioned with standard deviation.

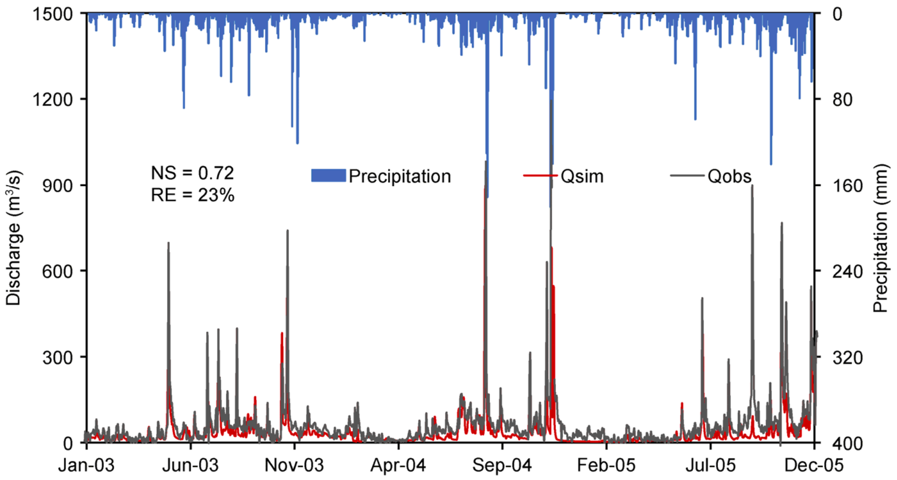

Figure 9 WEB-DHM calibration (2003) and validation in the Angat basin, Philippines. Qsim is simulated discharge, Qobs is observed discharge, NS is Nash coefficient, and Re is relative error of the calibration.

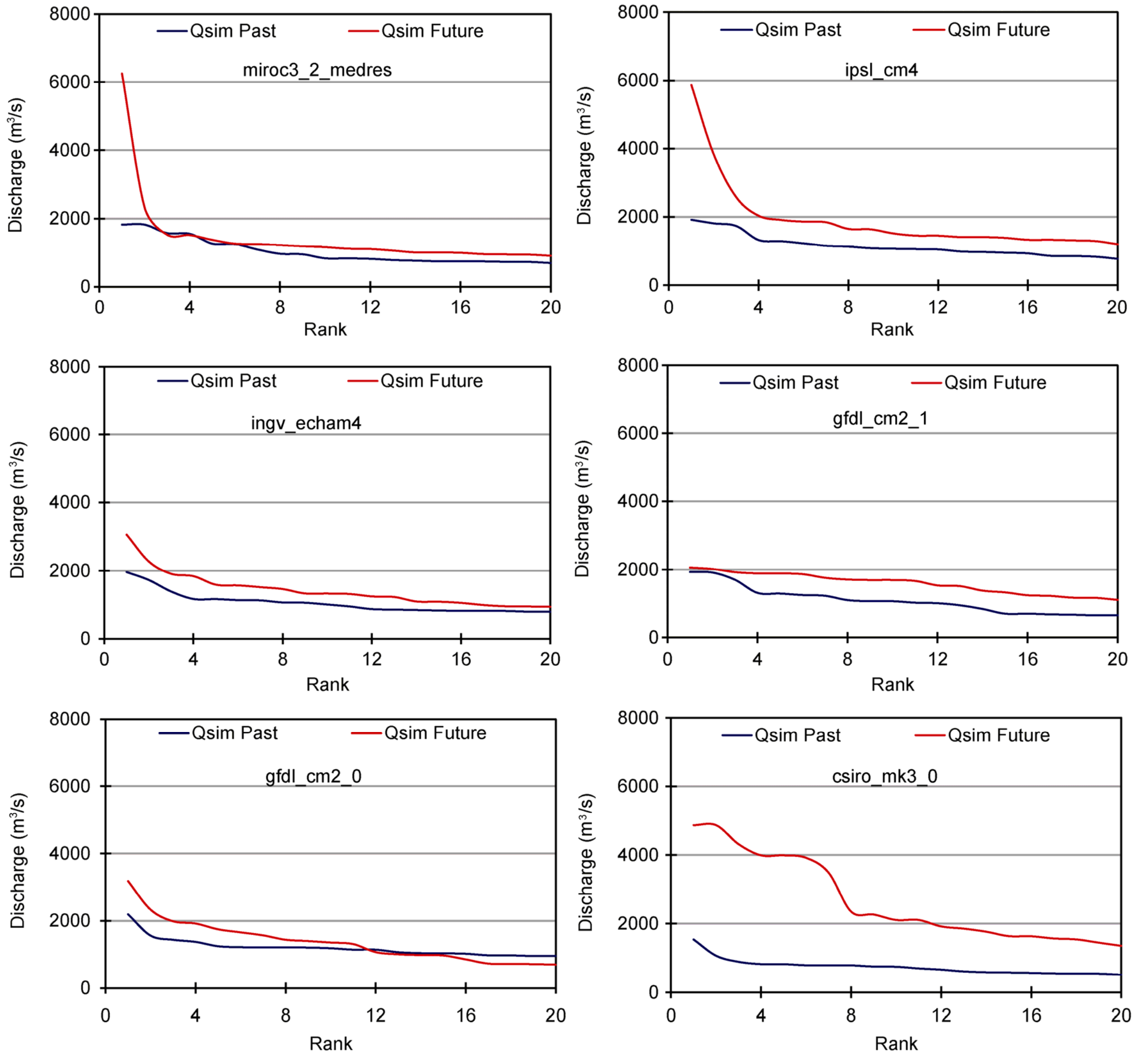

Figure 10 Climate trends of the top 20 peak discharges during 20 years for past and future. The Angat river basin, Philippines.

Table 7 Input data of the Vietnam study

Data	Spatial resolution	Temporal res.	Source
DEM	500 m	Static	Hydrosheds (http://hydrosheds.cr.usgs.gov/index.php) (90 m-SRTM; reprocessed by the CTGIAR Consortium for Spatial Information)
Land Use	500 m	Static	Global, USGS
Soil type/local	500 m	Static	FAO
Discharge	Point (Kim Long)	Daily	Provided by AWCI
Precipitation	Local Gauge Data, spatially interpolated by Inverse Distance (IDW) method)	Daily	Local Met Office
Meteorological data (Shortwave and longwave radiation, wind speed, humidity, air pressure, air temperature)	Gridded	6-hourly	Japan Reanalysis JRA-25, JMA
Vegetation indices: LAI, FPAR	Gridded (1 km)	8-day average	MODIS Terra

droughts.

The three presented studies illustrate how climate change may affect hydrological regimes in basins under different climate conditions in Asia. While more studies in a particular region must be done to confirm the tendencies, the current results indicate that higher variability of discharges may be expected in rather humid basins, with a likely increase in very extreme floods and extension of periods with lower discharges. On the other hand, the results for a semi-arid basin were not conclusive in terms of drought but indicated a similar trend for extreme peak flows, i.e. an increase in the future.

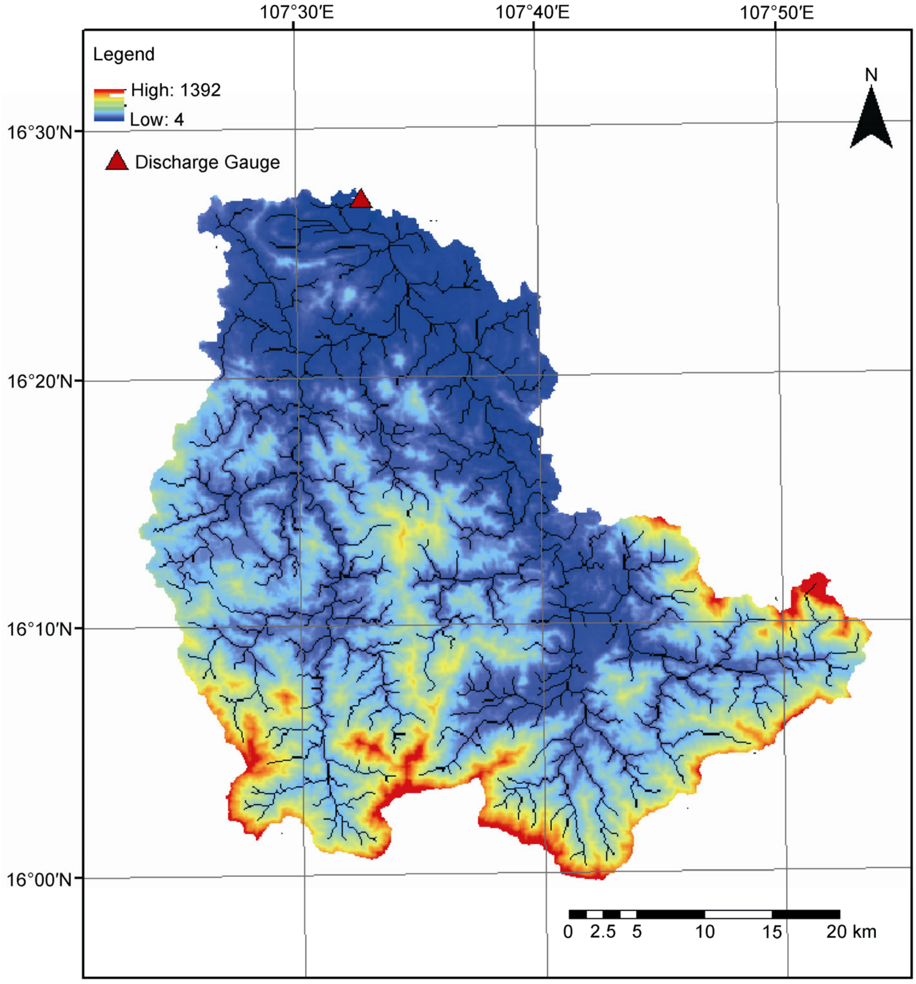

Figure 11 Huong River Basin, Vietnam: river network and elevation.

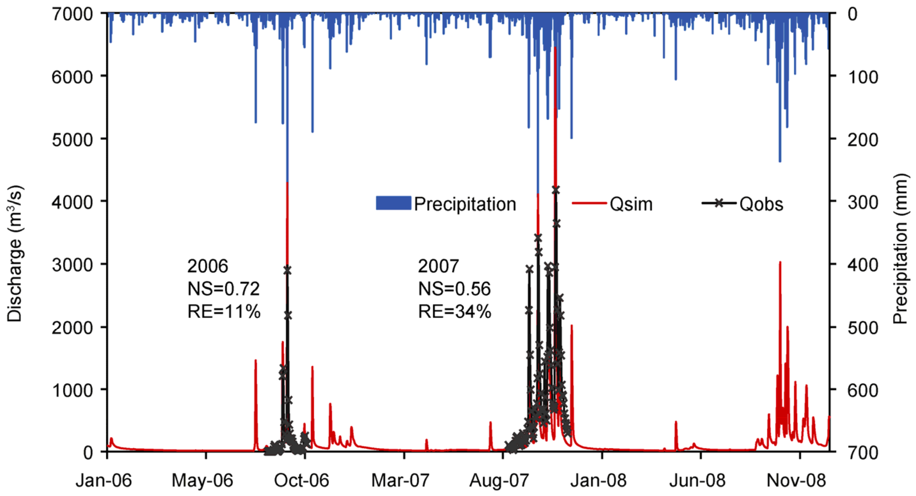

Figure 12 WEB-DHM calibration in the Huong basin, Vietnam. Calibration done for Sep-Oct 2006 and Sep-Nov 2007, when discharge data was available. Qsim is simulated discharge, Qobs is observed discharge, NS is Nash coefficient, and Re is relative error of the calibration.

Table 8 Summary of drought trends in the Huong River Basin, Vietnam[a)]

Models	Average Daily Discharge, ADavg (m^3/s) (Average of average daily discharge for 20 years)		Drought Discharge, DDavg (m^3/s) (Average of 355th rank for twenty years)		Longest no. of days/year below DDavg	
	Past	Future	Past	Future	Past	Future
gfdl_cm2_1	108.92±41.03	110.83±42.07	11.93±3.75	10.43±2.42	114	148
giss_aom	105.80±41.24	126.43±29.92	13.40±2.57	11.95±3.40	189	169
miroc3_2_hires	109.44±37.64	126.37±37.36	13.67±2.69	9.56±3.07	94	170
miroc3_2_medres	110.82±35.05	112.32±44.94	12.66±3.12	7.89±2.55	114	154
miub_echo_g	109.39±35.51	141.28±48.82	10.02±2.20	7.20±2.03	103	125

a) average values calculated over the 20 years of baseline period (past) and future projection period (future) and mentioned with standard deviation).

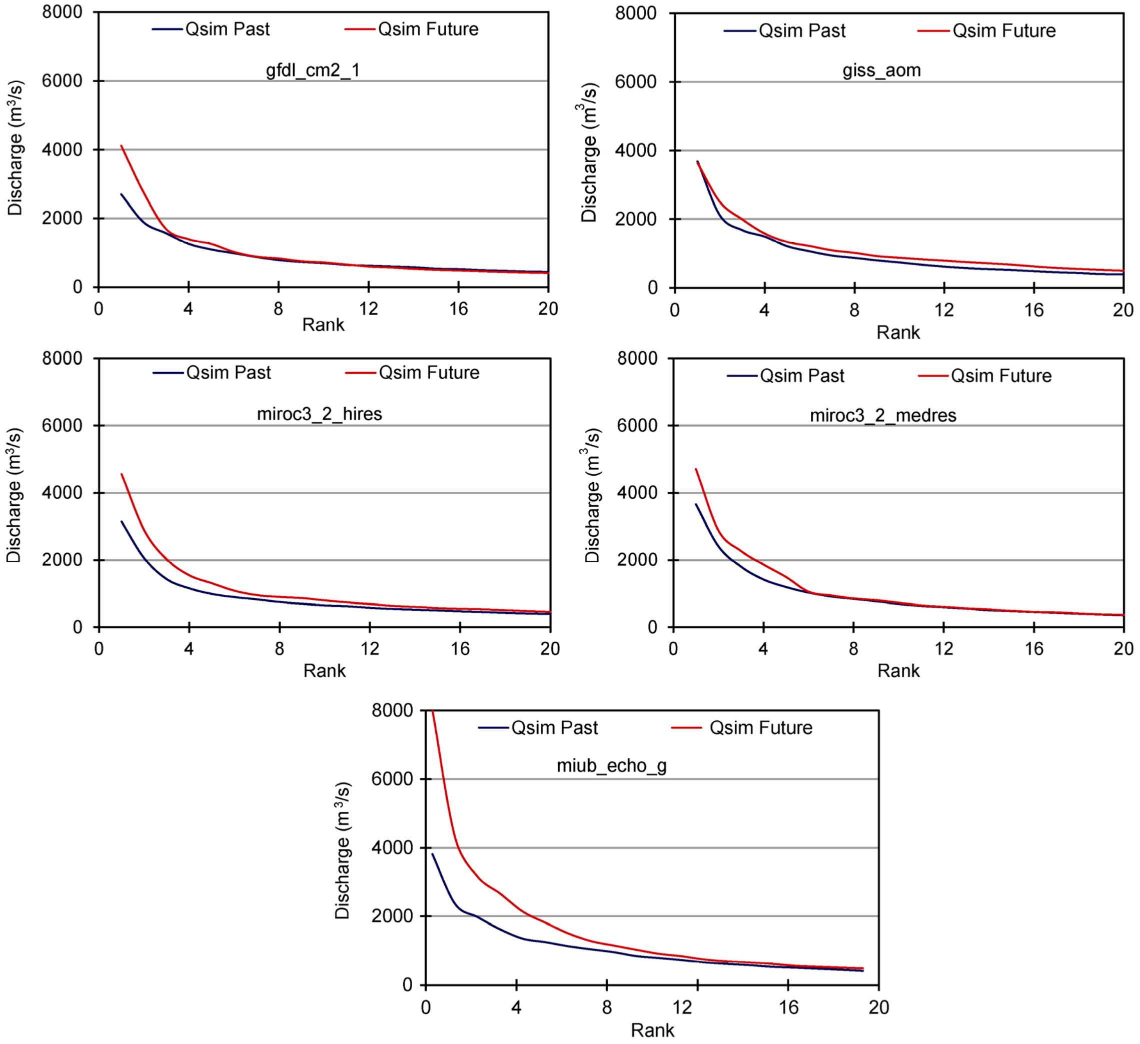

Figure 13 Climate trends of the top 20 peak discharges during 20 years for past and future. Huong river basin, Vietnam.

It should be noted, that all these simulations were under the assumption that climatology will be similar in the future as it was in the past. However, even after bias correction and temporal downscaling, only the intensities and frequency of the extreme events could be simulated. Further studies are still needed to improve the timing as to when the extreme events occur. Hence, careful considerations of these assumptions are needed prior to application of the results.

4 Conclusions

The presented project undertook the effort to develop a river management system based on data integration approach for a set of 18 demonstration basins in GEOSS AWCI countries, which included (1) development and adaptation of suitable hydrological modeling tools (WEB-DHM, WEB-DHM-S, satellite data retrieval algorithms, drought analysis method–standard anomaly indices) and climate change assessment techniques (GCM bias correction and statistical downscaling); (2) collection and quality control of *in-situ* data from the selected basins, equipping them with standardized metadata and archiving in the DIAS database; (3) carrying out pilot cases including climate change impact assessment analyses and demonstrating the capabilities and benefits of the system to policy- and decision-makers and other relevant stakeholders; and (4) promoting implementation in operational use and/or other practical applications and accomplishing these in several cases.

The completed demonstration applications have proven benefits of data integration approach that exploits sophisticated capabilities of complex data bases provided by data centers like DIAS. It also confirmed robustness and suitability of the WEB-DHM and WEB-DHM-S models as earth observation data integrator for hydrological analyses in all the studied basins. Coupled with other tools and techniques, it provides relevant information for water resources management at the basin level (e.g. drought analysis, flood prediction, dam operation optimization). In addition, the system is also suitable for assessment of climate change impact on basin hydrology and water budgets. The finding of the conducted full extent climate change assessment studies underlines the need to thoroughly explore the consequences of climate change on floods behavior and droughts by further integrating the hydrological outputs with socio-economic models to ensure water security for multiple purposes.

In addition, the statistical bias correction and statistical downscaling methods used in the presented studies have well known limitations in estimating extreme heavy rainfall intensity as well as frequency with seasonal consistency and it requires long observation records in the past with relatively dense coverage, which is often lacking in the developing countries. On the other hand, dynamical downscaling method using regional climate models can produce spatially, temporarily, and statistically consistent results with observation but requires very high spatial resolution and thus is computationally very expensive. Therefore, a newly emerging approach combining the dynamical downscaling with statistical bias correction has been considered for application in the AWCI countries and pilot studies carried out in the Yoshino river basin, Shikoku, Japan (Rasmy et al., 2013) and the Tone river basin, Japan (Rasmy et al., 2014a). This approach reduces the computational burden and overcomes biases of RCMs by utilizing long-term observations, while maintaining the effect of finer scale features (e.g. orography) and spatial/temporal continuity simulated by RCMs. In addition, the approach will be used with the Pseudo Global Warming Downscale (PGW-DS) method, which utilizes long-term reanalysis datasets as boundary conditions for nesting RCMs in past simulations to overcome strong biases in parent GCMs (Kawase et al., 2009, Yoshikane et at., 2012).

Furthermore, an intention is to include a coupled land-atmosphere data assimilation function on the System. Details of development of such tool and its great potential for river basin scale hydrological applications are provided in Rasmy et al. (2011), Rasmy et al. (2012), and Rasmy et al. (2014b).

The AWCI efforts have also included capacity building activities and local country teams have been encouraged to take the ownership over the activities and evolve them further in the most suitable manner for their country specific conditions while taking advantage of the international collaborative framework of GEOSS AWCI.

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