BRITISH GEOLOGICAL SURVEY

Philippine National Hydrological Model

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Executive summary

The Philippine National Hydrological Model is the first national-scale hydrological model of the country. Its primary purpose is to quantify components of the hydrological cycle at the national level, with model outputs of Spatio-temporal patterns of:

- precipitation
- evapotranspiration
- surface runoff
- river flow
- groundwater recharge
- groundwater flow

The model has been developed using a version of the macroscale hydrological modelling software Variable Infiltration Capacity (VIC), into which a gridded groundwater model has been added so that it simulates the integrated surface water and groundwater system. The model has been constructed using openly available global datasets and calibrated against local observations, principally of river flows. The resulting modelling framework provides a means to develop understanding of the water resources across the Philippines and aims to support future national water resources planning.

We present a summary of the results of the model using monthly district averaged components of the water cycle. We also briefly describe some of the potential benefits of the continued development and improvement of the model and of its future use.

Introduction

Over the past decade, the Philippines has improved its national water security index and now lies within the top third of Asian countries (Asian Development Bank, 2020). Nevertheless, changing climate and increasing urban population are putting more stress on water resources. Decreasing rainfall during the dry season and more intense rainfall during the wet season will exacerbate both water availability during periods of drought and the magnitude of flood events during periods of heavy rainfall. There has therefore been a need for a national-scale hydrological model to assess the current state of and future changes to water availability across the country.

Development of the Philippine National Hydrological Model began under the Philippine Groundwater Outlook (PhiGO) project, which was a collaboration between the British Geological Survey (BGS), Ateneo de Manila University (ADMU) and the Philippines National Water Resources Board (NWRB). The project was jointly funded under the NERC-Newton and DOST-PCIEERD programme 'Understanding the impacts of hydrometeorological hazards in South-east Asia' (project NE/S003118/1).

Models of the island of Panay and the province of Pampanga were developed under PhiGO. Using subsequent funding from BGS's International Geoscience Research and Development programme, the model was then expanded to cover the whole of the Philippines.

This report provides an overview of the Philippine National Hydrological Model and summarises the outputs, which are also published on a web portal[1].

[1] https://mapapps.bgs.ac.uk/philippines-national-hydrological-model

Model description

To simulate the hydrology of the Philippines, we used the integrated VIC hydrological model coupled to a lateral groundwater flow model (VIC-AMBHAS) (Figure 1), as developed by Scheidegger et al. (2021). VIC is a macroscale hydrological model that has been widely used for water and energy balance studies (Hamman et al., 2018). The model describes full water and energy transport over a grid cell. When precipitation reaches the land surface, it is partitioned into runoff and infiltration. To accumulate flows at river gauging stations, routing of runoff and baseflow is performed by post-processing model output (Lohmann et al., 1996).

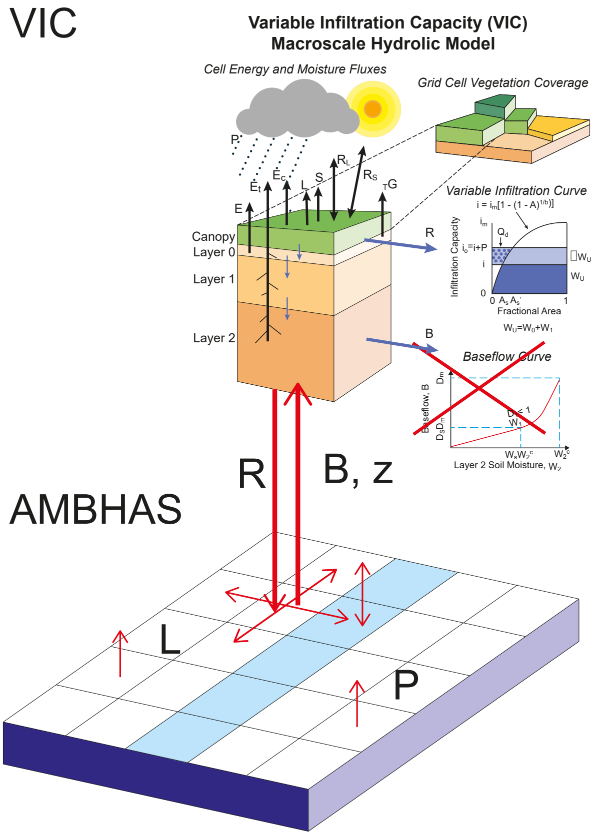

Figure 1 VIC-AMBHAS model framework. The soil column in VIC is coupled using bi-directional exchange of water between the soil and the aquifer. The aquifer allows for river baseflow, abstraction and leakage. BGS © UKRI.

The lateral groundwater model coupled to VIC is a distributed, one-layer, two-dimensional groundwater model driven by groundwater recharge and groundwater pumping. Groundwater recharge is derived from interaction of the groundwater model with the VIC soil by allowing bi-directional exchange of water between the aquifer and the soil. A full description of the lateral groundwater model and coupling to VIC is given in Scheidegger et al. (2021).

Model inputs and model outputs

The model is run on a 1/60° (approximately 2 km) grid across the country and is driven with openly available global datasets. The model is parameterised with spatially distributed parameters from a range of sources that describe the land surface, including soil properties and vegetation properties. Sources for the VIC model are:

- soil properties such as field capacity, plant-available water, wilting point, saturated hydraulic conductivity, and residual saturation: global high-resolution map of soil hydraulic properties (Zhang et al., 2018)
- quartz fraction and bulk density values: SoilGrid1km (Hengl et al., 2014)
- landcover vegetation parameters: Modis (Friedl and Sulla-Menashe, 2015)
- leaf area index and albedo: Copernicus (Copernicus Global Land Service, 2019)
- vegetation height: LiDAR-derived global estimates of forest canopy height (Healey et al., 2015)

The groundwater part of the model requires values for hydraulic conductivity and specific yield, which are classified based on the groundwater availability map of the Philippines (Bureau of Mines and Geo-Sciences and Ministry of Natural Resources, 1986). A full description of the model is given in Scheidegger et al. (2022).

The VIC model is driven by meteorological forcing data using a gridded, subdaily time-series of meteorological variables as input. The required variables are:

- average air temperature
- total precipitation
- atmospheric pressure
- incoming shortwave radiation
- incoming longwave radiation
- vapor pressure wind speed

For the historical simulation (1979 to 2018), ERA5 hourly data from 1979 to present are used (Hersbach et al., 2018). The meteorological forcing data is at 0.25°, which is a much coarser resolution than the soil and vegetation parameters. Therefore, the meteorological forcing data were downscaled to match the model grid using the delta method (Moreno and Hasenauer, 2016).

In order to find the best performing model, the soil infiltration capacity parameter, the soil thickness, the specific yield and the hydraulic conductivity of the aquifer were varied. The model was calibrated against observed river flows at gauging stations available from the National Hydrologic Data Collection Program (Department of Public Works and Highways, 2016). In order to increase the model skill, the model can be subdivided into different catchments and calibrated separately for each catchment.

In the future, other measures to evaluate the model could be included, such as soil moisture changes from remote sensing data, evapotranspiration and groundwater levels. This would improve the confidence of the variables separate to runoff.

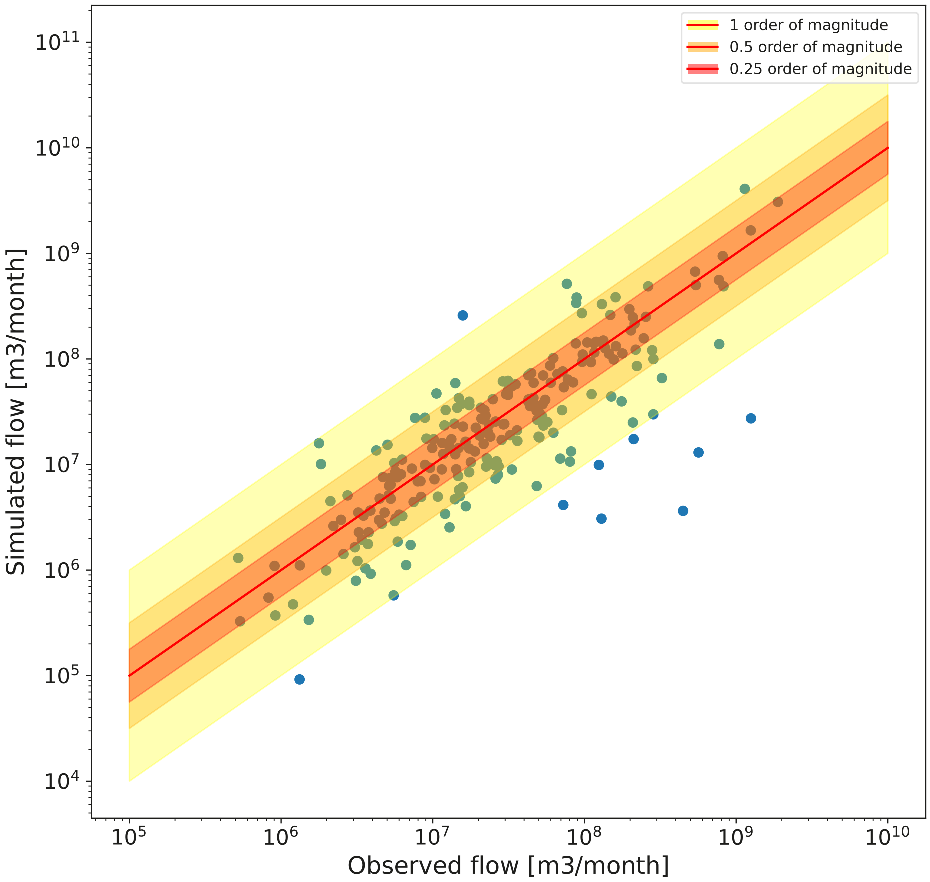

Figure 2 Comparison of simulated mean river flows and observed river flows obtained from Department of Public Works and Highways (2016).

Comparison of observed and simulated flow (Figure 2) shows that:

- 96 per cent of the simulated river flows are within one order of magnitude of the observed river flow
- 81 per cent are within half an order of magnitude of observed stream flow
- 55 per cent are within a quarter of order of magnitude

This means that, for a hypothetical stream flow of 10^8 m^3/month:

- one order of magnitude would be simulated flows between 10^7 m^3/month and 10^9 m^3/month
- half an order of magnitude would be between 3.2×10^7 m^3/month and 3.2×10^8 m^3/month
- a quarter order of magnitude would be between 5.6×10^7 m^3/month and 1.8×10^8 m^3/month

Only 28 per cent of the simulated river flows are within 26 per cent of observed flow.

Reasons for the discrepancy are many, from the model conceptualisation, the change in flow regime after the 1991 eruption of Mount Pinatubo, the lack of representing water management operations and irrigation practices, and the coarse resolution of the meteorological driving data and model parameterisation.

Simulated components of the water cycle

The model calculates evapotranspiration, runoff, infiltration, soil moisture, river baseflow and groundwater levels for each cell and six-hour time step. The full output can be viewed on the website, but an overview is given here.

Precipitation

Figure 3 shows that precipitation is generally highest in the northern and southern part of the country, with a maximum value of 318 mm/month in Lanao del Sur. The lowest precipitation is found on the islands to the south-west in Sulu with 125 mm/month, but generally, low values are found stretching from Pampanga along the eastern part of the country.

There is a strong difference in the annual signal: in Pampanga, there is a pronounced wet season from May to October and dry season runs from January to April. In Iloilo, the same seasonal pattern is visible; however, the minimum precipitation from January to April is higher than in Pampanga. In contrast, there is no dry season in the eastern part of the country

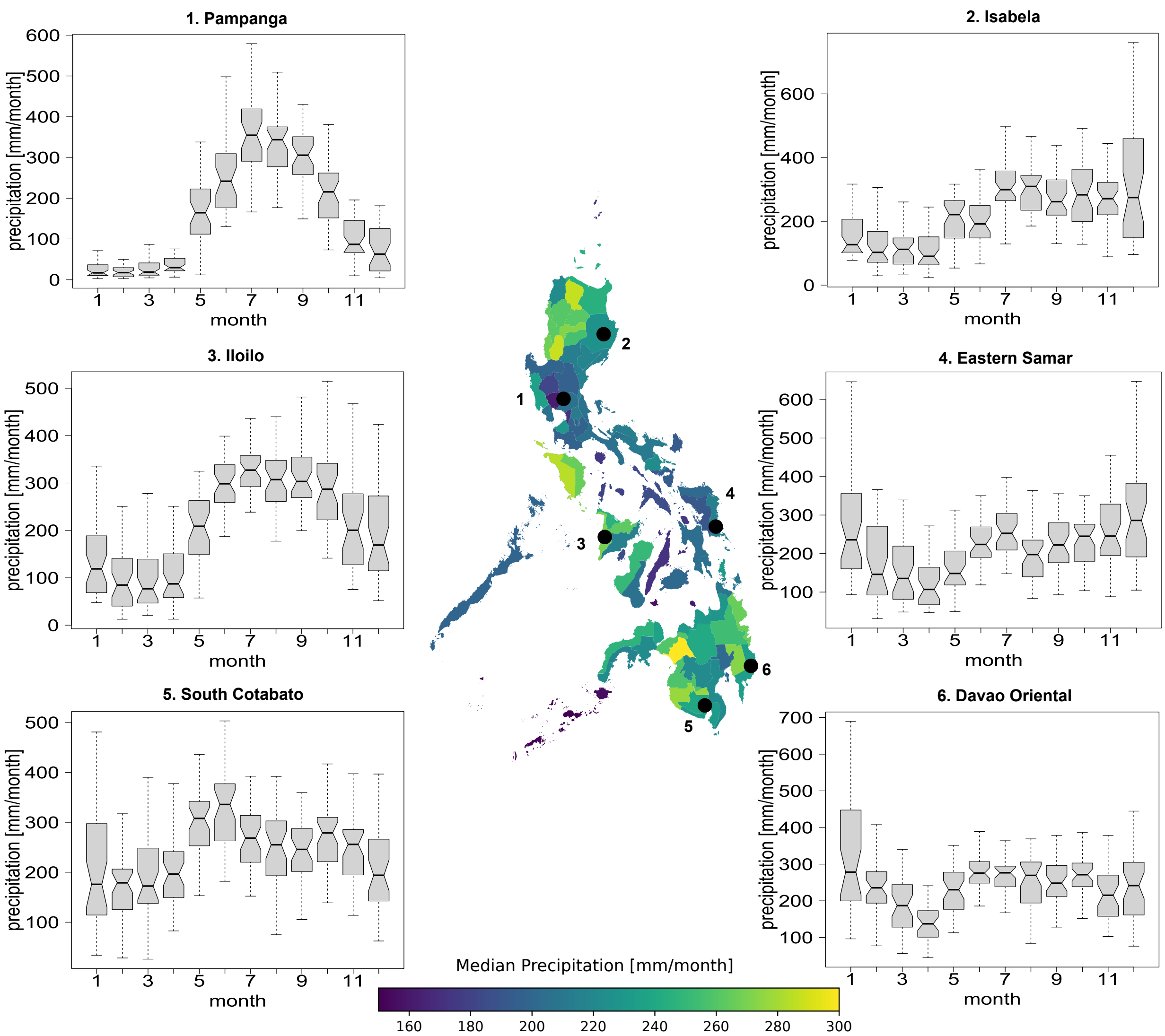

Figure 3 Median precipitation in mm/month based on downscaled ERA5 data (Hersbach et al., 2018, Moreno and Hasenauer, 2016) for six regions across the Philippines. Contains modified Copernicus Climate Change Service information (2023). BGS © UKRI.

and there is a very pronounced rainy season from December to February.

Evapotranspiraton

Figure 4 shows that evapotranspiration (a combination of transpiration from vegetation and evaporation from the soil) is generally highest in the southern part of the country, with maximum values in Sultan Kudarat of 161 mm/month, and lowest in the north-western part of the country, with minimum values in Pampanga of 86 mm/month. In Pampanga and Isabela, evapotranspiration peaks during the wet season. In Iloilo in the south, evapotranspiration is still highest during the wet season, however, it remains relatively high during the dry season due to the water availability from precipitation. In the eastern part of the country, there is no period of low evapotranspiration, following the signal from precipitation.

Recharge

Groundwater recharge is the flux from the soil to the aquifer and determines how much water the aquifer receives each year. Figure 5 shows that groundwater recharge is highest in the north-western part of the country, with maximum values in Benguet of 71 mm/month. Minimum values are found in the

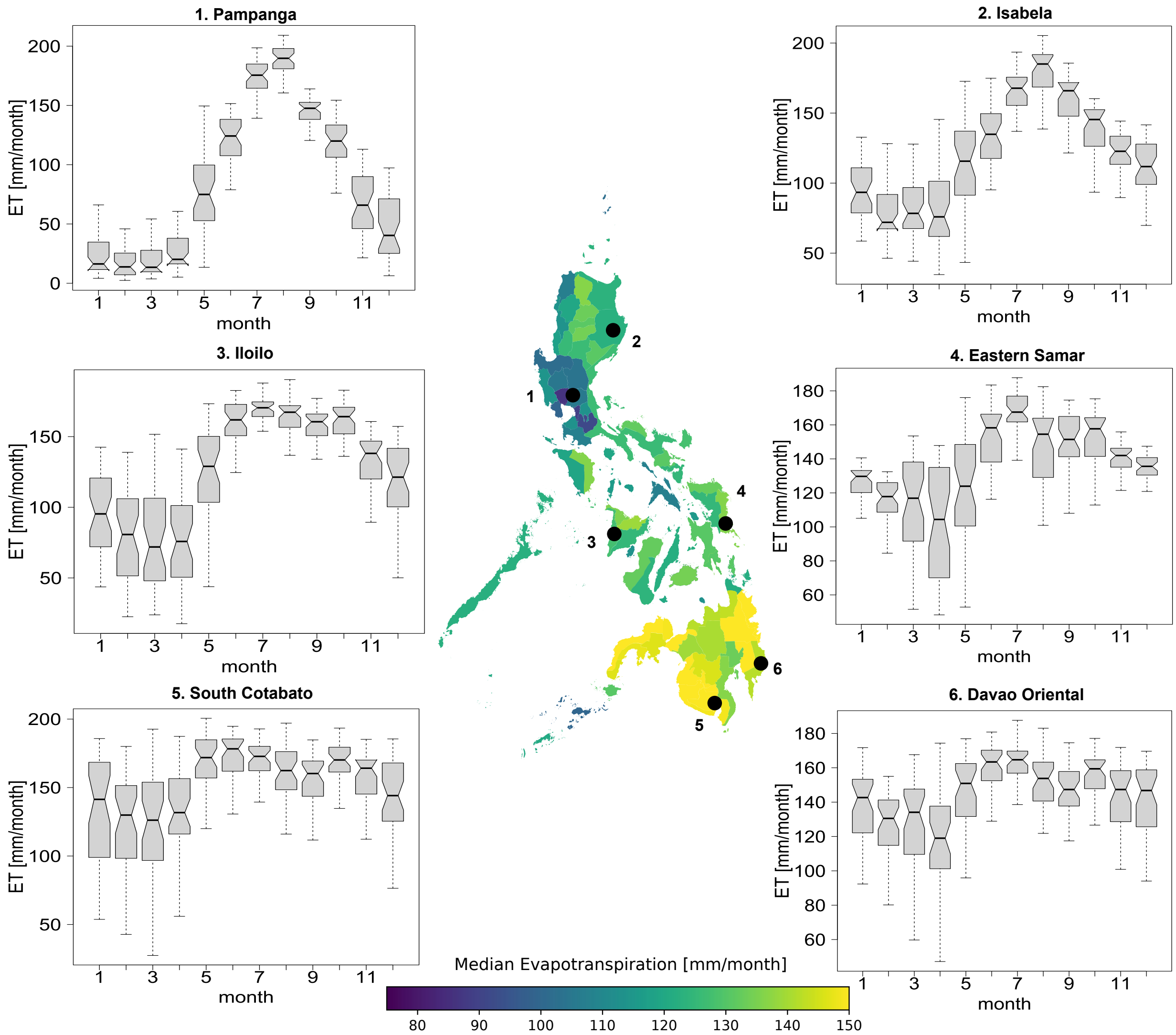

Figure 4 Median evapotranspiration in mm/month for six regions across the Philippines. BGS © UKRI.

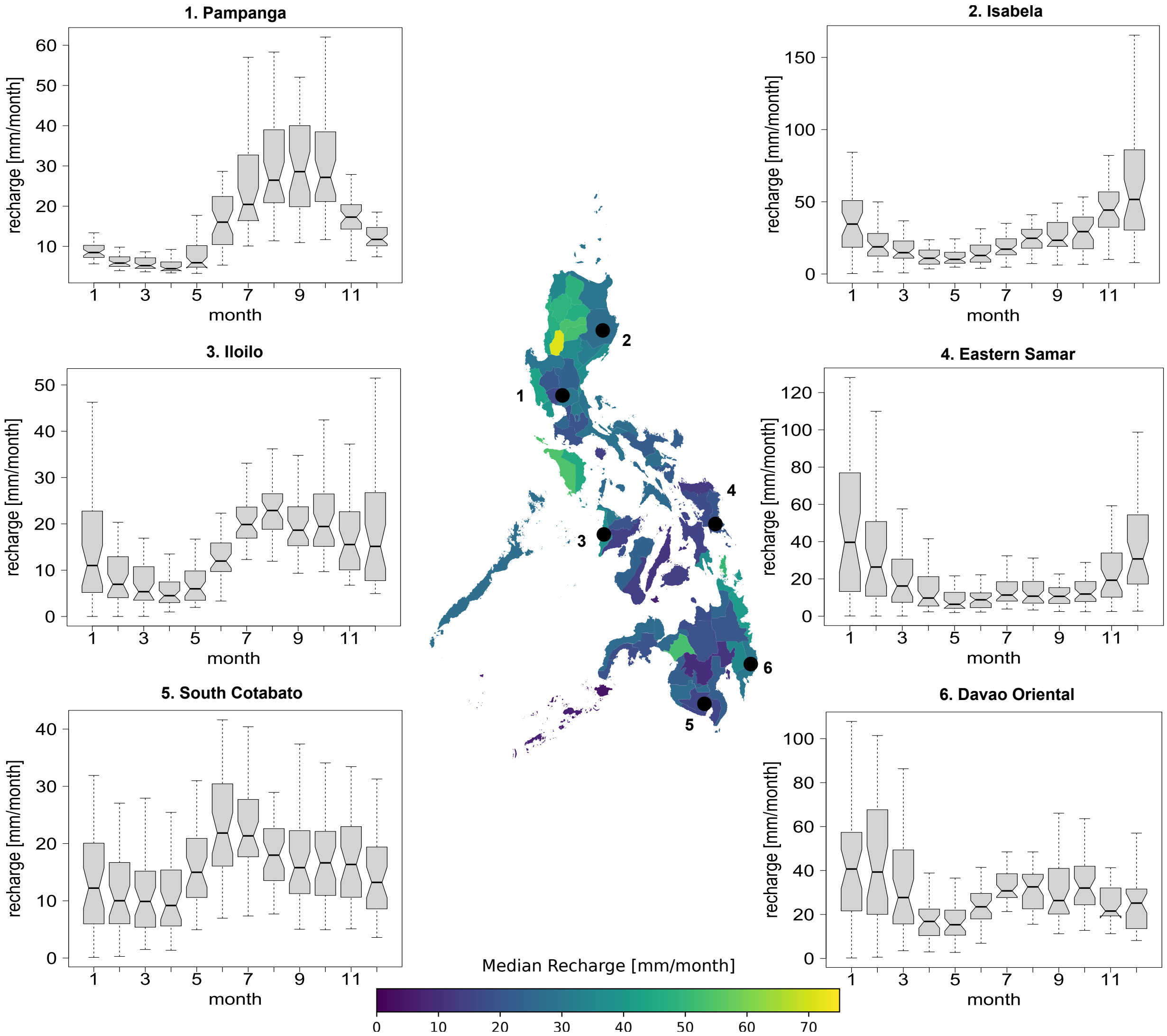

Figure 5 Median recharge in mm/month for six regions across the Philippines. BGS © UKRI.

islands to the south-west, with values in Basilan of 4 mm/month. As stated, the maximum values are found in Benguet, followed by Dinagat Islands, Occidental Mindoro and Mountain Province. The districts of Iloilo (14 mm/month) and Pampanga (16 mm/month) are at the lower end of the national groundwater recharge amounts.

Runoff and baseflow

Simulated runoff and baseflow were aggregated to derive river flows on a monthly time step. In Figure 6, these are compared to observed river flows (Department of Public Works and Highways, 2016) at a selected set of gauging stations on the largest rivers. The model simulates river flows reasonably well at these locations, though some of the peak flow events are not simulated well. As a result, extreme events are not well captured within the model; however, interannual variability is simulated reasonably well. In addition to model error there is, of course, uncertainty associated with the observations.

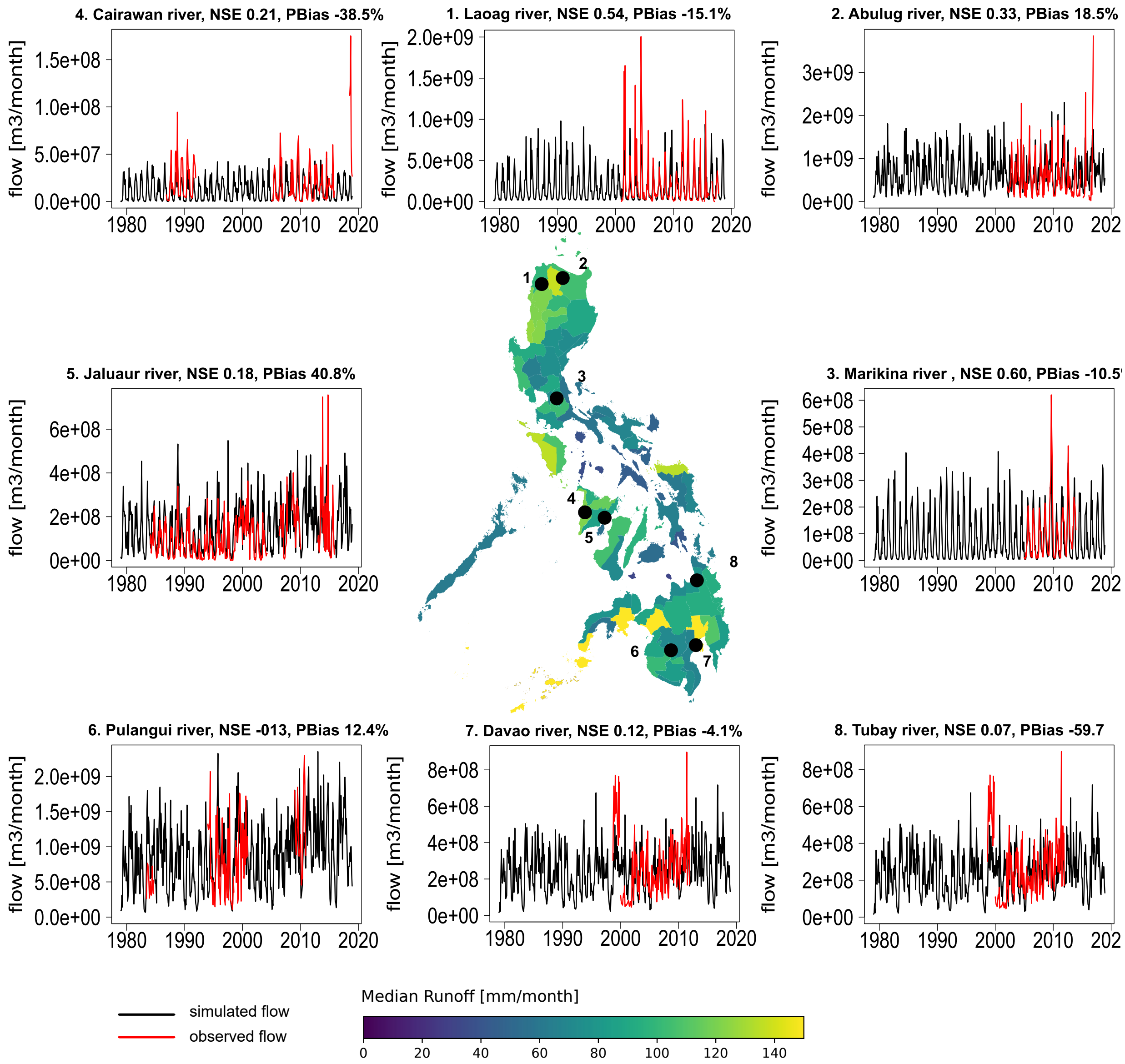

Figure 6 Median runoff in mm/month and simulated and observed stream flows (Department of Public Works and Highways, 2016) for eight gauging stations. BGS © UKRI.

Current status and future potential

This document briefly summarises the development of the first integrated surface and groundwater model of the Philippines through a collaboration between BGS, ADMU and NWRB. Whilst ongoing work is required to improve it (for example, representations of water use and irrigation practice need to be included) the results of this first version of the model are promising. We consider it to have the potential to underpin improved understanding of the hydrology of the Philippines, how future climate and anthropogenic change could affect water resources, and how management will need to adapt. Our vision is that it becomes a 'community model', that is, an openly accessible tool that is continually being developed by a range of users, and used by a variety of stakeholders in the Philippines, especially those responsible for regulating and managing the country's water resources and environment. There are challenges in doing this, but this vision is certainly achievable if we can build a community of interested researchers and stakeholders.

Contact

If you'd like to know more, please contact us by emailing enquiries@bgs.ac.uk.

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