Negotiation-support toolkit for learning landscapes

Editors
MEINE VAN NOORDWIJK
BETHA LUSIANA
BERIA LEIMONA
SONYA DEWI
DIAH WULANDARI

WORLD AGROFORESTRY CENTRE
Southeast Asia Regional Program

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31 | Rainfall simulator **(RainyDay)** and spatial rainfall **(SpatRain)**

Meine van Noordwijk, Lisa Tanika, Desi A. Suyamto, Rachmat Mulia, Betha Lusiana and Ai Farida

Rainfall Simulator (RainyDay) generates daily rainfall based on annual rainfall characteristics and an assumption that rainfall patterns follow statistical distribution functions, such as Weibull and Gamma. The model takes into account day-to-day variations in rainfall events as well as different patterns of rainfall across time or seasons. The model operates in MS Excel.

Spatial Rainfall (SpatRain) is a statistical tool to generate event-level rainfall maps across a watershed that represent the observed partial spatial correlation between daily rainfall at multiple locations. The results can be used by hydrological models that assess the influence of rainfall at watershed level on the scaling of river flow and its degree of buffering and flow persistence.

Introduction

Most hydrological and ecological models need daily rainfall data as input. Such a dataset is, however, not always readily available because, for example, the high cost of buying daily data from a weather-recording institution, human error in reading the daily rainfall amount from installed equipment in the field or a rainfall record that tends to produce rainfall data over several days so wet and dry days tend to be clumped together. Some studies can also need an extrapolation of rain events, for example, for simulations of hydrological process over 100 years into the future. An appropriate method to generate daily rainfall data is thus necessary.

RainyDay generates daily rainfall based on two main steps: 1) simulating rainfall occurrence, that is, determining whether or not a day is a rainy day; and 2) if rainfall occurs, determining the amount of rainfall on that wet day. Rainfall occurrence is simulated using a Markov chain model, while amount of rainfall is determined using Weibull and Gamma distribution functions.

Variations in river flow tend to decrease with an increasing area of consideration, partly owing to a decrease in temporal correlation of rainfall events across space. Patchiness of rainfall can contribute to an increase of crop-yield stability over space. To what degree does rainfall variability enhance stability of river flow? How do land cover and spatial patterns of rainfall interact in preventing flashiness of river flow? Being able to answer these questions is important for watershed management. The answers can determine how much changes one can expect from land rehabilitation efforts improveme watershed functions.

A hydrological model can answer these questions. However, a model requires the availability of rainfall data based on a dense network of rain gauges across a watershed. In the absence of such data, which is usually the case, especially in developing countries, a rainfall generator that can produce realistically resampled rainfall maps across a watershed is essential. Existing rainfall simulators, such as the ones included in WaNuLCAS and GenRiver, focus on station-level time series, not on the space/time autocorrelation that matters at higher scales.

Objectives

The objective of RainyDay is to generate daily data from monthly rainfall data.

The objective of SpatRain is to generate time series of rainfall that are fully compatible with existing station-level records of daily rainfall but yet can represent substantially different degrees of spatial autocorrelation. Using semivariance as as a function of increasing distance between observation points, SpatRain is also able to characterize the resulting rainfall patterns accumulated over specified lengths of time (days, weeks, months, years).

Steps in RainyDay

1. Prepare a minimum of one year's daily rainfall data as an input. These data are used to extract the characteristics of rainfall, that is, the wettest month, the month with the highest daily rainfall, the number of wet days, the monthly wet fraction, the monthly relative wet persistence and parameters for Weibull distribution.
2. Parameterize the model.
3. Generate daily rainfall data that has the closest characteristics to actual rainfall data.

Steps involved in SpatRain

Calculations start from the assumed spatial characteristics of a single rainstorm pathway, with a trajectory for the core area of the highest intensity and a decrease of rainfall intensity with increasing distance from this core. The model can derive daily amounts of rainfall for a grid of observation points by considering the possibility of multiple storm events per day but not exceeding the long-term maximum of observed station-level rainfall. Options exist for including elevation effects on rainfall amount.

SpatRain adheres to the following rules.

1. The simulated rainfall for any point in the landscape must be consistent with existing data on the frequency distribution of daily rainfall.
2. SpatRain must allow for spatial trends in the rainfall average (mean), for example, due to elevational effects.
3. SpatRain analyzes semivariance as a function of increasing distance between observation points as a way to characterize the resulting rainfall patterns accumulated over specified lengths of time and identify the storm-level parameters that lead to specified degrees of spatial correlation.
4. For use in combination with a hydrological model, SpatRain should allow for the
    a. identification of sub-catchments in a watershed area and allow averaging the point grid; and
    b. pattern to derive the daily average rainfall per sub-catchment.

The following steps are carried out prior to running SpatRain.

1. Calculate assumed storm (rain) properties.
2. Synchronize spatial pattern with temporal pattern.
3. Generate multiple storm events.
4. Calculate storm events probability.
5. Calculate patchiness indicator using semivariogram.

Case study: RainyDay in Sumberjaya

We applied RainyDay in Sumberjaya catchment, Lampung, Indonesia. Land use in the area was mostly (70%) coffee plantations. A reservoir for a hydroelectric plant was located downstream. The plant's management were concerned that the coffee plantations, which had been converted from forests, would disrupt the stability of river flow. They were interested in using a model to assess the hydrological function of the watershed. However, multi-year rainfall data were not available and so we used RainyDay to generate the data for the area. We tested the performance of RainyDay in generating rainfall by comparing its results with actual observations for a 1-year period.

Analysis of the rainfall data was carried out to create input parameters required to generate rainfall (tables 31.1 and 31.2). In general, the rainfall of Sumberjaya has one peak event. Thus, we could use uni-modal parameters. The offset value was smaller than -1 because in Sumberjaya there were no dry months (monthly rainfall is always larger than 0). The high Weibull value showed that the daily rainfall tended to be uniform.

Table 31.1. List of parameter inputs for RainyDay in Sumberjaya

Parameters	Value
Uni or bimodal?	1
Wettest month of rainy season	1
Peakiness of season	1
Probability	0.5
Offset (influence number of dry months)	-30.00
Weibull value	0.93
Average of wet fraction	0.81

Table 31.2. Monthly time series input for RainyDay in Sumberjaya

	Jan	Feb	Mar	Apr	May	Jun	Jul	Agt	Sep	Oct	Nov	Dec
Number of wet days	29	27	30	26	26	22	22	16	20	23	26	29
Montly rainfall	334	297	321	306	208	153	103	119	163	239	273	315
Relative wet persistence	1.01	1.00	1.00	1.02	1.07	1.15	1.19	1.45	1.27	1.15	1.08	1.01

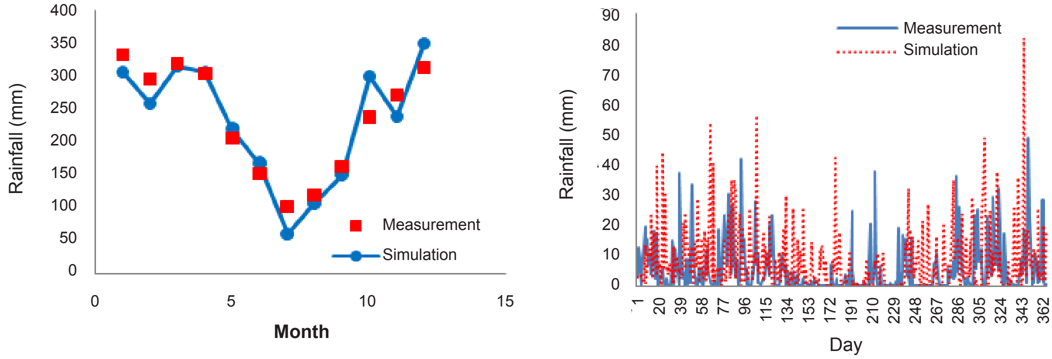

Figure 31.1. Comparison of simulated and observed rainfall data, total monthly rainfall (upper figure) and daily rainfall data (lower figure)

The comparison between simulated and actual rainfall showed that RainyDay was able to generate rainfall similar to actual rainfall with correlation above 80% and bias smaller than 8 mm.

Case study: SpatRain in Sumberjaya

SpatRain was used together with GenRiver to simulate the river flow of Way Besai River in Sumberjaya watershed, Lampung, Indonesia. The study tested the hypothesis that spatial variability of rainfall becomes increasingly important with increasing size of catchment areas in influencing the volume, seasonality and regularity of river flow.

A series of spatially explicit daily rainfall patterns was constructed that matched the monthly mean as derived from rainfall records on the site (Figure 31.2) with differences in pattern, homogeneity, intermediateness and patchiness (Figure 31.3). The fractal dimension (Bian 1997) of each rainfall type was 1.44, 2.34, and 2.90, for H ('homogeneous'), I ('intermediate') and P ('patchy'), respectively.

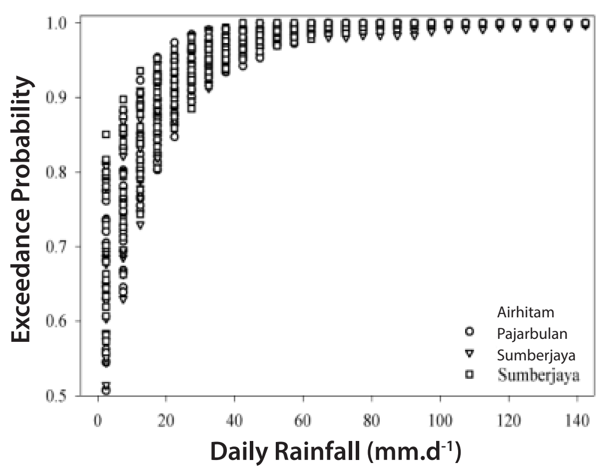

Figure 31.2. Probability of rainfall in Sumberjaya based on three rainfall stations

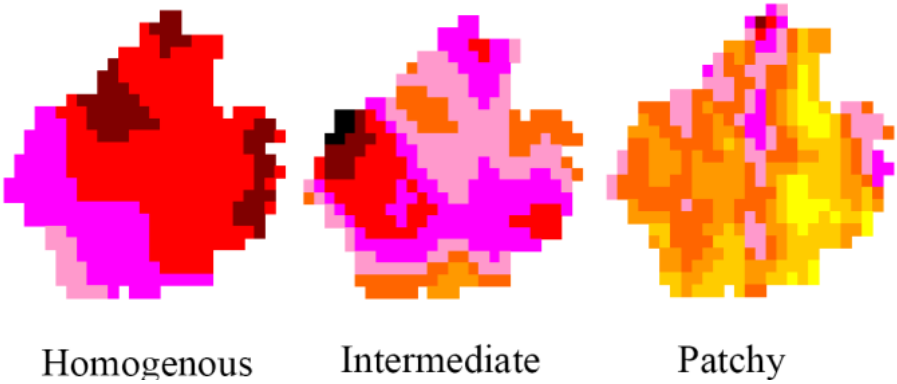

Figure 31.3. Example of the spatial distribution of rainfall on a single day for settings that are indicated as 'homogenous', 'intermediate' and 'patchy'

Using the rainfall patterns of SpatRain, we simulated river flow for the Way Besai River over 20 years to reveal the way annual rainfall is partitioned over evapotranspiration, groundwater discharge, surface and soil quick flows, showing some changes in response to land-use changes (Figure 31.4).

The difference between the three rainfall patterns, however, was larger than the land-use change signal, with an increasing surface quick flow fraction for more patchy rainfall events. The latter was due to higher local rainfall events in parts of the landscape exceeding infiltration capacity during the time available. The frequency distribution of river flow clearly corresponded with the simulations for 'patchy' rainfall much more closely that it did with those for homogeneous or intermediate rainfall types (Figure 31.5).

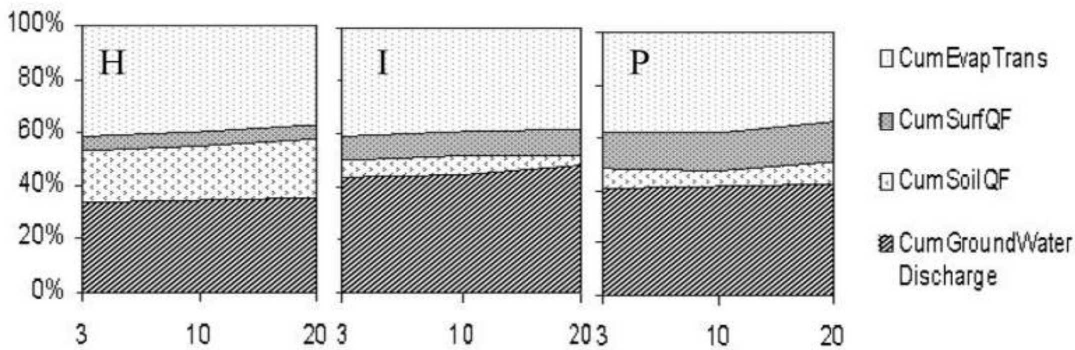

Figure 31.4. Water balance for homogenous (H), intermediate (I) and patchy (P) rainfall type

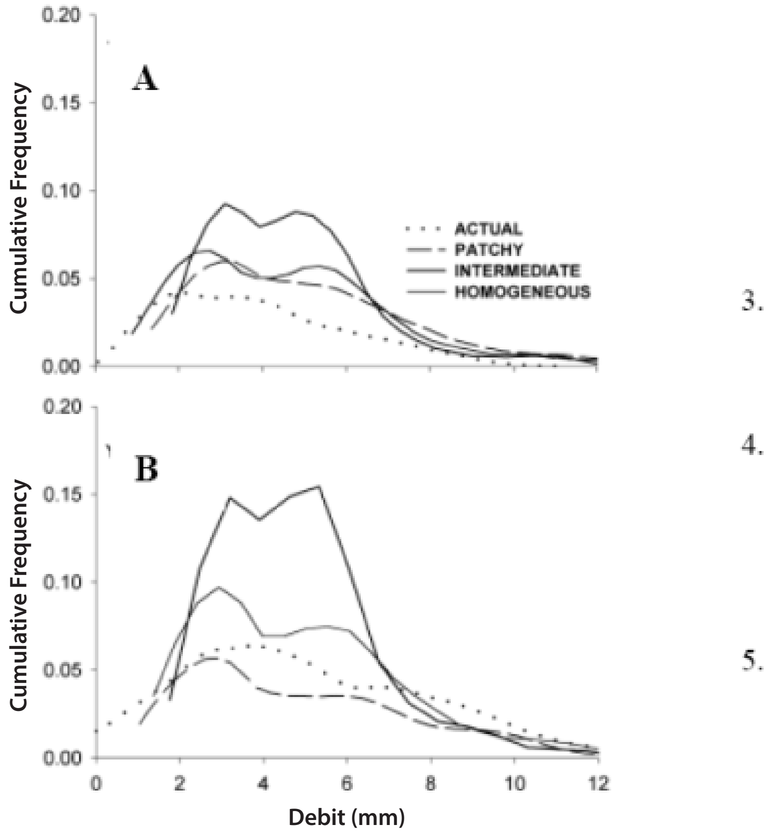

Figure 31.5. Probability/frequency distribution of the river debit

Note: Actual and as simulated by GenRiver driven by homogenous, intermediate or patchy rainfall patterns for year 3 (A) and year 20 (B)

■ Key references

Van Noordwijk M, Widodo RH, Farida A, Suyamto D, Lusiana B, Tanika L, Khasanah N. 2011. *GenRiver and FlowPer: Generic River and Flow Persistence models. User manual version 2.0*. Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia Regional Program. http://www.worldagroforestry.org/sea/publication?do=view_pub_detail&pub_no=MN0048-11.

Van Noordwijk M, Farida A, Suyamto D, Lusiana B, Khasanah N. 2003. Spatial variability of rainfall governs river flow and reduces effects of land use change at landscape scale: GenRiver and SpatRain simulations. In: Post DA, ed. *Proceedings of MODSIM 2003: International Congress on Modelling and Simulation*. Townsville, Australia: Modelling and Simulation Society of Australia and New Zealand. p. 572–577.

The landscape scale is a meeting point for bottom–up local initiatives to secure and improve livelihoods from agriculture, agroforestry and forest management, and top–down concerns and incentives related to planetary boundaries to human resource use.

Sustainable development goals require a substantial change of direction from the past when economic growth was usually accompanied by environmental degradation, with the increase of atmospheric greenhouse gasses as a symptom, but also as an issue that needs to be managed as such.

In landscapes around the world, active learning takes place with experiments that involve changes in technology, farming systems, value chains, livelihoods' strategies and institutions. An overarching hypothesis that is being tested is:

> Investment in institutionalising rewards for the environmental services that are provided by multifunctional landscapes with trees is a cost-effective and fair way to reduce vulnerability of rural livelihoods to climate change and to avoid larger costs of specific 'adaptation' while enhancing carbon stocks in the landscape.

Such changes can't come overnight. A complex process of negotiations among stakeholders is usually needed. The divergence of knowledge and claims to knowledge is a major hurdle in the negotiation process.

The collection of tools—methods, approaches and computer models—presented here was shaped by over a decade of involvement in supporting such negotiations in landscapes where a lot is at stake. The tools are meant to support further learning and effectively sharing experience towards smarter landscape management.

World Agroforestry Centre
ASB Partnership for the Tropical Forest Margins
AARD
Federal Ministry for Economic Cooperation and Development
Norad
IFAD
Enabling poor rural people to overcome poverty
CGIAR
Research Program on Forests, Trees, and Agroforestry