Brief communication: Comparing top-down and bottom-up paradigms for global flood hazard mapping

Giuliano Di Baldassarre¹,²,³, Fernando Nardi⁴,⁵, Antonio Annis⁴, Vincent Odongo¹,³, Maria Rusca¹,³, and Salvatore Grimaldi⁶

¹Department of Earth Sciences, Uppsala University, Uppsala, Sweden
²IHE-Delft Institute for Water Education, Delft, The Netherlands
³Centre of Natural Hazards and Disaster Science, CNDS, Sweden
⁴WARREDOC, University for Foreigners of Perugia, Perugia, Italy
⁵Institute of Water & Environment, Florida International University, Miami, USA
⁶Tuscia University, Viterbo, Italy

Correspondence to: Giuliano Di Baldassarre (giuliano.dibaldassarre@geo.uu.se)

Abstract. Global floodplain mapping has rapidly progressed over the past few years. Different methods have been proposed to identify areas prone to flooding, resulting into a plethora of freely available products. Here we assess the potential and limitations of two main paradigms, and provide guidance on the use of these global products in assessing flood risk in data-poor regions.

1 Introduction

As economic losses and fatalities caused by floods have dramatically increased over the past decades (Winsemius et al., 2016), there has been much progress in the development of analytical tools for the identification of the areas that can be potentially flooded (Ward et al., 2015; Dottori et al., 2018; Nardi et al., 2019). This progress has also been accelerated by the adoption of the Sendai Framework for Disaster Risk Reduction and the Warsaw International Mechanism for Loss and Damage Associated with Climate Change Impacts (Ward et al., 2015). As such, more and more scientists, experts and practitioners use global floodplain maps in data-poor regions for the identification of flood risk hotspots or the mapping of flood-prone areas (Ward et al., 2015; Winsemius et al., 2016; Dottori et al., 2018; Nardi et al., 2019).

2 The top-down paradigm

There are two main paradigms to map flooding. The traditional paradigm is (implicitly or explicitly) based on a definition of the floodplain as the area falling within the extent of a given flood event. In this paradigm, which can be seen as top-down, a synthetic event with a given probability of occurrence or return period (Pappenberger et al., 2013; Ward et al., 2015; Dottori et al., 2018), such as the 1-in-200 year flood event, is typically estimated via hydrological modelling or statistical analysis of flood data. This synthetic event is then propagated along the river with hydrodynamic models to estimate the corresponding...
inundated areas. The top-down paradigm has been widely used across multiple places and scales (Ward et al., 2015), including large-scale flood hazard modelling in data-poor regions in Africa (Figure 1). While hydrodynamic modelling of floods has been successful in simulating historical events (Horritt and Bates, 2002), large uncertainties come into play when used to simulate synthetic events (Di Baldassarre, 2012). The estimation of a flood hydrograph with a given return period, for example, is extremely uncertain as time series of flood data are hardly ever available, especially in data-poor areas (Blöschl et al., 2013).

Figure 1. Top-down and bottom-up paradigms to map flooding in Africa. Continental floodplain mapping using hydrodynamic models (top-down) is color-coded cyan-to-violet representing water depths (WD, Dottori et al., 2016) with a return period of 200 years. The floodplain areas derived with the hydrogeomorphic approach (bottom-up) are shown in green color and based on the GFPLAIN250m dataset. The inset shows estimated flood-prone areas in Kinshasa (Democratic Republic of the Congo) as well as the Global Man-made Impervious Surface (GMIS) layer (Brown de Colstoun et al., 2017) depicting urban areas as percent of impervious cover in an orange-to-red scale.
3 The bottom-up paradigm

An alternative paradigm to map flooding is based on a definition of floodplains as distinguished landscape features that have been historically shaped by the accumulated effects of floods of varying magnitudes, and their associated hydrogeomorphic processes (Nardi et al., 2006; Dodov and Foufoula-Georgiou, 2006). In this paradigm, which can be seen as bottom-up, floodplains are identified directly from the topography (Nobre et al., 2011; Samela et al., 2017; Nardi et al., 2019), which is assumed to have been shaped by past flooding events, and building on the concept of fractal river basins (Bras and Rodriguez-Iturbe, 1985; Rodríguez-Iturbe and Rinaldo, 2001) or hydrogeomorphic theories (Bhowmik, 1984; Tarboton et al., 1988). The bottom-up paradigm does not require the estimation of a synthetic flood hydrograph, and consistently identify flood-prone areas across diverse climatic regimes with varying parametrizations (Manfreda et al., 2014; Nardi et al., 2018; Annis et al., 2019) which can be seen as an advantage in data-poor regions. Also, with the recent development of global DTMs (Ward et al., 2015; Nardi et al., 2019) and EO-based cloud computing platforms (Pekel, et al., 2016), worldwide mapping of floodplain areas is a reality and these global maps can be derived in a standard PC with a single click and limited computation time. Hence, it allows to easily detect floodplains, and it is a useful tool for a variety of environmental and socio-economic analyses at large or global scale.

4 Comparing top-down and bottom-up paradigms

Figure 1 shows, as an example, floodplains of the African continent derived with both paradigms (Dottori et al., 2016; Nardi et al., 2019), while its insert compares them in the area around the city of Kinshasa, Democratic Republic of the Congo. International development banks, water sector organizations, national and international bodies mandated with disaster risk reduction, sustainable development and humanitarian response use these global maps in data-poor regions for mapping risk hotspots and flood-prone areas (Ward et al., 2015). To provide guidance in using these global products, we list limitations and advantages of the products derived using the two main paradigms in Table 1.
Table 1. Advantages and limitations of the two paradigms in mapping floodplain areas.

| Cons | Pros | Links to an example of global datasets (references) |
|------|------|----------------------------------------------------|
| Top-down paradigm (based on hydrodynamic models) | More sensitive to data scarcity (time series of flood data are only seldom available and often too short for a robust estimation of a design flood). | Less sensitive to scales.<br>Floodplains are defined based on a specific probability of occurrence: this allows cost-benefit analyses for e.g. the design of risk reduction measures is not possible.<br>It can explicitly account for the role of hydraulic structures, e.g. flood gates.<br>It provides additional variables, such as maximum flow depth, velocity and volume useful for some applications. | Flood Hazard Maps at European and Global Scale by the Joint Research Center (JRC)<br>https://data.jrc.ec.europa.eu/collection/id-0054<br>(Dottori et al., 2016) |
| Bottom-up Paradigm (based on hydrogeomorphic theories) | Less sensitive to data scarcity (it does not require any time series).<br>Computationally efficient.<br>More consistent over time, e.g. floodplain is identified as if protection structures were not in place. This can be seen as an advantage as erring on the side of least consequences (and total protection is impossible anyway). | More sensitive to scales.<br>Do not provide a specific probability of occurrence: cost-benefit analyses for the design of e.g. risk reduction measures are not possible.<br>It cannot account for the role of hydraulic structures, e.g. flood gates.<br>Scaling laws have limitations in dry climates. | Global High-resolution Dataset of Earth’s Floodplains (GFPLAIN250m)<br>https://figshare.com/articles/GFPLAIN250m/6665165/1<br>(Nardi et al., 2019) |

5 Conclusions

Both paradigms are based on consolidated theories, and they have opposite advantages and uncertainties (Table 1). Thus, we argue that these maps are complementary and they should be exploited following the precautionary principle (Foster et al., 2000), which is an important component of much of the environmental legislation in the western world. The principle calls for erring on the side of least consequences. In this context, this means the identification of flood risk hotspots in data-poor areas should consider both flood inundation areas derived by the two paradigms as depicted in the insert of Figure 1.
Data availability

Maps and data are available online, and can be accessed using the links provided in Table 1 (last access: 12 December 2019).

Author contributions

GDB, FN, and SG conceptualized the study. AA prepared the figure with the support of GDB, FN and SG. GDB wrote the original draft of the brief communication. FN, AA, VO, MR, and SG provided comments and reviewed the original draft.

Competing interests

The authors declare that they have no conflict of interest.

Acknowledgements

This work was developed within the activities of the Panta Rhei research initiative of the International Association of Hydrological Sciences (IAHS). GDB, MR and VO are supported by the European Research Council (ERC) within the project “HydroSocialExtremes: Uncovering the Mutual Shaping of Hydrological Extremes and Society”, H2020 Excellent Science, Consolidator Grant no. 761678.

References

Annis, A., Nardi, F., Morrison, R. R., and Castelli, F., Investigating hydrogeomorphic floodplain mapping performance with varying DTM resolution and stream order. Hydrological Sciences Journal, 64(5), 525-538, 2019.

Bhowmik, N. G.: Hydraulic geometry of floodplains, Journal of Hydrology, 68, 369–374, doi:10.1016/0022-1694(84)90221-X, 1984.

Blöschl, G., Sivapalan, M., Savenije, H., Wagener, T., and Viglione, A.: Runoff prediction in ungauged basins: synthesis across processes, places and scales. Cambridge University Press, 2013.

Bras, R.L., and Rodriguez-Iturbe, I.: Random functions and hydrology, Courier Corporation, 1985.

Brown de Colstoun, E. C., Huang, C., Wang, P., Tilton, J. C., Tan, B., Phillips, J., and Wolfe, R. E.: Global Man-Made Impervious Surface (GMIS) Dataset from Landsat, NASA Socioeconomic Data and Applications Center (SEDAC): Palisades, NY, USA, doi:10.7927/H4P55KKF, 2017.

Di Baldassarre, G.: Floods in a Changing Climate: Inundation Modelling, Cambridge University Press, 2012.

Dodov, B.A., and Foufoula-Georgiou, E.: Floodplain morphometry extraction from a high-resolution digital elevation model: a simple algorithm for regional analysis studies, Geosci. Remote Sens. Lett. IEEE, 3 (3), 410–413, doi:10.1109/LGRS.2006.874161, 2006.

Dottori, F., Salamon, P., Bianchi, A., Alfieri, L., Hirpa, F. A., and Feyen, L.: Development and evaluation of a framework for global flood hazard mapping, Advances in Water Resources, 94, 87-102, doi:10.1016/j.advwatres.2016.05.002, 2016.
Dottori, F., Szewczyk, W., Ciscar, J. C., Zhao, F., Alfieri, L., Hirabayashi, Y., and Feyen, L.: Increased human and economic losses from river flooding with anthropogenic warming, Nature Climate Change, 8(9), 781, doi:10.1038/s41558-018-0257-z, 2018.

Foster, K. R., Vecchia, P., and Repacholi, M. H.: Science and the precautionary principle, Science, 288(5468), 979-981, doi:10.1126/science.288.5468.979, 2000.

Horritt, M. S., and Bates, P.D.: Evaluation of 1D and 2D numerical models for predicting river flood inundation, Journal of Hydrology, 268(1-4), 87-99, doi:10.1016/S0022-1694(02)00121-X, 2002.

Manfreda, S., Nardi, F., Samela, C., Grimaldi, S., Taramasso, A. C., Roth, G., and Sole, A.: Investigation on the use of geomorphic approaches for the delineation of flood prone areas. Journal of Hydrology, 517, 863-876, 2014.

Nardi, F., Morrison, R. R., Annis, A., & Grantham, T. E.: Hydrologic scaling for hydrogeomorphic floodplain mapping: Insights into human-induced floodplain disconnectivity, River Research and Applications, 34(7), 675-685, 2018.

Nardi, F., Annis, A., Di Baldassarre, G., Vivoni E.R., and S. Grimaldi: GFPLAIN250m, a global high-resolution dataset of Earth’s floodplains, Scientific Data, 6, 180309, doi:10.1038/sdata.2018.309, 2019.

Nardi, F., Vivoni, E. R., and Grimaldi, S.: Investigating a floodplain scaling relation using a hydrogeomorphic delineation method, Water Resources Research, 42, W09409, doi:10.1029/2005WR004155, 2006.

Nobre, A. D., Cuartas, L. A., Hodnett, M., Rennó, C. D., Rodrigues, G., Silveira, A., Waterloo, M., and Saleska, S.: Height Above the Nearest Drainage—a hydrologically relevant new terrain model, Journal of Hydrology, 404(1-2), 13-29, 2011.

Pappenberger, F., Dutra, E., Wetterhall, F., and Cloke, H: Deriving global flood hazard maps of fluvial floods through a physical model cascade, Hydrology and Earth System Sciences, 16, 4143-4156, doi:10.5194/hess-16-4143-2012, 2013.

Rodríguez-Iturbe, I., and Rinaldo, A.: Fractal river basins: chance and self-organization, Cambridge University Press, 2001.

Sampson, C. C., Smith, A. M., Bates, P.D., Neal, J. C., Alfieri L., and Freer, J. E: A high-resolution global flood hazard model, Water Resources Research, 51, 7358–7381, doi:10.1002/2015WR016954, 2015.

Pekel, J. F., Cottam, A., Gorelick, N., and Belward, A. S.: High-resolution mapping of global surface water and its long-term changes, Nature, 540, 418–422, doi:10.1038/nature20584, 2016.

Samela, C., Troy, T.J., and Manfreda, S.: Geomorphic classifiers for flood-prone areas delineation for data-scarce environments, Advances in Water Resources, 102, 13-28, doi:10.1016/j.advwatres.2017.01.007, 2017.

Tarboton, D. G., Bras, R. L., and Rodriguez-Iturbe, I.: The fractal nature of river networks, Water Resources Research, 24(8), 1317–1322, doi:10.1029/WR024i008p01317, 1988.

Ward, P. J., Jongman, B., Salamon, P., et al.: Usefulness and limitations of global flood risk models, Nature Climate Change, 5(8), 712-715, doi:10.1038/nclimate2742, 2015.

Winsemius, H.C., Aerts, J. C., van Beek, L. P., et al.: Global drivers of future river flood risk, Nature Climate Change, 6, 381-385, doi:10.1038/nclimate2893, 2016.