Environmental Modelling & Software 76 (2016) 137–153

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

Nexus Tools Platform: Web-based comparison of modelling tools for analysis of water-soil-waste nexus

T. Mannschatz [1], T. Wolf, S. Hülsmann*

United Nations University Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES), Dresden, Germany

A R T I C L E I N F O

Article history:
Received 23 April 2015
Received in revised form
17 September 2015
Accepted 29 October 2015
Available online 21 November 2015

Keywords:
Model tools repository
Model inventory
Integrated models
Web-based service
Decision support tool
Interactive comparison
Near real-time visualization

A B S T R A C T

Exploring the inter-linkages of water, soil and waste resources and advancing an integrated management (or Nexus-) approach requires integrated modelling tools. Numerous models are available dealing with specific environmental processes, covering certain spatial and temporal scales and applying different mathematical process-describing relationships. However, finding and selecting the most appropriate (suite of) model(s) for a particular purpose is challenging, since current inventories do not allow any interactive filtering or model comparison. Therefore, we developed an interactive web-based platform, called Nexus Tools Platform (NTP), for inter-model comparison of existing modelling tools, which provides detailed information and allows for advanced filtering based on real-time visualizations. The alpha version of NTP (September 2015) comprises 73 models and covers a wide range of model types and environmental processes. We present selected NTP application examples for how to find and select the most appropriate modelling tools for a specific application using meta-analysis.

Software availability

- Name: Nexus Tools Platform (NTP) – Interactive comparison of Nexus related modelling tools.
- Availability URL: https://data.flores.unu.edu/projects/ntp/(No additional software required).
- DOI: 10.13140/RG.2.1.1909.7128.
- Access: free, open source.
- NTP_flores@unu.edu.
- Technical requirements: platform independent (web-based).
- Tutorials: General introduction (no audio): https://www.youtube.com/watch?v=Id4qv7vUJWQ; Examples of the platform use (with audio): https://www.youtube.com/watch?v=vAwTh1birVI.

1. Introduction

The interaction between environmental processes – with innumerable known and unknown inter-linkages and feedback loops (Liu et al., 2015) – is of extreme complexity and driven by natural as well as man-made factors, termed the complexity theory by An (2012). For instance, the resources water, soil and waste are, not only but mainly, connected by the hydrological, energy and biogeochemical cycle (Lal, 2015). An example of the water-soil-waste interconnection, which can be called a 'nexus', is the cycle of plant growth and residual recycling (Lal, 2013). Plants take up *water* with solute nutrients from the *soil* to produce biomass, which in turn after the completion of vegetation period liberates nutrients through decomposition of the plant residuals (i.e. '*waste*'); and transpired water as part of the hydrological cycle will finally be reintroduced into the soil.

The outlined water-soil-waste nexus is affected by human activities such as urbanization, agriculture expansion and

* Corresponding author. UNU-FLORES, Ammonstr. 74, 01067 Dresden, Germany.
E-mail address: huelsmann@unu.edu (S. Hülsmann).
[1] Present address: ResearchGate GmbH, Invalidenstr. 115, 10115 Berlin, Germany.

http://dx.doi.org/10.1016/j.envsoft.2015.10.031
1364-8152/© 2015 Elsevier Ltd. All rights reserved.

intensification, civil engineering, waste and energy production, and overexploitation of natural resources; all of which impact the water- and soil-related ecosystems services and functions. These influences along with the rapid increase of technological and demographic development lead to strong global change processes including climate change, environmental pollution, desertification, soil degradation, deforestation and biodiversity loss – amongst others. The consequences of these global change processes are decline of food security (e.g. due to soil fertility loss, Lal, 2013), extreme weather events (e.g. droughts, floods, Gan et al., 2015), water scarcity (e.g. overexploitation of water resources, Schewe et al., 2014) or impact on human health (e.g. environmental contamination, Corcoran et al., 2010). It is of high importance to evaluate, quantify and predict global change impact on the environment in order to efficiently react (An, 2012b).

The complex character and the multiple process interaction make it necessary to implement an Integrated Environmental Modelling (IEM) approach to comprehensively capture and predict global change impact (Laniak et al., 2013) and the inter-relation of resources in general (Kelly Letcher et al., 2013). To date, no single modelling tool is available or conceivable which would cover all processes, interactions and drivers related to water, soil and waste resources. However, a vast number of models is available and in use dealing with specific environmental processes related to water, soil and waste resources, at varying degree of detail, covering certain spatial and temporal scales and applying different mathematical process-describing relationships. For a specific research question or management issue to address, in particular when aiming at an integrated (nexus) approach, instead of developing an appropriate modelling tool from scratch, it should be more efficient and feasible to make use of available tools and modify or couple them as required. Indeed, in recent years various modelling frameworks and information systems have been developed which combine several models, often intended as decision support systems for integrated management (LandCare DSS[2]: Wenkel et al. (2013); ARIES[3]: Villa et al. (2014); APSIM[4]: Keating et al. (2003); BioMA,[5] European Commission). Likewise, an increasing number of studies make use of several modelling tools (e.g. as modelling framework) with different degree of coupling or even without an explicit coupling due to the high technical complexity of the coupling process (e.g. different programming languages) (Bazilian et al., 2011; Bruggeman and Bolding, 2014; Chen et al., 2011; Kelly Letcher et al., 2013; Laniak et al., 2013; Overeem et al., 2013). A review of the challenges and current state of the use of diverse models and their coupling is given by Voinov and Shugart (2013) and Kelly Letcher et al. (2013). A major challenge in such studies and approaches is the identification and choice of the best suite of models for a particular purpose.

To address this challenge and advance IEM, it would be very helpful to make use of a comprehensive model overview and user-specific comparison tool, because knowledge about model capabilities, application range and potential for coupling is a prerequisite for integrated modelling. Research review articles (e.g. Bagstad et al., 2013) and online inventories (see section 1.1) try to fill this gap. Research papers reviewing modelling tools are mostly limited to a detailed review of 3–4 models and/or refereeing to others (e.g. Aksoy and Kavvas, 2005; Bagstad et al., 2013; Gentil et al., 2010; Köhne et al., 2009a, b; Ranatunga et al., 2008; and Srivastava and Migliaccio, 2007) which makes it very exhausting to obtain the required model information – especially if one is starting the model selection process from scratch. However, to our knowledge, until today there is no model database available that goes beyond a static model-description list. Due to the fact that probably nobody is fully aware of the available models on environmental resources and their capabilities, a lot of time is spent on the development of new models instead of the recycling and further development of existing well-established models.

With the objective of addressing the abovementioned information gap, we have developed a web-based model inventory platform ('Nexus Tools Platform' (NTP)) that allows interactive comparison of models in a statistical way. The NTP allows comparing them based on processes covered, application purpose and any other full-text searchable term. Our review study includes modelling tools that are relevant for enabling an integrated approach for the sustainable management of water, soil and waste considering global change and socio-economic aspects. Neither the presented review of available models nor the database claims to be exhaustive. It is also beyond the scope of the paper to present a detailed review or evaluation of the single model tools. Rather, we intend to present a web-based open platform for a comprehensible model comparison as well as for statistical analysis of model capabilities. The paper explains the objectives of NTP, the technical implementation and presents several applications to illustrate its purpose and usage.

1.1. Improving nexus research and modelling – the need of model inventory

Integrated environmental resources management aims to enable a sustainable management of natural resources through balancing the diverse complex needs of both, the biophysical (e.g. maintaining ecosystem functions) and social-economic systems (e.g. need for drinking water, minerals etc.) (Pahl-Wostl, 2007).

As an example, integrated water resources management (IWRM) not only considers the amount and availability of water for usage across spatial scales and sectors, but also balances social, economic and environmental values (GWP, 2000). This requires the consideration of the inter-linkage with other resources, e.g. soil, however, typically this has been done from a water perspective.

Likewise, "integrated" approaches have been developed for the management of other resources such as soil (e.g. integrated soil fertility management, sustainable land management: i.e. Giller et al. 2011; Killham 2011; Moore et al. 2011; Schönhart et al. 2011 or waste: i.e. Eriksson and Bisaillon, 2011; Eriksson et al., 2014; Koroneos and Nanaki, 2012; Zhao et al., 2011)), in each case considering inter-relations with other resources to a certain extent, but sticking to a sectorial view. It is increasingly recognized that the achievement of real sustainability, balancing of trade-offs and building synergies across sectors needs an even more holistic view that allows the comprehensive understanding of the impact and influence that a single action creates within the natural-social-economic space on diverse temporal and spatial scales and boundaries (Ewert et al., 2014; Halbe et al., 2014; Hamilton et al., 2015; Pahl-Wostl, 2007; Wan Alwi et al., 2014). We propose that such a holistic approach is realized through the integrated management of the resources water, soil and waste, thus constituting a nexus approach instead of focusing on the management of a single resource (Lal, 2015; Schwärzel et al., 2014). Such a nexus approach to environmental resources management "examines the inter-relatedness and interdependencies of environmental resources and their transitions and fluxes across spatial scales and between

[2] Land, Climate and Resources – Decision Support System (LandCare DSS); http://www.landcare-dss.de.

[3] Artificial Intelligence for Ecosystem Services (ARIES); http://www.ariesonline.org/.

[4] Agricultural Production Systems sIMulator (APSIM); http://www.apsim.info.

[5] Biophysical Model Applications (BioMA); http://bioma.jrc.ec.europa.eu/index.htm.