# Landscape dependent derivation of J2000 model parameters for hydrological modelling in ungauged basins

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**Abstract** The HRU (*Hydrological Response Units*) regionalisation concept is realised with a GIS-based intersection of landscape parameters such as topography, soils, geology and land use. In many catchments of the world the required data are only available on a coarse spatial resolution and there is often a lack of discharge and precipitation data. But there is a demand to involve these catchments in planning of water management. The assumption of a process-driven feedback between the topography and further landscape components, as well as runoff dynamics, leads to a modified delineation of process entities by a topographic oriented HRU approach on the basis of SRTM elevation data. The approach is based on the expectation that the water balance of ungauged basins can be estimated using SRTM-based delineations of process-oriented model entities to get a suitable prediction of runoff dynamics with disposable landscape components in spite of an insufficient hydro-meteorological database.

**Key words** SRTM; hydrological modelling; prediction in ungauged basins; hydrological response unit; Germany; South Africa

## INTRODUCTION

Considering the increasing number of extreme hydrological events (floods and aridity) and the frequently discussed trends of global climate change, water resources attract scientific attention. Against the background of an inadequate water supply situation in developing and threshold countries, and associated actual and future challenges for water management activities, there is a great demand to find solutions to the limited water availability. Distributive hydrological models are an important and useful instrument to meet the requirements of a well-adapted water management system considering local conditions. These models are based on the derivation of model entities for regionalisation of landscape characteristics. Integrated landscape elements are land use, soil, geology and particularly the relief and its geomorphological form (Flügel, 2000).

The interaction of hydrological processes is controlled by the three-dimensional and unique landscape properties of each catchment (Flügel, 1996). Hereby, topography is the most important factor, influencing other landscape components such as evolution of the soil catena or the forming of land cover patterns. Consequently, relief is a fundamental component for each hydrological system analysis. Together with geological and climatic boundary conditions, the topography generally represents the natural landscape potential from which important conclusions can be drawn (Horton, 1945). Moore *et al.* (1992) observed that the topography of a catchment has crucial impact for all hydrological, geomorphological and biological processes in the landscape. Flügel (1996) expanded this relief relation by connecting it with land use and other landscape components as an expression of the landscape retention. The concept of distributive hydrological models is based on the integration of topographical indices from digital elevation models (DEM) and other landscape components to delineate distributed process entities. These so-called Hydrological Response Units (HRU) are topological connected model entities and represent areas of a homogeneous topographic and physiographic environment, and so determine the hydrological system response. The HRU regionalisation concept of catchments is based on the intersection of data layers from landscape parameters such as land use, soil, hydrogeology and indices derived from the DEM using geographical information systems (GIS) operations. In this process, HRUs as consistent analysed process dynamics will be generated from the respective digital data layer. Afterwards, these single entities will be topologically connected for runoff routing.

In many river catchments world-wide, most of these required input data are only available on a coarse spatial resolution or in insufficient quality. Furthermore, there is often a lack of data for discharge to run and validate hydrological models, so that the majority of all river catchments (~90% worldwide) can be described as ungauged basins (Young & Romanowicz, 2004). The availability of precipitation data and climate data is an assumption for modelling nevertheless. However, there is a high demand to involve these catchments in planning of water management for determining the goals of the IAHS research initiative *Prediction in Ungauged Basins* (PUB). The availability of new remote sensing products provides an opportunity to by-pass the problem of poor input data and offers a suitable GIS-database for regionalising river catchments based on HRUs.

Regardless of the significant importance of digital relief information for a multiplicity of research subjects (hydrology, meteorology, geomorphology, geology, water economy, etc.), no global and consistent relief data with sufficient spatial resolution have been available for decades, which are useable in distributed hydrological modelling of mesoscale catchments. Global DEMs like GTOPO30, with a spatial resolution of 1 km, are too coarse to describe the catchment heterogeneity and simulate the hydrological processes. With the realisation of the *Shuttle Radar Topography Mission* (SRTM) in 2000, elevation data became available with spatial resolutions of 30 m and 90 m. These data provide a new opportunity for mesoscale hydrological modelling whose potential will be analysed. The provision of SRTM elevation data offers, despite existing limitations, relief information in consistent quality, and for cross-border catchments (Ludwig *et al*., 2003). Besides the relief, land use is a relevant component for landscape water balance and so for the delineation of HRU process areas. With the remote sensing product GLOBCOVER released in 2008, a new innovative global land-use data set is available that allows the integration of this landscape component for catchment regionalisation and parameterisation of process entities world-wide.

Referring to the aims of PUB for integrating ungauged basins in water management decisions, and the availability of innovative global GIS data as well as the potential of distributive hydrological models, the following key question can be asked for this research: *Is it possible to get a realistic analysis and modelling of runoff dynamics on a river catchment despite an insufficient hydro-meteorological data base and a lack of other disposable landscape components*? Because the data required for developing countries are often not available at the desired spatial resolution and quality, this question should be answered by developing a geomorphology-oriented HRU approach. For this objective the globally available and free SRTM-DEMs shall be used.

## OBJECTIVES

Within the framework of PUB, regional hydrological modelling mainly gained great importance for water management decisions in regions vulnerable to floods in the Third World (Nasri *et al*., 2004). As a consequence, in the case of missing expert knowledge about the hydrological dynamics in catchment water management, decisions could be taken that are likely to fail the increasing demand for the essential but limited water resource.

Through the integration of remote sensing, GIS and regional hydrological modelling using globally available SRTM elevation data, there is a promising opportunity to automate the scale comprehensive HRU regionalisation concept based on unified geomorphologically based GIS derivation methods.

The research is related to two research hypotheses:

(a) The method relies on the assumption of a strong, process-driven feedback between the topography and further landscape components as well as runoff dynamics which can be quantified using geoinformation techniques.

(b) It is expected that the landscape water balance of catchments with insufficient hydrometric infrastructure and data availability can be estimated and predicted using SRTM-based delineations of process-oriented model entities. The entities in this case represent *hydrological response units* (HRU) which were implemented in distributive hydrological models.

These hypotheses should be validated by the following objectives and working focus:

(i) Investigation of the scale of comprehensive applicability of SRTM elevation data for delineating process relevant response units (HRU).
(ii) Compensation of missing adequate input data of other required landscape components through the development of a new geomorphologically oriented HRU-approach based on the integration of SRTM-derived topographic indices for the delineation of HRUs in ungauged basins.
(iii) Hydrological modelling in catchments with different relief characteristics to identify sensitive landscape dependent model parameters using SRTM-based HRUs as regionalised model entities. The Main Objective is an estimation of close bounded parameter ranges to generate parameter compositions which can reproduce the hydrological dynamic with clearly defined domain of uncertainty.
(iv) Transfer of the extracted parameter compositions and comparative modelling of the runoff dynamics in selected river catchments of different climate regions with the distributive hydrological model J2000. It is essential to specify the parameters in narrow ranges to afford *a priori* parameter setting to catchments which are difficult to calibrate with respect to modelling under ungauged basin conditions.
(v) Assessment of the analysis potential of the SRTM-based modelling and the usage of other regionalised landscape components for simulating the landscape water balance in poor calibrated catchments by validating with available comparative model runs.

As a result, a method will be provided to prepare and optimise SRTM elevation data for hydrological modelling of river catchments on the basis of HRU regionalisation. Through comparative model studies in selected test catchments of different climate and relief characteristics in South Africa and the Himalaya, it should be possible to define which explanatory powers for simulating hydrological dynamics exist purely from the landscape components in the catchment. In addition, its relevance to the calibration and parameterisation with hydrometeorological measurements should be identified. This leads to the evaluation of accuracy by applying this method in ungauged basins as a research contribution to the PUB initiative of IAHS.

## METHODS

### Derivation of landscape oriented Hydrological Response Units

The major difficulty using conceptual models in catchments with insufficient data consists in the calibration of the model results, because reliable validation data for the derivation of applicable model parameter sets, which should simulate the hydrological processes inside the catchment, are often not available. Nevertheless, to get a realistic model prediction it is necessary to narrow down the parameter ranges as far as possible and to attain the hydrological system's response based on ensemble computations. These computations should have a high probability of appearance and should be differentiated by a defined uncertainty. The narrowing of the model parameter range shall be conducted by means of comparative modelling of catchments having a sound hydrometeorological database. The test sites are located in the German river catchment *Saale* and its subcatchments. For the model parameter transfer it is essential to derive relationships between the generally available information and promising parameter sets in order to reach transferable parameter compositions for different landscape classes, similar to a transfer function. Therefore, the hydrological catchment modelling requires spatially-related information about the distribution and characteristics of the relevant landscape components. For mesoscale and macroscale catchments, the data can be acquired using remote sensing systems and handled by GIS systems (Becchi *et al.*, 2001).

For land use data, the product GLOBCOVER is available which was released in 2008. This land use classification offers a good free database for global approaches. Concerning the relief, the SRTM elevation data are a very valuable remote sensing product for PUB. These data have a spatial resolution of approximately 90 m and 30 m, respectively (X-SAR-SRTM). The DEM has to be prepared for hydrological applications using GIS. The regionalisation of the spatial information was realised such that the delineation of the distributive model entities represents the heterogeneity of the catchment as far as possible. Furthermore, there are trans-regional GIS data sets for soil and hydrogeology such as the European Soil Database (ESDB) for Europe, or the Soil and Terrain Database (SOTER) for Africa. However, the spatial resolution of 1 km for these data sets is too coarse to describe the catchment heterogeneity. Therefore, the main focus is laid on the geomorphological DEM derivations.

To parameterise the hydrological response units, all input datasets have to be prepared and reclassified in a model adequate classification scheme.

**Evaluation and clustering of suitable terrain indices to derive HRUs**

The conventional method is intersecting the corresponding GIS layers of the several landscape components and their derivations or reclassification. According to the guidelines of the HRU concept after Flügel (1996) the relevant reclassified GIS layers are land use, soil, hydrogeology as well as slope, aspect and subcatchments derived from the DEM. The results are process entities as smallest common geometries. These HRU sub-areas shall be parameterised with regard to the hydrologically relevant processes, water storages and flow characteristics according to the J2000 input parameters. Because the data basis of the landscape components soil and geology of the trans-regional and global data sets is too coarse for a useful implementation in the GIS intersection to delineate HRUs, a new approach is developed within this research to generate HRU geometries. This primarily relief-related method is based on a clustering of selected terrain indices computed from the pre-processed SRTM DEM. Thus, geomorphological HRU geometries will be obtained. Depending on research task and spatial resolution of the input data the information for land use, soil and geology can either be intersected or the attributes of these components can be assigned to the HRU entities after a statistical matching. In the intersection approach for delineating hydrological response units the slope is the most significant relief parameter because it affects surface runoff and interflow processes as well as the degree of soil erosion. However, there is no relation to the hillside curvature which is an important factor for spatial distribution of erosion or accumulation zones and flow convergences or divergences of surface runoff. Additionally, a linkage to the upslope contribution area is lacking; that is essential for the development of saturation areas. Hence, the newly developed clustering approach integrates different relief parameters, such as Topographic Wetness Index (after Böhner *et al*., 2002), Mass Balance Index, Annual Solar Radiation Index (McCune & Dylan, 2002) and various curvature parameters, which are all related to hydrological processes. The selection of the parameters used for the clustering is dependent on the significance of the processes in different landscapes and relief units. For example, the curvature dominates in mountain regions, and in flat areas the Topographic Wetness Index is more important for runoff, infiltration, evaporation and other relevant processes. Comprehensible HRUs were delineated on the basis of the selected terrain indices from SRTM elevations. The delineation of homogenous model entities was realized by a complete linkage cluster analysis with the program IVHG. In result, the demarcation of local relief units can be optimised and a well balanced differentiation of landform units will be achieved. The HRU geometry in the geomorphologically-based cluster method is more related to the runoff processes than the GIS layer intersection method. Valleys and hillside structures are well differentiated in relation to runoff process delivery.

The validity of the delineated process entities was analysed and interpreted in terms of hydrological process understanding during a field trip to the South African test catchments *Sandspruit*, *Mooi*, *Great Letaba* and *Mkomazi*. In general, good results were reached in hilly and mountainous terrain. The shapes of erosion channels, ridges, river valleys and hillside forms were reasonably and plausibly delineated. The land-use layers were intersected with these HRU geometries and the attributes for the layers soil and geology were assigned by overlay analyses. More details to the process of HRU clustering are documented in Pfennig & Wolf (2007).

**Comparative hydrological modelling**

The previously delineated HRU entities were then parameterised and prepared for input to the hydrological model J2000. This model enables physically-based modelling of the water balance from mesoscale and macroscale river catchments. Besides the simulation of the hydrological processes, which affects the runoff generation and concentration, the model contains routines for the regionalisation of measured precipitation and climate station data. Simulation of the hydrological processes takes place in separated and enclosed program modules. The simulated runoff results are a summing up of the particular runoff components, which were separately calculated in the model runs. Regulation of the model execution takes place by the set-up opportunities of 30 model parameters. Based on measured runoff data, the model is to be calibrated so that the simulated runoff is adapted to the characteristics of the hydrological system in the catchment (Krause & Flügel, 2001).

For the comparative hydrological model analysis the following data sets and model runs were realised:

(i) **Basis Modelling** HRU sets delineated by the conservative intersection method based on DTM (25 m) for the German catchments *Upper Ilm* (landscape: mountainous), *Bode* (landscape: hilly) and *Helbe* (landscape: smooth).

(ii) **Basis Modelling** HRU sets delineated by the conservative intersection method based on SRTM-DEM (90 m) for the German catchments *Upper Ilm* (landscape: mountainous), *Bode* (landscape: hilly) und *Helbe* (landscape: smooth).

(iii) **PUB Modelling** Geomorphologically-oriented HRU sets delineated by the new cluster method based on SRTM-DEM (90 m) for the German catchments *Upper Ilm* (landscape: mountainous), *Bode* (landscape: hilly) and *Helbe* (landscape: smooth).

(iv) **PUB Modelling** Geomorphologically-oriented HRU sets delineated by the new cluster method based on SRTM-DEM (90 m) for the South African catchments *Mooi* (landscape: mountainous), *Great Letaba* (landscape: hilly) und *Sandspruit* (landscape: smooth).

(v) **Basis Modelling** HRU sets delineated by the conservative intersection method based on available national elevation data for the South African catchments *Mooi* (landscape: mountainous), *Great Letaba* (landscape: hilly) and *Sandspruit* (landscape: smooth).

The description “basis modelling” refers to a model composition which is grounded on valuable hydrometeorological measurements (runoff, temperature, air humidity, precipitation, sun hours, wind speed) as well as GIS data of high quality and resolution, for example a DTM (25 m) from the Thuringia Survey Agency. The HRUs were generated thereof by intersecting the GIS data layers corresponding to the conservative HRU delineation method (i). This model composition worked for each of three German catchments with various landscape classes. The catchment *Upper Ilm* represents a mountainous, *Bode* a hilly, and *Helbe* a smooth, landscape. Another basis modelling set (ii) uses the same scheme but with the SRTM-DEM as base for derivation of the geomorphological indices. The third set represents the so-called PUB modelling (iii) based exclusively on free global or trans-regional GIS data, where the HRUs were generated by the previously described cluster method. These model runs were also applied comparatively to the basis modelling for all of the tree landscape classes. It contains calibration and validation analysis to find transferable landscape dependent J2000 model parameters to fit the simulated runoff hydrograph. The result is a modification of the initial model parameter set by the extracted sensitive parameters. For this selection, narrow parameter borders should be defined for each landscape class. Afterwards, a transfer of these evaluated parameters to South African catchments with corresponding relief characteristics is planned. Therefore, a PUB modelling (iv) of the catchments *Mooi* (mountainous), *Great Letaba* (hilly) and *Sandspruit* (smooth) was realised. The results will be validated by comparison with available basis modelling runs (v) of these South African catchments, which have a good local database. Through the analysis of the modelling results the potential of the “PUB Modelling method” for applications in ungauged basins should be estimated. The schema of extracting landscape dependent and model sensitive parameters for defining J2000 parameter ensembles is illustrated in Fig. 1 and described below.

## Evaluation of sensitive landscape dependent model parameters

A main goal of the developed method is the determination of model parameter ensembles that are especially significant and sensitive regarding to different landscape classes and relief characteristics

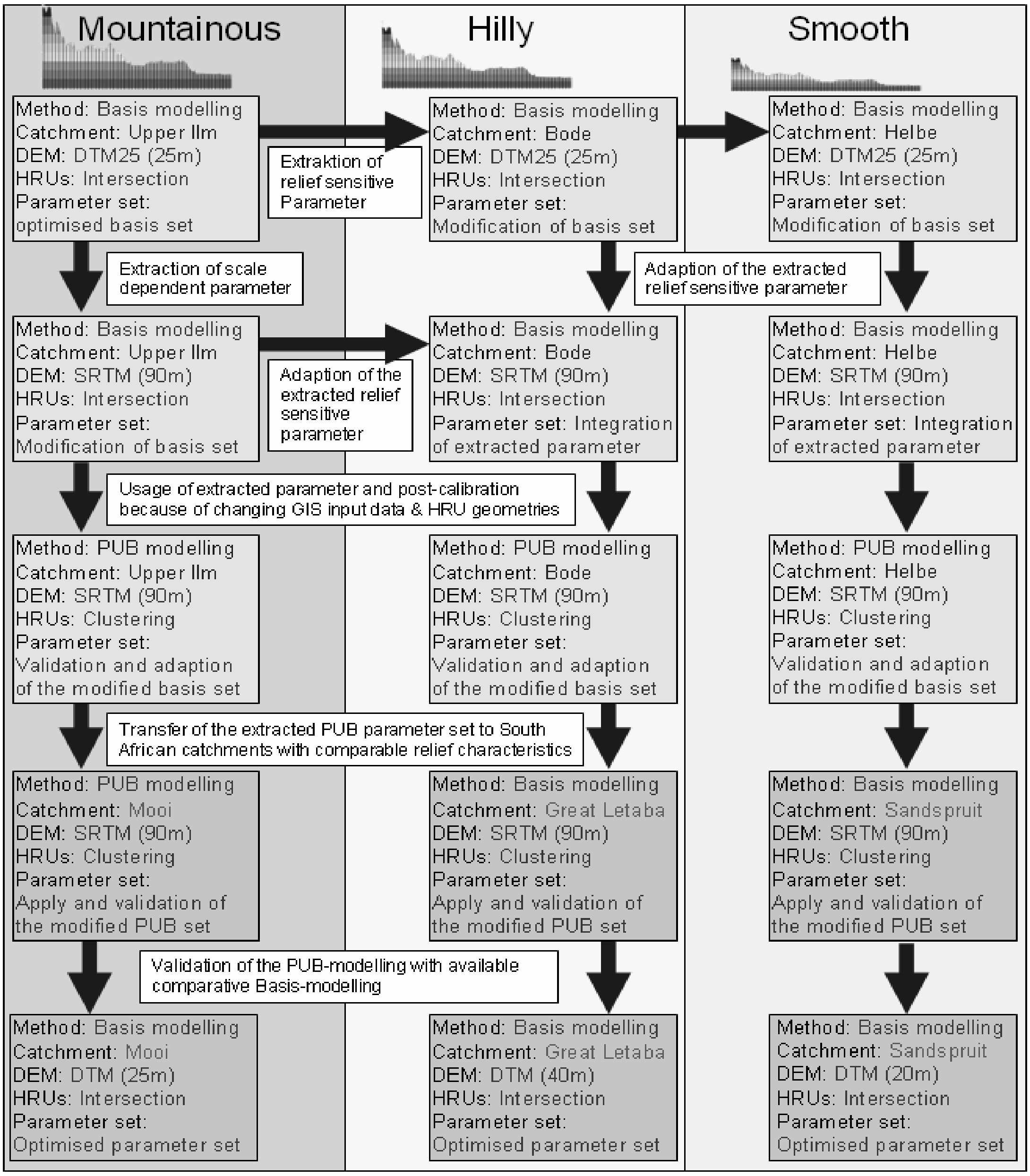


**Fig. 1** Schema of extracting landscape dependent and model sensitive parameter for defining J2000 parameter ensembles for the various landscape classes.

inside the catchments and therefore affecting the quality of model results. The extraction of these model parameters is hindered due to the multilateral input factors such as land use, soil and geology, which are also difficult to quantify. To isolate the influence of the other landscape components the geomorphologically-based derivation of model entities was developed. The arrangement of the landscape classes is based on the DEM calculation of the relief amplitude and terrain roughness in a user-defined moving window (420 m × 420 m) after the approach of Friedrich (1996). A validation of the delineated landscape classes with a national landscape data set from the *Thuringia Survey Servic*e shows satisfying results. The studies take place in investigation areas with a very good database. The parameter sets were initially transferred to South African river basins catchments with comparable terrain roughness and will later be transferred to other regions of the world. For these test sites, good validation data exist and the first model results look very promising.

In the following, the procedure of extracting landscape dependent parameters to define J2000 parameter ensembles for the various landscape classes will be explained. The main objective consists in the evaluation of sensitive model parameter ensembles to adapt the parameter set to the relief characteristics. These predefined J2000 parameter sets should be adaptable for ungauged basins on the basis of relief classes to give a good approximation of the catchment runoff reaction and adequate model results, in spite of missing validation opportunities.

The starting point of the comparative analysis was a physically well-tuned and calibrated model parameter set with very good efficiency values and adaptation to the measured runoff hydrograph. That set was used in a model run of the catchment *Upper Ilm* (mountainous landscape) for the "basis modelling" (I) with the 25 m resolved DTM derivations. That model run determines the reference for the following analysis.

In a first step, this optimized parameter set was transferred to the basis modelling (ii) consisting of SRTM-based HRU entities into the same catchment (Upper Ilm). After an accurate calibration, the parameter sets were modified by a sensitivity analysis of each parameter to fit the hydrograph and the efficiency values of the simulated runoff. Thereby manual calibrations were made by changing the value of a single model parameter and analysing the model results. In this way parameters which show the strongest influence on the model simulation were separated. The optimised setting for each parameter was evaluated after intensive test runs.

The adapted parameters were usually sensitively related to the change in raster resolution from 25 m up to 90 m. In this way an adapted parameter selection of five sensitive scale-dependent parameters could be isolated. Efficiency improvements could be reached through post-calibration of two parameters from the snow module (*r_factor*, *g_factor*) and tree parameters of the soil module (*soilConcRD1*, *soilLatVertLPS*, *soilMaxPerc*). The relative variations of the efficiency values for these extracted parameters are illustrated in Fig. 2. The 3-d diagram shows how the efficiency values Nash-Sutcliffe Coefficient ($e^2$), the logarithm of Nash-Sutcliffe Coefficient, ioa1, $r^2$ and RMSE (root mean square error) changed after a manual optimisation of the model parameters *r_factor*, *g_factor*, *soilConcRD1*, *soilLatVertLPS* and *soilMaxPerc.* While the most adapted parameters indicate an improvement of all efficiencies, the log_$e^2$ of the parameter *g_factor* and *soilConcRD1* is worsening in this configuration. The decrease of relative RMSE values reflects a better simulation fit because the scale of this index converges to zero.

The application of this modified parameter set effectuated an improvement of the absolute model results (Table 1(a)) and a better fit of the runoff simulation. The model runs considering all of the five modified parameters. Eye-catching is a positive effect onto the efficiencies for RMSE, $r^2$, ioa1 and the Nash-Sutcliff-Coefficient ($e^2$). $E^2$ is especially sensitive for runoff peaks

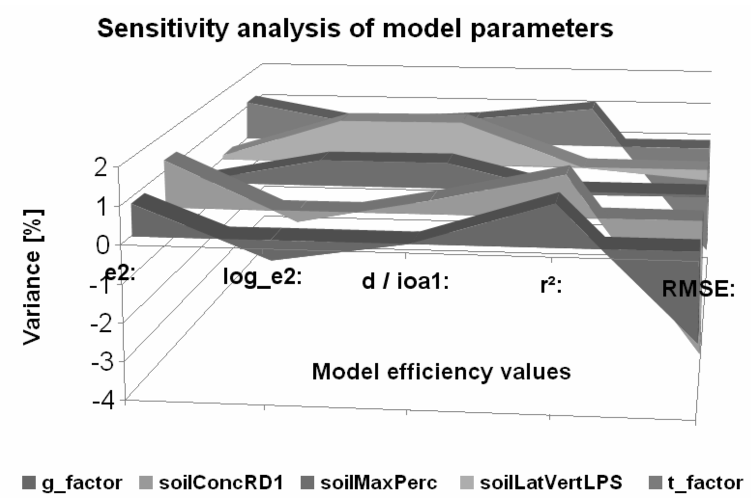


**Fig. 2** Relative variations of efficiency values for extracted scale dependent J2000 model parameter as a result of a sensitivity analysis on the base of the SRTM 'basis modelling' in the catchment Upper Ilm.

**Table 1(a)** Absolute variation of efficiency values for sensitivity analysis of landscape dependent model parameter in the Upper Ilm catchment.

| Absolute | Time period: 01.11.1980 – 31.10.1983 | | |
|---|---|---|---|
| Efficiency | Basis modelling DTM25 | Basis modelling SRTM | Modified SRTM modelling |
| e2 | 0.83 | 0.85 | 0.86 |
| log_e2 | 0.88 | 0.87 | 0.82 |
| ioa1 | 0.84 | 0.85 | 0.85 |
| r² | 0.84 | 0.85 | 0.86 |
| RMSE | 1.79 | 1.70 | 1.62 |

**Table 1(b)** Absolute variations of efficiency values for comparative modelling in the Bode catchment.

| Absolute | Time period: 01.11.1990 – 31.10.1993 | | |
|---|---|---|---|
| Efficiency | Basis modelling DTM25 | Basis modelling SRTM | PUB modelling SRTM |
| e2 | 0.63 | 0.60 | 0.56 |
| log_e2 | 0.50 | 0.45 | 0.41 |
| ioa1 | 0.74 | 0.74 | 0.68 |
| r² | 0.70 | 0.68 | 0.66 |
| RMSE | 0.93 | 0.97 | 1.18 |

and fast runoff components. In contrast, the logarithm of the Nash-Sutcliffe coefficient (log_$e^2$) is worsening, which is an indicator for the simulation of groundwater drainage. Finally, a parameter ensemble was determined that enables transfer of the optimized model configuration from the reference modelling to the SRTM basis modelling. Thereby, scale-sensitive model parameters were identified and optimized.

In the next step, the initial parameter sets were used again for a transfer to a modelling of the catchment Bode, which has lower relief energy and roughness index then the Upper Ilm. The landscape is classified as hilly. Additionally, a manual calibration and sensitivity analysis were done to quantify potential relief sensitive model parameters which are especially characterised by landscape dependent influence of the model results. So a selection of four parameters was identified that are particularly marked through their landscape-dependent influence on the model results. In this way the soil module parameter *maxPerc* (maximum percolation rate), *soilLateVertLPS* (lateral-vertical distribution coefficient), *soilOutLPS* (outflow coefficient for large pore storage) and the ground water module parameter *capRise* (capillary rise of ground water) were isolated as especially sensitive to changes in terrain. Notably, some parameters showed relatively large deviations between the results of the efficiency values and the knowledge based analysis of the runoff hydrograph. This step was continued in the catchment Helbe, which is characterised by a smooth landscape and roughness. In conclusion, an optimised model parameter set is available for each relief class.

In a third step the previously extracted scale and landscape sensitive parameter selections were applied together as a PUB model parameter selection to the PUB Modelling approaches in each of the three catchments (iii). The PUB Modelling contains the geomorphologically-oriented HRU entities, which were delineated by the new cluster method based on SRTM-DEM and global GIS data for land use (GLOBCOVER), soil (ESDB) and lithogeology (ESDB). So, PUB conditions will be simulated virtually.

In Fig. 3 the hydrographs of the Basis Modelling and the PUB-Modelling using the extracted PUB model parameter selection are compared. Together with the measured runoff data that is the base for a validation and model result analysis. Deviations in the simulated runoff hydrograph in comparison to the basis modelling are caused by varied geometries of the process entities with the cluster method and the changing input data of the landscape components. A post-calibration of the PUB model parameter selection was realized using a statistical SCE (*Shuffle Complex Evolution*) optimisation module for J2000 to get the best fit for the parameters configuration. Table 1(b) shows the efficiency values for the comparative modelling of the PUB modelling and the Basis modelling based on the reference DTM25. It is understandable that the efficiencies of the PUB model approach cannot be as good as the Basis modelling because of the input data. But a good approximation was reached. Finally, the universal J2000 model parameter sets for the relief classes mountainous, hilly and smooth were provided for use in ungauged basins.

## Transfer of the landscape dependent model parameter

In a fourth step these acquired and post-calibrated PUB model parameter selections from the three German test sites were transferred to catchments in South Africa with corresponding landscape

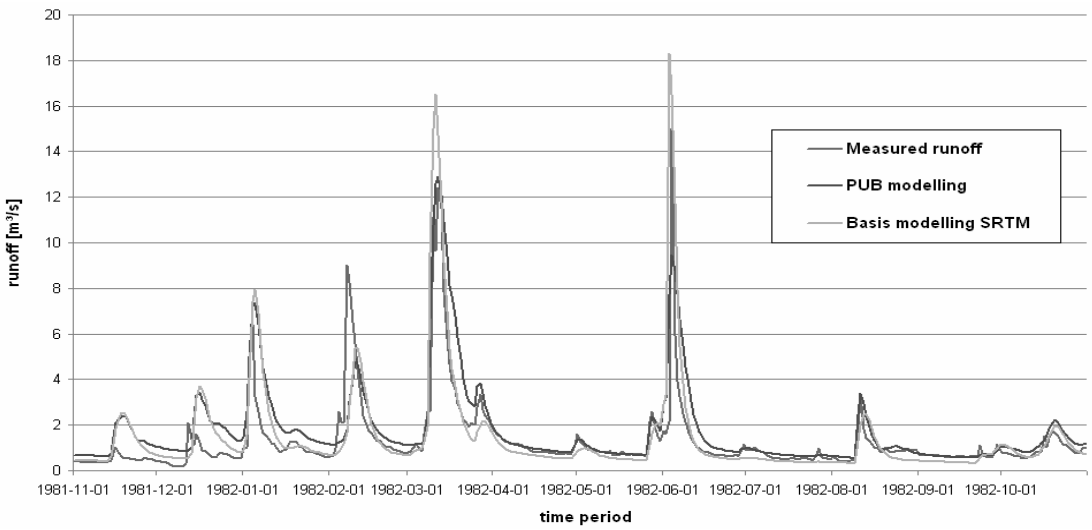


**Fig. 3** Comparison of the hydrographs from the "Base modelling SRTM" and the "PUB modelling" in the Bode catchment.

characteristics. The corresponding catchments pairs are *Upper Ilm–Mooi*, *Bode–Letaba* and *Helbe –Sandspruit*. As a simulation of PUB conditions a PUB Modelling of the three South African test catchments (iv) was initiated. Here SRTM-DEM and CLOBCOVER data were also used as GIS input data for the derivation of geomorphological indices and land use. The landscape components soil and lithology were acquired from the trans-regional SOTER database. The density of hydro-meteorological measurements and climate data is less than in the German test areas. But for the validation of the model results there are measured runoff data at a daily time interval. Problems are local specifics with an impact on the hydrological modelling such as farm dams and irrigation. The first model results offer promising results in the simulated runoff hydrograph. Detailed analyses will be done in the coming steps.

### Validation of the "PUB-modelling"

In real ungauged basins no opportunity for model calibration and validation of the simulated runoff by measured data is possible. But for this research, daily runoff measurements and diverse comparative hydrological model results from other research activities (totally independent from this PUB modelling) are available in each of the selected catchments. By means of these comparative model results the quality of the PUB Modelling can be validated and derivations can be interpreted. Further tests to transfer the PUB model parameter selection are planned for test sites in the Brahmaputra catchment and in the Alps (Austria) to prove and optimise the methodology.

## RESULT ANALYSIS FOR PUB

With the global SRTM elevation data the opportunity exists to extend the developed geomorphological HRU regionalisation concept in a scale comprehensive way by unified topographically based GIS derivations, and to realise these derivations of model entities in user-driven automatic tools. Consequently, the approach will be transparent and reproducible relating to comparative studies with similar objectives in other catchments. The comparative modelling of the PUB modelling and Basis modelling in the South African test catchments aims to define what explanatory potential of the hydrological dynamics of the landscape water balance can be evaluated alone from the landscape components (primary relief). Narrow ranges for the J2000 parameters shall be determined to get the possibility of *a priori* parameter estimations. Thus, hydrological processes in poorly calibrated models under PUB conditions can be simulated on the basis of these ensemble calculations. The model results obtained lead to an estimation of the accuracy for the usage of this method in ungauged basins. But this approach does not claim to be a finalised or completed hydrological modelling. It should be an orientation and a suitable base for parameterisation for hydrological model runs with J2000 in catchments with poor data availability on the basis of available information about the relief and other landscape components. Constructing a finer model calibration on this for catchment specific conditions can be realised.

To make the parameter ensembles transfer to catchments with comparable landscape characteristics assessable for watersheds having various large landscape classes, a nested catchment modelling with individual landscape dependent parameter sets is planned. Therefore the mean relief amplitude (RA) will be calculated for the included subcatchments. The subcatchments will be summarised to landscape classes (PS) and each of the landscape classes will be modelled separately with an individual parameter set. Figure 4 illustrates an example of this nested catchment approach for the South African River Mkomazi.

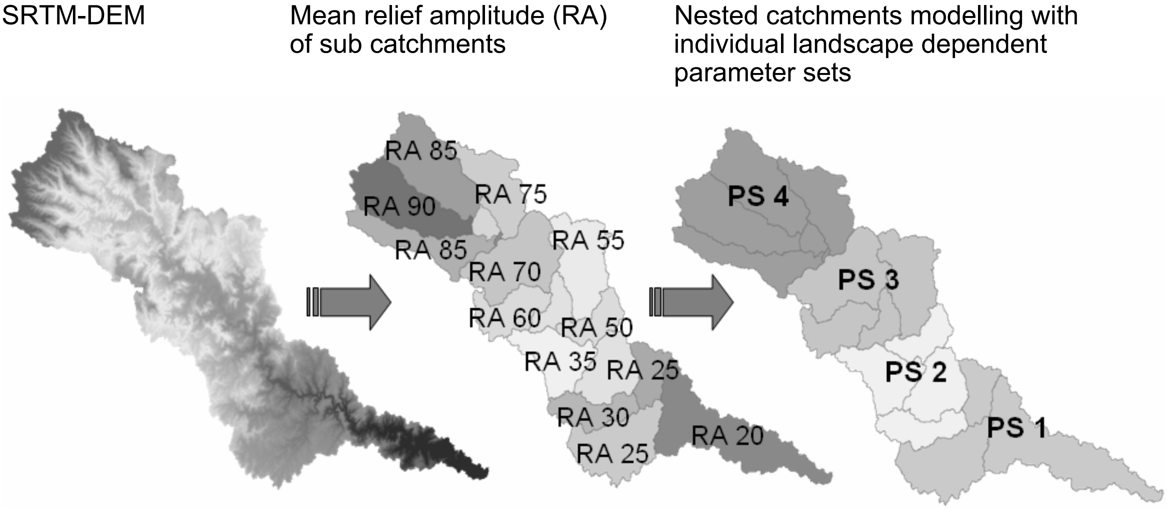


**Fig. 4** Calculation of mean relief amplitude (RA) of sub catchments for modelling a nested catchments modelling approach based on individual parameter sets (PS).

## DISCUSSION AND CONCLUSION

SRTM offers a solid base for mesoscale and macroscale hydrologically-oriented applications in most parts of the world. The investigation of the potential of SRTM data for delineation of process relevant response units over various scales was one important aim of this research. An optimisation of the elevation data was therefore required to improve the SRTM topology for hydrological applications. Improvements are necessary to embrace drawbacks in the interferometric radar data. Those effects result from geometric and radiometric errors as well as interaction properties of electro-magnetic waves with the surface. Resulting limitations in the SRTM data could be diminished using several GIS procedures and new algorithms for void filling, vegetation reduction, hydrologically-oriented filter combinations and stream burning. Amongst others preparations, a newly developed sink fill method was implemented with the name LaSA (Landscape based Sink Algorithm). The corrected and optimised SRTM data produced a better delineated stream network which has been validated with the digitised streams from the topographic map TK 1:25000. Thus, large errors in the delineated surface runoff were corrected and hydrologically optimized, and physically-based relief parameters were provided. The parameters were prepared according to the heterogeneity of landscape using the methodology introduced. As a result of the DEM preparation, hydrologically-corrected SRTM data were available to establish a ruled-based framework for RU-delineation. Numerous topographic indices were applied on these data whereas the index selection was oriented on different relief driven processes. Taking into account the scale problem several indices such as Topographic Wetness

Index, Stream Power Index and Solar Radiation Index were investigated in three subcatchments of the River Saale (Germany) with different landscape characteristics and thresholds for their classification were determined. The resulting data sets were analysed by the Cluster Analysis IVHG. This approach combines areas with small displacements in the multivariate space only under the constraint of an immediate neighbourhood. Under consideration of method transferability and scale, a landscape-dependent roughness index was integrated into data preparation. That led to a balanced representation of different landscape types. In order to determine the best level of generalisation, significant changes of distance vectors were analysed. Finally, different patterns of process-driven RU combining various topographic indices were delineated for the three mesoscale catchments within different landscape types. This procedure allows a well balanced delineation of process relevant surface objects and their classification independently of the respective landscape. These model entities represent hydrological response units as part of the regionalisation concept of distributive hydrological modelling. The analysis of the significance of the different landscape components in estimating runoff dynamics will define the potential of this approach for use in Ungauged Basins. These RU-sets were used as input entities in the hydrological model J2000.

Currently, the work is focused on the analysis of the transferability of the evaluated J2000 model parameter ensembles to corresponding South African catchments. To model with the described PUB-approach in catchments which consist of various significant landscape classes, a reorganisation of the J2000 model structure is aspired. Comparably with a nested catchment approach, a partition of the model run into sub catchments is planned. Each of the sub catchments should be modelled by the parameter set up of the dominant relief class.

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