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River basin management: What about climatic changes?

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Abstract Like many Mediterranean regions the State of Brandenburg in Eastern Germany suffers from a water deficit. The present study describes a methodology to assess the hydrological situation of a mesoscale region and the influences of possible climate changes. Trend analyses already show a significant decrease of percolation under the present climate. Strong changes of various water balance components are calculated under climate change conditions, assuming a temperature increase of 1.4K for the period 2001–2055. The results reveal a high sensitivity of the regional water cycle to relatively small changes of meteorological variables, and the need for suitable adaptation strategies to avoid future water availability problems. One step towards a more sustainable water use is the European Water Directive, which also represents the framework for a new project funded by the German BMBF. A basic part of this project is the development of a decision-support system (DSS) which will help to clarify the question as to why certain management options are recommended and others are not.

Key words climate change impacts; decision support system; European Water Framework Directive; large-scale hydrology; river basin management; State of Brandenburg, Germany; spatially distributed modelling approach; trend analyses

INTRODUCTION

Like many Mediterranean regions, the State of Brandenburg (30 000 km^2), situated in the German part of the Elbe basin (see Fig. 1), is characterized by water scarcity, resulting from a mean annual precipitation of about 610 mm. This differs from the situation in the rest of Germany, where the meteorological conditions in general do not induce water availability problems. Therefore, water management in the semiarid eastern parts of Germany represents a challenge which is studied by various research programmes.

The first part of this paper deals with regional climatic variability and its hydrological consequences, and a better understanding of the phenomena observed under the semiarid climate. Simulation results derived for the period 1961–1998 are discussed with respect to the spatial and temporal variability of various water balance components. The results of spatially distributed trend analyses are presented, indicating a general decrease of percolation. Based on these analyses, results are presented for the impacts of climatic changes on the regional water cycle in the second part of the paper.

The last part of the paper raises the question as to whether climate can be considered constant in medium- to long-term integrated water resources management

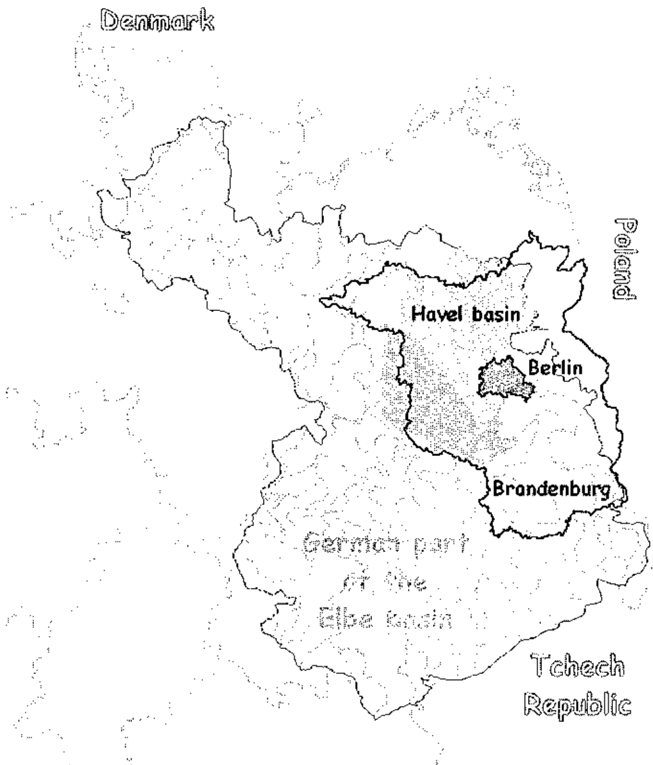

Fig. 1 Overview of the German part of the Elbe River basin, the State of Brandenburg and the Havel River basin.

plans. The aims and concepts of a new project are discussed, which was established within the European Water Directive (EWD) framework.

HYDROLOGICAL STUDIES

Methodology

In order to describe the hydrological situation of a mesoscale region, appropriate modelling strategies are necessary. In the present study, an approach is applied that uses the GIS-based derivation of model parameters from generally available spatial data. It is based on variable spatial disaggregation and aggregation techniques to take the spatial heterogeneity of the study region properly into account (see e.g. Lahmer, 1998; Lahmer & Becker, 1998; Lahmer *et al.*, 1999a) and to ensure an effective simulation of the regional hydrological cycle. The basic element of this approach is the modelling system ArcEGMO (Pfützner *et al.*, 1997, 2002; Becker *et al.*, 2002; www.arcegmo.de), which was successfully applied in various investigations (i.e. Lahmer, 1998; Becker & Lahmer, 1999; Lahmer *et al.*, 1999a; Lahmer *et al.*, 2001c; Lahmer & Pfützner, 2001).

The results presented here are part of two studies performed for the Brandenburg Environmental Agency (Lahmer *et al.*, 2001c; Lahmer & Pfützner, 2001). Water balance calculations were performed on the basis of 57 836 spatial units resulting from the GIS-based combination of land use, soil, groundwater table depth and sub-basin maps and spatially aggregated into 1599 hydrotopes and 15 hydrotope classes (for details see e.g. Lahmer & Becker, 1998; Lahmer *et al.*, 1999a; Becker *et al.*, 2002). Since the spatial distribution of meteorological input variables plays a key role in meso- to large-scale hydrological modelling (Lahmer, 1998; Lahmer & Pfützner, 2000; Lahmer *et al.*, 2000b), meteorological time series of 23 climate and 54 precipitation stations were included in the simulation runs. In addition, an appropriate interpolation method was used for their distribution (Lahmer & Becker, 1998; Lahmer *et al.*, 1999b; Lahmer *et al.*, 2000b).

Trend analyses of percolation

Based on the aggregated digital maps and the interpolated meteorological information, spatially distributed water balance calculations were performed on a daily basis for the period 1961–1998. As a result of the simulation runs, Fig. 2 shows the high variability of the annual sums of percolation, which is strongly determined by precipitation and evapotranspiration. The annual mean for the period 1961–1998 amounts to +86 mm (+107 mm in the winter and –21 mm in the summer period). In general, the results indicate some considerable changes of water balance components in Brandenburg occurring under the current climate. They also explain a considerable decrease of water table depths at numerous groundwater logging stations.

Changes of the meteorological conditions (decreasing precipitation and increasing temperature) may be the main reason for this decrease. However, in analysing the respective climatic time series (annual values) only the increase of mean daily

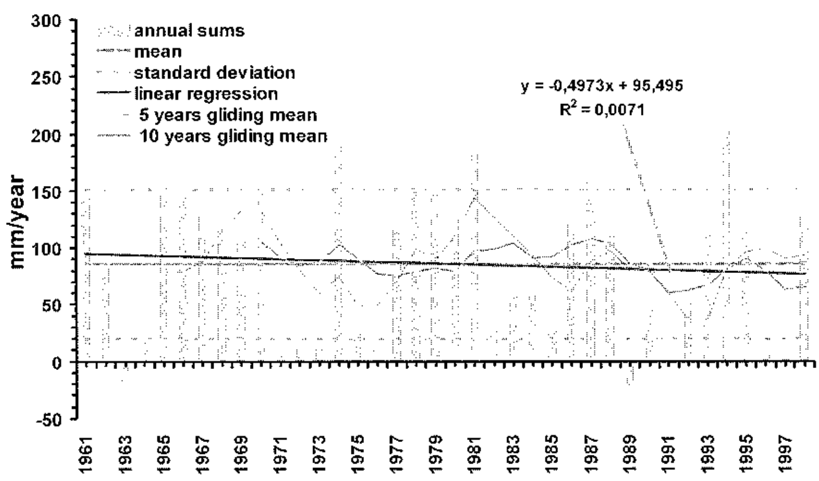

Fig. 2 Annual percolation calculated for the State of Brandenburg, 1961–1998. The decrease indicated by the regression curve turns out to be non-significant (mean, standard deviation and sliding averages for 5 and 10 years are also given).

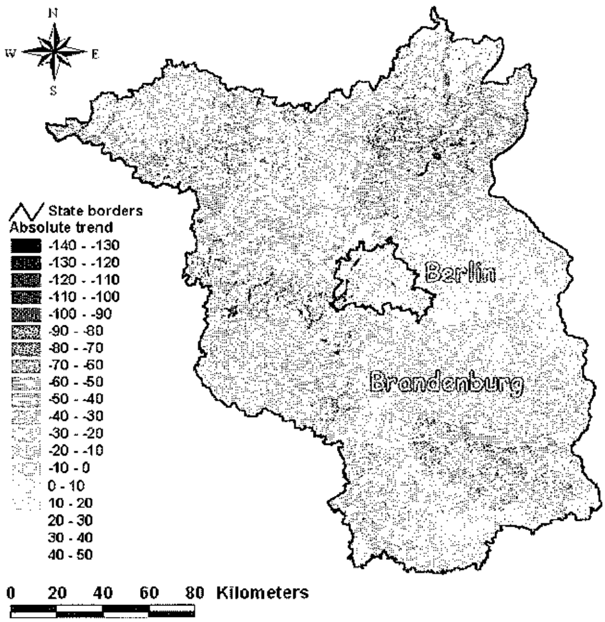

Fig. 3 Absolute changes of percolation calculated for the State of Brandenburg in the period 1961–1998 (in mm).

temperature by about 1°C in the period 1961–1998 turns out to be statistically significant. All other meteorological variables show non-significant changes. This is also true for precipitation, which decreases by 13 mm between 1961 and 1998.

Analyses on a half-year basis result in significant changes (trends) only for mean daily temperature and potential evapotranspiration in winter (changes of +1.6°C and +24.2 mm, respectively). For percolation, the linear regression of annual values given in Fig. 2 indicates a decrease from 95 mm in 1961 to about 77 mm in 1998. However, this decrease of almost 20% turns out to be not statistically significant. The same is true for winter, summer and quarterly values. Only for May is a significant negative trend derived.

To identify areas characterized by a significant change of percolation, spatially distributed trend analyses were performed for all 1599 hydrotopes. According to Fig. 3, the absolute changes range from –140 to +50 mm. About 75% of the total area show a decrease in percolation. However, the Mann-Kendall significance test shows that only 4.4% (or 1.331 km^2) is characterized by a significant (negative) change from –12 to –98 mm. Analysing the map given in Fig. 3 with respect to the 15 hydrotope classes used in the simulation runs reveals that only areas characterized by a shallow groundwater table show a significant decrease in percolation.

In summary, the trend analyses in Brandenburg demonstrate that only areas with a shallow groundwater table are characterized by a significant decrease of percolation in the period 1961–1998. The basic reasons are decreasing precipitation amounts (statistically not significant) and increasing mean daily temperatures (significant). The last decade (1991–1998), characterized by many hot summers, contributes considerably to this behaviour.

Climate change impact study

Since hydrological processes depend directly on climatic conditions, important consequences for regional water resources are expected under a changed climate. In principle, influences of climatic changes on the regional water cycle may result from spatial and temporal precipitation shifts, changes of actual evapotranspiration, and an increase of extreme events (prolongation of dry periods, draughts, high intensity precipitation, etc.). Already some early studies (e.g. Nemec & Schaake, 1982; Gleick, 1986) provided the first tentative evidence that relatively small changes in regional precipitation and evapotranspiration patterns might result in large changes in regional water availability.

Studies in the last few years have shown important regional vulnerabilities to changes of temperature and precipitation (Becker *et al.*, 1999; Lahmer, 2000; Müller-Wohlfeil *et al.*, 2000; Lahmer & Becker, 2000; Lahmer *et al.*, 2000a, 2001a,b). They clearly indicate that climatic changes will alter basic components of the hydrological cycle like soil moisture, groundwater availability and the magnitude and timing of runoff. As a consequence, dramatic environmental dislocations and widespread implications for water resources planning and management are expected in the future. However, such effects will differ from region to region, depending on the magnitude and spatial distribution of the climatic changes in combination with the hydrological characteristics of the study region.

In order to assess the impacts of climatic changes on regional hydrological processes, quantitative estimates are needed for the major long-term climatic variables such as temperature and precipitation. Since General Circulation Models (GCMs) are still not able to provide valuable detailed information on regional impacts on water supplies, alternative approaches must be used to promote the understanding of climatic vulnerabilities (see e.g. Lahmer *et al.*, 2001a). The present study is based on a physically consistent regional scenario, which includes general trends of GCM model calculations. Based on the assumption that GCM results on the average are more exact for large scales than for a defined region, long-term observed time series can be prepared by statistical methods to reflect the changes calculated by GCMs. In the case of a further unlimited increase of the CO_2 concentration in the atmosphere, the current GCMs calculate a global warming of between 1.5 and 4.5K up to the year 2100. For Central Europe a temperature increase of about 2 to 4K can be assumed within the next 100 years. The climate change scenario used in the present study assumes a moderate temperature increase of 1.4K and a precipitation decrease of 8% in the period 2001–2055 at 85 climate stations in the study region.

The main objectives of the impact study were to investigate the direction and magnitude of changes in the regional hydrological cycle and to identify specifically vulnerable land-cover types. High resolution water balance calculations on a daily basis were performed for the whole State of Brandenburg, both for the reference state (climatic variability of the period 1951–2000) and the climate change scenario (period 2001–2055). From the variety of results obtained for various water balance components, only the results for percolation will be discussed here.

In contradiction to time series for the whole study region, spatially distributed results can provide additional information, e.g. concerning sensitive sub-areas. As an example, Fig. 4 shows three maps of percolation. On the left hand side the mean

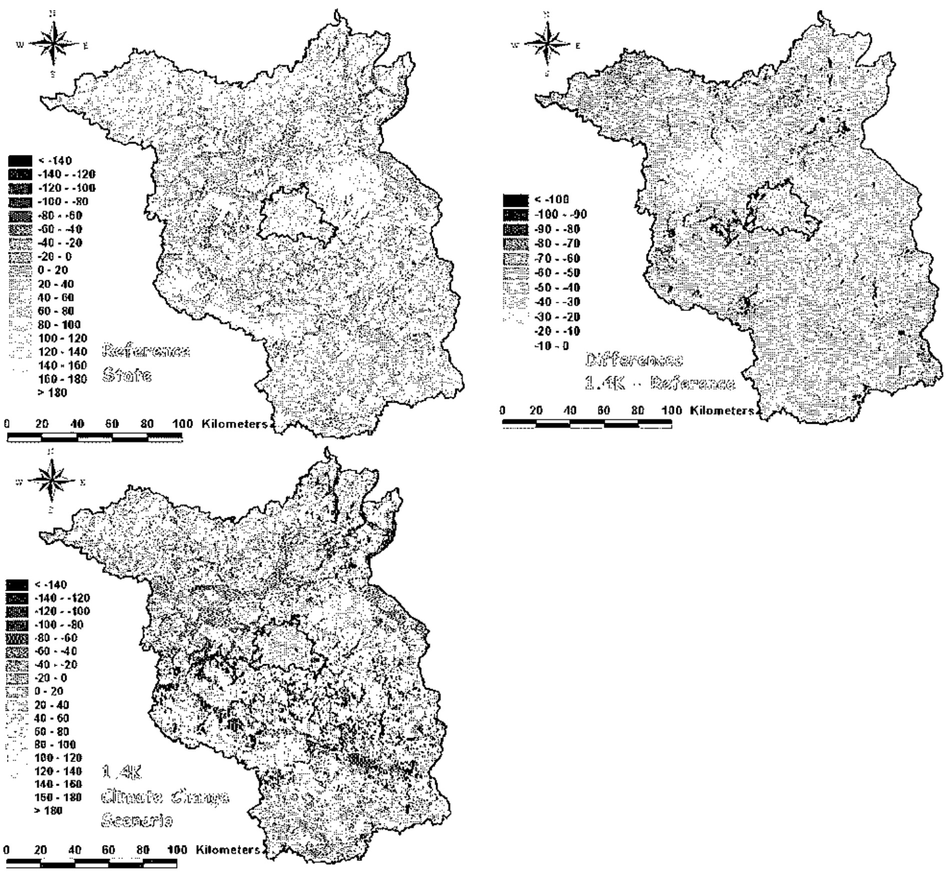

Fig. 4 Spatial distribution of percolation (mean annual total) in the State of Brandenburg for the reference state (period 1951–2000, upper left) and the 1.4K climate change scenario (period 2001–2055, lower left). On the right hand side the differences between the climate scenario and the reference state are given (all values in mm).

annual totals for the reference state and the 1.4K climate change scenario are given. They are characterized by the spatial distribution of the meteorological input variables and the heterogeneities of the underlying land use, soil, and groundwater level map. The maps clearly demonstrate a dramatic, region-wide change of percolation, which is especially evident in the differences between the climate scenario and the reference state (Fig. 4, right hand side). Due to the increase of evapotranspiration, percolation under climate change conditions decreases considerably (about 57% on the long-term mean). The reductions are especially high for open water bodies and for areas with a shallow groundwater table (up to about –100 mm).

This means that the summer water deficit already present would intensify in Brandenburg under the supposed changed climate. The main reasons for the calculated changes are a comparatively small reduction of annual precipitation combined with a considerable increase of mean daily temperatures, especially in the winter period. Besides percolation, total runoff turns out to be most sensitive under climatic change.

The climate change impact study clearly demonstrates that there is a strong need to understand and appropriately simulate the hydrological regime of semiarid regions, taking into account the specific natural characteristics of the region as well as the spatial and temporal variability of the meteorological driving forces.

RIVER BASIN MANAGEMENT

An important step towards a more sustainable water use is the European Water Directive (EWD), which aims at a general improvement of water quality in European river basins. It also represents the framework for the research project "Management Options in the Havel River Basin" funded by the German BMBF (Bronstert & Lahmer, 2001; www.havelmanagement.de). The project intends to implement the EWD in the Havel River basin, one of the largest river basins of the River Elbe. The main aims are to develop a methodology for the modelling of regional water resource issues applicable to policy formulation and to solve some of the most severe water-related challenges of the 21st century in that basin.

Due to the complexity of alternative management options, policy makers are often not able to decide between different proposals. Therefore, one of the basic goals of the project is to develop a user-friendly decision-support system (DSS), which will enable decision makers and water authorities to evaluate various management options and their influence on water quantity and quality. The tool integrates the results of various dynamic models and will help to clarify the question as to why certain management scenarios are recommended and others are not, taking into account the needs of various water users, the goals of the regional water planning and exploitation, and the agricultural land use. As an instrument to assess the effects of manmade changes on hydrology, the DSS stands at the interface of scientific research, practical application, and policy and forms the basis for an effective and comprehensive management of water resources.

The potential benefit and the effectiveness of the approach must be discussed in the framework of hydrological impacts due to land use and climatic changes, which were analysed earlier in the region and outlined dramatic potential changes of various water balance components (Lahmer, 2002). The general question arises as to whether climate can be considered constant in medium- to long-term water resources management plans or should river basin management take into account both present day and projected future conditions.

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