Sensitivity of Water Resources and Soil Erosion to Climate Change in Portuguese Semi-arid Watersheds

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Introduction

Climate change is expected to lead to increased temperatures and lower rainfall in the semi-arid regions of Portugal; these parameters could have a significant influence in the amount of available surface water and soil erosion rates in these regions.

However, there is some uncertainty as to the exact amount of change caused by climate change. Climate model results for Portugal in 2100 suggest an increase in temperature of 24 to 36%, while rainfall is expected change from +4 to -34% (Cunha *et al.*, 2001). This uncertainty limits the prediction capacity of models to quantify actual changes to water resources and erosion caused by climate change.

This work circumvented this problem by analyzing the sensitivity of water resources and soil erosion to varying degrees of change to both temperature and rainfall, following the approach used by Pruski and Nearing (2002) for single slope scenarios and adapting it for the watershed scale. The study area consisted of nine large watersheds in the semi-arid Alentejo region (Portugal), with a total area of 27 780 km^2. This region has experienced severe droughts and land abandonment in the recent past and is considered in risk of desertification.

Materials and Methods

The SWAT watershed model (Neitsch *et al.*, 2002) was applied to the study area to simulate several incremental changes to climate variables. The model was calibrated and validated using 1980-1990 runoff and sediment data using a split-sample test, with good results for both monthly surface water flow (r^2 = 0.75; Nash-Sutcliffe index = 0.75) and monthly sediment export (r^2 = 0.78; Nash-Sutcliffe index = 0.64).

The sensitivity of water resources and soil erosion to climate change was evaluated by running the SWAT model with several changes to climatic parameters in the model's in-built weather generator. Changes included +10 to +40% increases in temperature and -10 to -40% decreases in precipitation, evenly distributed between lower rainfall intensity and diminished number of rainfall days. The analysis of the results included correlating changes in precipitation and temperature to changes in evapotranspiration, water yield and sediment yield. Water yield was further decomposed into surface water yield (i.e. direct runoff) and ground water yield (i.e. subsurface runoff).

Results

The main simulation results show a significant sensitivity of both water yield and soil erosion to changes in precipitation; a 1% decrease in precipitation causes a 2% decrease in water yield and a 2.2% decrease in soil erosion. Changes to subsurface flow are slightly more important than changes to surface runoff (Figure 1, left).

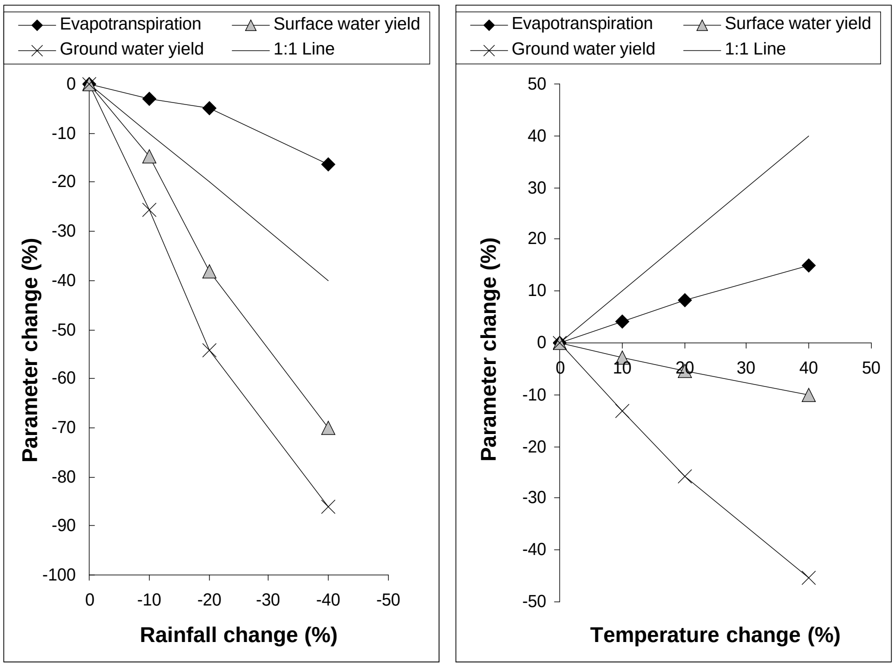

Figure 1: Changes to evapotranspiration, surface water and ground water yield due to changes in Rainfall (left) and Temperature (right).

This appears to be a consequence of the scarcer rainfall being increasingly diverted for evapotranspiration (Figure 2, left). Changes to sediment yield appear to be highly correlated with changes to surface water yield (Figure 3, left) and therefore can be explain as a result of less available surface runoff for soil detachment and transport.

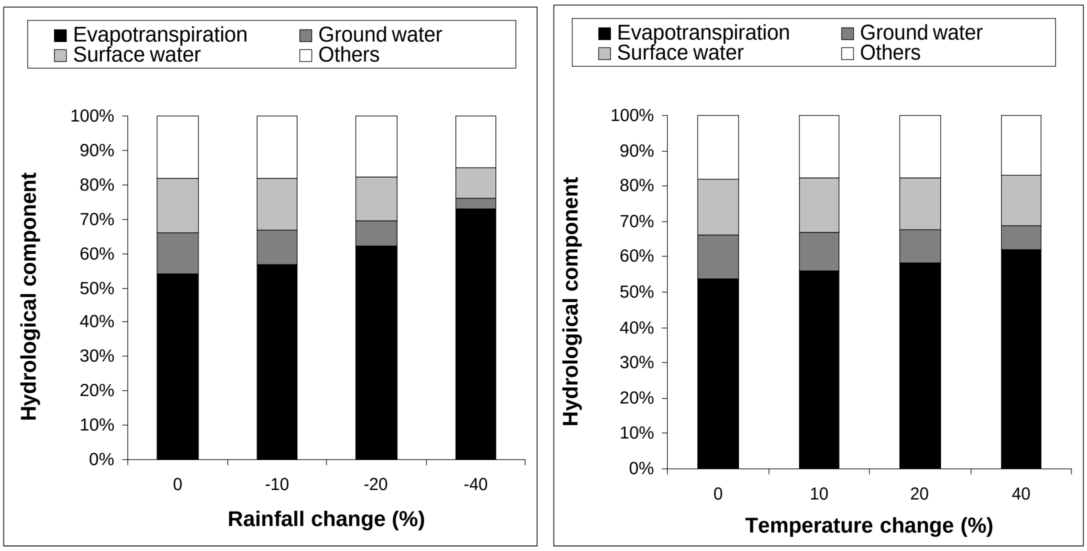

Figure 2: Changes to the importance of different hydrological components due to changes in Rainfall (left) and Temperature (right).

The sensitivity to changes in temperature appears to be more complex. Water yield decreases c. 0.7% per 1% increase in temperature. Most of these changes affect subsurface flow, since this reduction is linked to an increase in evapotranspiration (Figure 1, right); however, while evapotranspiration also tends to grow in importance with increasing temperatures, this effect in not as pronounced as in the previous case (Figure 2, right).

Despite the decrease of surface water yield, soil erosion increases c. 1.2% per 1% increase in temperature (Figure 3, right), a consequence of the increasingly unfavorable development conditions for the vegetation, especially as temperatures move away from optimum values, leading to less vegetation cover to protect the soil from the erosive effects of rainfall and surface runoff.

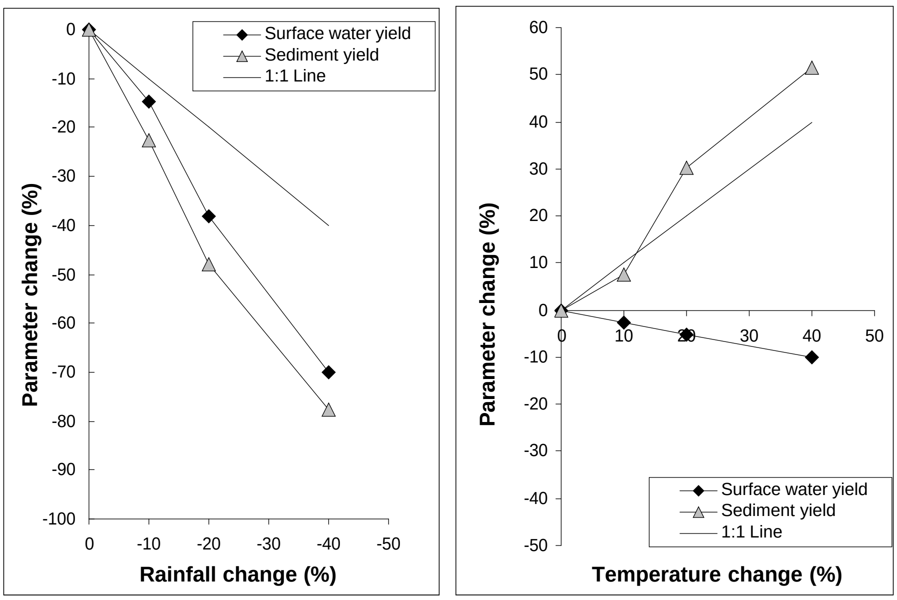

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Figure 3: Changes to surface water and sediment yield due to changes in Rainfall (left) and Temperature (right).

Discussion and conclusions

This work presents a methodology to analyze the possible consequences of climatic change for semi-arid regions when there is extreme uncertainty associated with climatic predictions. It can be applied to at the watershed scale and is useful both to assess the range of possible impacts on water resources and soil erosion, and the processes associated with increasingly greater levels of climate change.

The results show that the relationship between climate change and water resources in this semi-arid region are not linear; for example, a 30% rainfall decrease could lead to a 60% drop in available surface water. The most affected parameter appears to be ground water yield from subsurface runoff. Two possible explanations can be found. First, increased demands on water for evapotranspiration (due to either less available rainfall or higher temperatures) will lower the soil water content, reducing the amount of water available for subsurface flow. Second, surface runoff has an excess infiltration component that will be present regardless of vegetation water demands.

This result indicates that both a decrease in rainfall and an increase in temperature would lead mainly to intermittent rivers flooding after storms, a characteristic consistent with hydrological behaviour in arid regions.

In the case of decreasing rainfall, one interesting result is that, as rainfall drops more than 20%, changes to surface and ground water yield appears to level up as changes to evapotranspiration increase (Figure 1, left). This result could indicate a threshold below which changes to rainfall start to mostly affect water availability to plants.

The relationship between climate change and land degradation is more complex. While a decrease in surface runoff could also diminish soil erosion, increased temperature rates could lead to reduced plant growth, leading to poor soil cover and increased soil erosion, thus increasing the desertification process in cultivated areas.

Finally, one interesting result is that some vegetation types, especially mediterranean shrubs and cultivated cork oak trees, actually increase soil cover with a mild increase in temperature and could therefore be used as a replacement cover for the most affected vegetation cover, winter wheat.

Literature cited

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