SCIENCE FOR A SUSTAINABLE DEVELOPMENT
(SSD)

Climate

FINAL REPORT PHASE I

CLIMATE CHANGE IMPACT ON HYDROLOGICAL EXTREMES ALONG RIVERS AND URBAN DRAINAGE SYSTEMS IN BELGIUM

«CCI-HYDR»

SD/CP/03A

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Summary

Project description

The CCI-HYDR project was supported by the Belgian Science Policy Office (BELSPO) through their Science for a Sustainable Development (SSD) programme. The key aim of the project was to investigate the regional climate change impact on the risk of hydrological extremes along rivers and urban drainage systems in Belgium. The research was primarily based on results from the high resolution PRUDENCE regional climate models (RCMs) and later extended to include the Global Circulation Models (GCMs) from the Fourth Assessment Report (AR4) of the United Nations Intergovernmental Panel on Climate Change (IPCC). Various modelling centres and climate experts were involved in the simulations with these climate models, hence supporting good confidence in their results. The PRUDENCE project moreover made a substantial contribution to the latest IPCC AR4 report.

The CCI-HYDR project engaged a collaborative team of meteorological, hydrological and water engineering researchers from the Katholieke Universiteit Leuven and the Royal Meteorological Institute (RMI) in Belgium. However, a collaboration was also arranged with the ADAPT project, which is responsible for examining the wider implications of the CCI-HYDR outcomes to the society, water managers, and policy makers.

Research context

Flood risk is in Belgium as well as in other European countries of considerable importance especially due to the dense populations and high industrialization along the river banks. Also, since the last decades, sewer systems are being built at large scale. Drought risks are less significant in the country, due to the humid climate and the limited length of the dry spells in summer. However, extreme low flows may occur along rivers, causing severe problems of water shortage for drinking water supply, for agriculture and for the environment.

The concerns about the impact of climate change on the hydrological water cycle (including floods and droughts) have triggered specific studies since the 1980s. RMI has been pioneering in putting into evidence differences in the sensitivity of catchments with contrasted characteristics to a $2xCO_2$ scenario. They extended their study to a larger set of catchments and used the first set of climate change scenarios made available by IPCC. The scope was further extended to the whole Meuse river basin and Scheldt river basin using a new set of climate scenarios based on transient experiments, for instance based on the results of the GCMs forced with increasing greenhouse gas content. However, the GCMs have since improved, and high resolution regional climate models have been nested within to downscale the climate variables to regional scale. This has sparked new research related to regional impacts relevant at local scales. Hydrological impact assessments can now be performed with increased confidence.

Project objectives

The CCI-HYDR research project was set up to investigate in a detailed objective way and based on the most recent data and climate modelling results, the climate change impact on the risk of hydrological extremes along rivers and urban drainage systems in Belgium. To accomplish the project objectives, the research was subdivided into two phases. Phase 1 of the project focused on the selection of the RCM simulations and the long-term historical investigation of rainfall and evapotranspiration. In Phase 2 of the project, the implications of the scenarios on the hydrological extremes will be studied. This will require an investigation of flood and low flow risks along rivers and flood risks along selected urban drainage systems in Belgium. The project results will provide useful additional support for policy development especially related to sustainable development such as the Kyoto Protocol.

Overview of methodology

The study required a comprehensive assessment of the climate data relevant for hydrological impact analysis. Thus, there was a need for investigating the historical trends from the observed series and the future predictions from the most recent regional climate models. The latter was accomplished by evaluating the RCM model outputs relevant to the hydrological impact through statistical techniques while the former was studied by applying a trend analysis technique that combines the frequency and magnitude of extremes.

The historical trend analysis was performed for both the potential reference evapotranspiration (ETo) and rainfall series. A unique 10-minute rainfall series for the period 1898-2005 was made available by IRM including a daily ETo series for the period 1901-2005. A technique that derives the temporal changes in the magnitudes of extremes and tests for their statistical significance was developed for the trend analysis. The technique was used to identify the anomalous periods within the observed time periods. The historical trends would also provide a basis for verifying the consistencies of the climate model predictions.

The evaluation of the RCMs was achieved through statistical tests and graphical interpretation of the related outputs. The RCMs were evaluated against the observed measurements for the consistency in mean statistics, seasonality, spatial variability, inter-annual variability, and trends. The project primarily concentrated on the regional results from the PRUDENCE project (http://prudence.dmi.dk). The project provides European high resolution data (12-50km) for both the observed climate (control period 1961-1990) and the future climate at the end of the twenty-first century (scenario period 2071-2100). The PRUDENCE project provides several experiments from an array of 11 RCMs nested in two main GCMs. The experiments were run for the IPCC regional A2 and B2 future greenhouse gas emission scenarios. Since the PRUDENCE RCM models were based on only the A2 and B2 scenarios, scaling factors were required to make the scenarios more exhaustive (reducing the emissions uncertainty) by including changes from extra scenarios (notably the A1B and B1). These were derived from the IPCC AR4 models.

The study evaluated outputs with direct relevance to hydrological impacts such as rainfall and ETo. Rainfall was taken as a direct measurement while ETo was estimated from other measurements (wind speed, humidity, cloud covering, pressure, temperature, and radiation). The models were tested for their performance at both the local and regional scales. The combination of regional and point performance measures led to a selection of climate models suitable for the Belgian climate. These selected models were used to investigate the climate change seasonal characteristics at both the local scale and the regional scale. The local scale primarily focused on observed data from the reliable Uccle station while regional analysis was based on various stations covering Belgium.

The statistical evaluations of the PRUDENCE models revealed that the direct use of the biased model results would subsequently lead to biased impact analysis. Even so, the large set of models implied that the interpretations would be difficult for the impact analysts. Therefore, three scenarios were proposed which would simplify the interpretation and at the same time account for the overall uncertainty from the selected models. The three scenarios were derived through a statistical downscaling method that involved the transfer of the changes estimated from the climate models to an observed time series. The changes mainly concerned the number of wet days and the intensities of the wet days for rainfall and the intensity changes for ETo. Based on the entire set of the models the high, mean and low scenario cases were derived to represent the overall expected range. Impact modellers would benefit from the provided scenarios. Based on the statistically probed scenarios, the CCI-HYDR project Phase 1 provides scenarios for rainfall and ETo, which are constructed specifically for the Belgian climate.

Results from phase 1

Historical assessment

The historical trend analysis was carried out for the four climatological seasons: winter (December, January and February), spring (March, April, May), summer (June, July, August) and autumn (September, October and November). Long term (more than 100 years) historical rainfall and evapotranspiration series were assessed for evidence of climate change traits manifested as significant trends, taking into account the natural oscillations. The perturbation factor, which is a measure of changes in quantiles, was chosen as an index because of its use of ordered statistics that enables an investigation of the changes in extremes.

For extreme rainfall quantiles, oscillations were observed with higher extreme rainfall quantiles in the 1910s-1920s, the 1960s and recently during the past 15 years. Lower extreme rainfall quantiles were observed in the 1930s-1940s, and in the 1970s. During the past 108 years, the multidecadal oscillations in rainfall extremes appeared in a nearly cyclic manner with periods of 30 to 40 years. A period with only 3 cycles is too short to draw statistically strong conclusions on this property, but results clearly indicate the presence of long-term temporal persistence in the rainfall extremes, with a cluster of rainfall extremes during the past 15 years. These conclusions were consistent for all time scales varying from 10 minutes to the monthly scale, and for the winter and summer seasons. For the summer period, highest extreme rainfall quantiles were observed in the 1960s, slightly higher than the more recent ones from the past 15 years. These results suggest that the recent increase in the number of heavy showers causing sewerage system flooding, is caused by hydrometeorologic conditions which are less or equally extreme than what was observed during the 1960s. Of course, in the mean time, land use strongly changed (e.g. urban areas expanded and sewerage systems were built at a large scale) such that hydrological effects nowadays strongly differ from the ones in the 1960s. During the winter period, extreme rainfall quantiles during the past 15 years were significantly higher than during earlier periods, indicating that the climate change effect most probably amplified the multidecadal oscillation effect. During the transitional seasons of autumn and spring, results were less significant.

The evapotranspiration trends showed similar seasonal characteristics especially during winter. Like rainfall, the evapotranspiration during the winter season showed the most significant changes with the most recent decades (1990s) appearing more pronounced. Generally, since the 1980s there have been increasing evapotranspiration trends for all the seasons especially during the most recent decade with winter showing the most pronounced changes. These changes are consistent with the current temperature trends which have pointed to warmer winters than previously recorded. Various studies have also indicated that the future winters will become milder which implies that the evapotranspiration rates will increase further. This increase will partly explain the increased rainfall during winter related to additional water vapour in the atmosphere.

Model performance

The selection of the climate models was based on an amalgam of several criteria. The outlier tests, frequency analysis, trend tests, bias measures, and spatial variability were the main criteria used for the climate model evaluation. By observing the behaviour of the PRUDENCE control and scenario series using various statistics, some models were found to consistently perform poorly. It is notable, that no model performed well for all the criteria but some models were generally better than others. However, temperature was simulated better than rainfall which was expected as GCMs have been found to be better at modelling temperature than the intermittent rainfall. Based on the analysis for temperature and rainfall, the ICTP (RegCM) and the GKSS (CLM) models were omitted from the list due to consistent discordant tendencies.

Climate change estimates

The selected PRUDENCE models exhibited both negative and positive changes (-40% to +10%) in rainfall during summer, and positive changes during winter (+5% to +50%). There were no significant regional differences in the climate change signals over Belgium; with the exception of the coastal region. The rainfall increases are for the main Belgian lands around 15% lower than the ones over the coastal area. This means that the climate change translates to more significant precipitation increase during winter and less significant precipitation decrease (or even no change at all) during summer for the coast compared to the rest of the country. The inclusion of more scenarios (A1B and B1) creates a significant difference in summer (there is a relative increase of up to 16%). Winter also showed a relative increase of up to 10%. This demonstrates the importance investigating the entire scenario ranges which allows for corrections in the uncertainty ranges.

Climate change downscaling

The challenge still remains as to how end users can make use of a large set of models. This study borrowed some concepts of ensemble modeling by making use of the probabilistic perturbations derived from the selected PRUDENCE RCMs. The set of the 28 model results (from selected RCMs) implied that there were 28 possible scenarios (A2 and B2) which required close examination as all were equally plausible. From the 28 scenarios, three probabilistic scenarios were extracted to allow end users to investigate the range of changes. The scenarios were appropriately named high, mean and low. The use of probabilistic techniques ensured that the expected outputs represented the spectrum of all the projections. For rainfall, particular attention was paid to the wet day perturbation, and the wet day intensity perturbation. The two perturbations are considered crucial for hydrological impact analysis. For ETo, only the intensity perturbation was applied. It is worth noting that scaling factors were derived from the IPCC AR4 A1B and B1 scenarios to reduce on the emission scenario uncertainty. An Excel based algorithm has been developed to perturb observed rainfall and ETo series. It generates the three scenarios for high, mean, and low. Based on these scenarios, impact modellers can now assess the impact of climate change on the hydrological extremes for time scales ranging from 10 minutes to daily.

Synthesis of phase 1 results

During Phase 1 of the CCI-HYDR project both the theoretical and practical contexts of the climate change impacts on hydrological extremes were established. The theoretical contexts involved literature studies that were influential in understanding the past and future changes in the Belgian climate. The practical context involved applying the extracted changes from the RCMs to the hydrological models. This required a range of statistical techniques especially aimed at capturing the spectrum of future projections.

It was established that the historic patterns showed deviant behaviour from the long term average. There is a reason to be concerned as the recent significant trends in rainfall and evapotranspiration suggest. In particular, winter showed pronounced changes during the most recent decade: positively significant rainfall and ETo amounts. The future predictions (2071-2100) also point to a continuation of the same trends; the winters generally get wetter and the summers get drier. ETo will increase for all the seasons.

The next steps: future research

Future research will primarily deal with impact modelling towards flood risk and low flows using hydrological and coupled hydrological-hydrodynamic river models. Flood risk will be assessed for urban drainage systems by considering the impact on sewer flood frequencies and magnitudes, combined sewer overflow frequencies and receiving river impact for selected systems. Flood risk and low flows will be investigated for rivers.

The implications of the changes in flood and drought risks will continue to be investigated through a collaboration with the ADAPT project. The implications to society, water mangers and policy makers will be assessed.

More information about the CCI-HYDR project can be found on the project website: http://www.kuleuven.be/hydr/CCI-HYDR.htm.