Synopsis

River Hydrology and the North Atlantic Oscillation: A General Review

INTRODUCTION

The connection between the North Atlantic Oscillation (NAO) and hydrological conditions has been a subject of interest since the influence of NAO on climate phenomena was substantiated. NAO is one of the major regional systems controlling atmospheric circulation that influences climate in Europe, northern Africa, and Greenland, as well as in North America and much of northern Asia (1–7).

The mechanism of the NAO has been previously explained and described in many detailed studies devoted to both general and particular regions and to chosen meteorological elements (8, 9). Of particular importance has been the research and studies on the influence of NAO on precipitation and air temperature (10–18). Precipitation and air temperature are the two most important meteorological factors controlling runoff and evapotranspiration, i.e., the two basic elements of water balance. In the hydrological system, the precipitation is the element that is transformed into runoff. Hence, climatic fluctuations affect available water resources and the demands of humans and biota (Fig. 1). Knowledge about variability of hydrological regimes would improve the management of water resources at a catchment, regional, and global scale.

The influence of the NAO on meteorological conditions is especially strong in winter. This influence is varied depending on area; it is determined by what is known as teleconnections, i.e., covariability of meteorological elements on distant areas of the globe. The positive NAO phase results in warm and wet winters in Europe, cold and dry winters in northern Canada and Greenland, and mild winters in the eastern United States. The negative NAO phase results in cold weather in northern Europe, moist weather in the Mediterranean region, mild winters in Greenland, and cold and snowy weather in the eastern United States (19, 20). Our aim here is to survey the present-day research on the NAO influence on river hydrology, with particular interest in the regional range of the NAO’s impact on river runoff, relationships between the NAO and river runoff, and potential possibilities of the results’ use in forecasting the quantity of runoff in various seasons of the year.

So far the studies on the NAO’s impact on river runoff have been concentrated on seeking links between the winter NAO conditions (expressed mainly by the Hurrell NAO index and mean annual, seasonal, monthly, and seasonal extreme discharges. Most studies use correlation and factor analysis. The size of the analyzed river basins was differentiated. Most of the relationships between the NAO winter index and the river runoff is asynchronous.

REGIONAL RANGE OF THE NAO

In northern Europe, river flow in winter is positively correlated with the winter NAO index, which is connected with high precipitation at that time (3, 21). What is more, if there is a positive NAO phase in winter, the inflow of river waters to the Baltic Sea from the northern part of the Scandinavian Peninsula is higher than usual in the whole year; in the southern part of the peninsula, there are usually no droughts in such a year in winter and autumn (15, 22, 23).

The area directly influenced by the NAO is Iceland. It has been stated that in the years when there is a positive NAO phase in winter, the average annual river flow in the next year is higher than usual, especially for rivers situated in the western part of the island (24, 25).

In the British Isles, the influence of the NAO on hydrometeorological conditions has been stated: there is a considerable inversely proportional connection between the winter NAO index and the precipitation from June to August of the next year. The strongest connection refers to the eastern part of Scotland: if the winter NAO index is higher than usual, the summer is dry (15). This phenomenon is reflected in drought in summer, especially in rivers in England and Wales (7, 26). After winters dominated by negative NAO index, the river runoff in autumn is very low. Connections have been determined that allow us to forecast the quantity of the river runoff in England and Wales several months beforehand (26–28). In Scotland, an increase of the positive NAO phase is seen in considerable river flows in winter (23). In Ireland after 1975, a considerable increase in precipitation in March and October has been noted, especially in the west of the country. This is also accompanied by an increase in the river runoff. Those changes are caused by increased western air circulation, which is reflected in the increase of the NAO winter index (29).

In central Europe, the influence of the NAO winter on yearly river flow is seen mainly in the spring meltwater runoff. At extremely low NAO winter indices, the risk of floods is increased—e.g., considerable high flooding of the Wisła and Odra Rivers occurs after winters that are characterized by extremely low NAO indices. Further west, this influence is weaker (23, 30, 31). There is a link between the NAO and the runoff of the Warta River in April, August, and September (32). There is also an interdependence between the NAO winter index and the runoff of some Carpathian rivers and the Wisła River (in Sandomierz). If there is a strong positive NAO phase in December and January, the runoff of the Skawa and Dunajec Rivers at the end of summer and the beginning of autumn are lower than usual (33, 34). Also, a link between extreme discharges of some Carpathian rivers and the NAO winter index and the SCAND index (35) has been noted (Table 1).

In the case of Alpine rivers, the domination of the positive NAO phase in winter results in low risk of flood (23). Increase of the NAO component in air circulation is associated with an increased winter maximum daily storm flow of the Alzette River, Luxemburg, since 1970 (36). In southern Europe, long droughts occur when winter is dominated by a positive NAO phase, which can be observed in Romania (37). In the case of the Danube River, there is a strong relationship between the NAO winter index and the average yearly flows and average flows in subsequent months of the year (asynchronous correlation). If winter is dominated by a strong positive NAO phase, the subsequent hydrological year is dry. A link between Danube River flow and the El Niño–Southern Oscillation has also been observed (38, 39).

Figure 1. Simplified diagram of hydrological system.