Experimental studies of changes in the water balance of an urban area

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Abstract. The Institute of Geography of the USSR Academy of Sciences, Moscow, has been conducting studies on water balance changes under urban influences and industrial agglomerations, in Kursk. This is a city typical of the European part of the USSR with a population of 300 000. It is one of the economic and cultural centres of the forest-steppe zone. The results of observations on the water balance elements of the urban area are compared with data from earlier similar studies conducted near Kursk in the virgin area of the Central Chernozem Reserve and also on arable land. As a result of these studies seasonal and yearly water balances were made for the urban area and the water balance changes were estimated. The research is based on a method adopted by the Institute of Geography.

L'experimentation sur les changements du bilan d'eau d'un territoire urbain

Résumé. L'Institut de géographie auprès de l'Académie des sciences de l'URSS a accompli des recherches sur les changements du bilan d'eau du territoire urbain de Koursk sous l'influence de l'urbanisation et de l'industrialisation. Koursk est une ville typique pour la partie européenne de l'URSS, surtout pour la zone forêt-steppe; sa population compte maintenant 300 000. Les traits particuliers de ce projet consistent en la comparaison des séries des observations sur les éléments d'un bilan d'eau en ville et en territoires vierges et agricoles non loin de Koursk.

Les résultats de cette recherche permettent d'apprécier le bilan d'eau saisonnier et annuel d'un territoire urbain, ainsi que les changements d'un bilan d'eau et de la qualité des eaux superficiels sous l'influence de l'urbanisation et de l'industrialisation à la base d'une méthode élaborée à l'Institut de géographie de l'Académie des sciences de l'URSS.

About 60 per cent of the population of the USSR live in cities, where the water balances differ from those in rural areas. The study of the problem is essential to assess changes in any element of the environment. Through such experimental studies knowledge of surface runoff and the water balance of urban areas become better known. Such studies have been conducted in the city of Kursk and the Kurskaya Oblast (the Province of Kursk) by the Institute of Geography of the USSR Academy of Sciences, Moscow. Kursk is a city typical of the European part of the USSR with a population of 300 000. It is one of the economic and cultural centres of the forest-steppe zone.

The results of the observations on the water balance elements of the urban area are compared with data from similar studies conducted earlier near Kursk in the virgin area of the Central Chernozem Reserve and also in areas of arable land. The results of the studies on the rural areas are given in a series of works (Green, 1965; *The Water Balance of the USSR and its Transformation,* 1969; Koronkevich, 1973; Lvovich, 1973; *The Water Balance of Major Ecosystems in the Central Forest-Steppe,* 1974; Koronkevich and Chernishov, 1976). Due to the ergodic character of hydrological processes the methodology of such studies conducted in different areas makes it possible to reconstruct the water balance for many centuries of economic development in the forest-steppe zone from before the time of the massive development of agriculture in this area.

A major reason for water balance changes in an area under the effect of economic development is the influence on soil as a result of which the infiltration capacity of the soil changes (Lvovich, 1963).

For the three types of land-use studied (city, ploughed land, virgin land) the largest infiltration capacity is characteristic of soils of virgin land. These areas are covered by deep rooted grass stands with a layer of dead plant residues on the soil surface. Under such conditions during spring snowmelt and even during heavy rainfalls almost all the water percolates into the soil and the surface runoff is rather low. The same is true of oak groves which cover 6–10 per cent in the forest-steppe zone. Water balance studies on the virgin steppe, which remains in the forest-steppe zone only in individual reserves, gave very interesting results, which made it possible to follow the water balance transformation in this zone for almost 1000 years.

Ploughed lands, covering about 80 per cent of the area in the forest-steppe zone have a somewhat lower infiltration capacity. This is particularly so for autumn-ploughed lands, which have become widespread since the 1930s due to agricultural mechanization. In pre-Revolutionary Russia spring ploughing prevailed, therefore during snowmelt soils were compact and water slowly percolated into them. At that time the surface runoff from the ploughed land was almost twice the present value, for this reason soil erosion developed.

The least infiltration capacity belongs to the surface of urban areas and this is caused by the housing developments and the asphalt surfaces of streets and roads. The runoff coefficient for house roofs is practically close to unity and for asphalt surfaces it is over 0.8.

Within Kursk, experimental water balance studies were conducted on small catchments. Of the two urban catchments, the Zhdanovsky catchment belongs to the most built-up central part of the city, and the Western catchment, which is situated nearer the outskirts, predominantly covers an area with one-storeyed houses, gardens and kitchen gardens. Trees and lawns cover a significant area in the central part of the city.

The results of the studies given in Table 1 require some comments. First of all it is essential to note that both years during which the studies were conducted were dry: on average in Kursk and in the surrounding rural area 600 mm of precipitation occur, i.e. 100–180 mm more than during the years of observation. In normal years in spring the surface runoff from the virgin steppe is about 10 mm, that from the area under winter crops reaches 80 mm and that from autumn-ploughed land is 30 mm. In summer and autumn, rainfalls on these lands are spent through infiltration and do not form surface runoff. In oak groves in wet years the surface runoff is non-existent.

In the Kurskaya Oblast as a rule a stable snow cover is formed in winter. Melting usually occurs over a period of 15–20 days in March but sometimes not until the beginning of April. In the years of observation snowmelt on the virgin lands and on ploughed lands took place over a period of a week and within the city it continued for about a month. This is explained by the uneven distribution of snow because of snow-drifts formed in the process of street cleaning, and by the slow melting of the trodden snow which sometimes turns into ice. The difference in the water equivalents of the snow cover in the different areas by the beginning of snowmelt is caused by wind blown snow drifts, with snow blowing mostly off the land ploughed in autumn for spring crops. The greatest amount of snow accumulated on vegetation cover including shoots of winter crops which spend the winter under snow cover. Within the central part of the city the water equivalent of the snow cover is reduced due to the clearing of snow from streets and roofs and also because it blows away.

For the two years of observations the amount of precipitation falling during single rain storms in summer and in autumn did not exceed 10 mm in the majority of cases with a mean intensity of 0.04 mm/min. With such a regime of precipitation and even with

TABLE 1. Water balance of different areas in the Kurskaya Oblast (the Province of Kursk) and in the city of Kursk (1975–1976)

	Virgin lands of the reserve		Ploughed lands		City of Kursk	
Water balance elements	Steppe	Oak groves	Winter crops	Spring crops	Zhdanovsky catchment	Western catchment
Winter–spring period (snowmelt)						
Water equivalent of snow cover and precipitation during snowmelt [mm]	136	131	122	82	109	132
Runoff [mm]	0	0	14	7	33	23
Infiltration [mm]	136	131	108	75	76	109
Runoff coefficient	0	0	0.11	0.08	0.30	0.17
Summer–autumn period						
Precipitation [mm]	366	366	382	382	313	313
Runoff [mm]	0	0	0	0	76	22
Infiltration [mm]	366	366	382	382	237	291
Runoff coefficient	0	0	0	0	0.24	0.07
Year						
Precipitation [mm]	502	497	504	464	422	445
Runoff [mm]	0	0	14	7	109	45
Infiltration [mm]	502	497	490	457	313	400
Runoff coefficient	0	0	0.03	0.015	0.26	0.10

more intense rainfalls as a rule no surface runoff is formed on the virgin and ploughed lands: all the water percolates into the soil. However, in the central part of the city where the major part of the area is only slightly pervious even rainfalls of ⩾ 1 mm form surface runoff. On the Western catchment which is an area of private houses, gardens and kitchen gardens, rainfalls of over 5 mm form surface runoff.

In the city the spring surface runoff is 2–3 times as large as that from ploughed land. The difference in values of annual runoff (due to summer–autumn runoff) is much greater: in the city it is 6 times that from ploughed land. At the same time the annual amount of water infiltrating in the city is 100–120 mm less than that in agricultural lands. This results in a reduced amount of evaporation and groundwater recharge.

Spring runoff is characterized by daily cycles caused by daily variations in air temperature and solar radiation. Changes in daily runoff cycles as well as in the maximum spring runoff are greater in the city than on ploughed land (Fig. 1).

Similar experimental water balance investigations were conducted on agricultural lands in other geographical zones of the USSR. The results of these investigations helped to assess the effect of the intensification of agriculture on runoff during the last decade (Lvovich, 1963; Koronkevich, 1973). Runoff greatly decreased during spring floods in the rivers of the steppe and forest-steppe zones, where the retention of surface runoff from fields and its accumulation in the soil are effective means of increasing crop yields. Under the influence of this factor the spring flood runoff in the rivers of the southern half of the European part of the USSR has decreased in recent decades by about 12–15 km^3/year or by over 10 per cent.

The urban areas have the reverse influence on the water balance: the flood runoff increases. At present such changes are especially significant due to the intensive growth of cities including those in the black-soil belt of the forest-steppe zone to which the Kurskaya Oblast belongs.

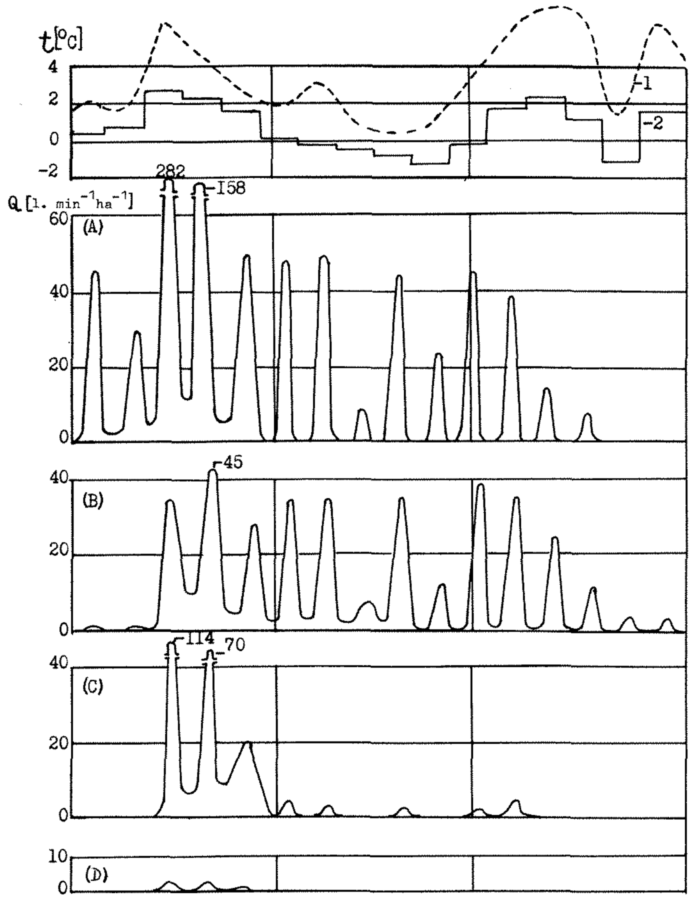

FIGURE 1. Surface runoff for different areas in the spring of 1975: (A) Zhdanovsky catchment, (B) Western catchment (C) 'distant' catchment, (D) 'near' catchment. Curve 1 is the maximum daily air temperature, and curve 2 is the mean daily air temperature.

This paper does not deal with other aspects of urban influences on water resources which are related to their use for water supply. Consumptive use in cities is small as a rule and seldom exceeds 10 per cent. However, after use 90 per cent of the water becomes polluted waste water to some extent. Even modern methods of cleaning do not completely remove pollutants. Since the increase in waste waters in industrialized countries usually outpaces the development of cleansing techniques, antipollution measures should be prophylactic. The idea is advanced that discharges even of treated waste water into rivers and water bodies should be ceased, i.e. waste waters should be isolated from sources of water supply. This way of solving the problem is based on the forecast of the world water resources situation for the year 2000 and is described in detail in English by Lvovich (1973). This solution is complicated but quite realistic provided it is realized during the next two or three decades. This will require the transfer of enterprises to a 'dry' technology and to closed recirculation water supply systems. The chemical industry of the USSR has basically taken this approach. To solve the problem of domestic and municipal waste waters of cities is much more difficult. However, in the future it is quite realistic to re-use treated waste water where possible. Another method which is likely to require a longer period before it is put into practice is the regeneration of domestic and municipal waste waters. In this case cities can be converted to a recirculating water supply since there will be no sense in discharging the regenerated water into rivers and water bodies. This water will be cleaner and more suitable for drinking water supply than water from natural sources.

This is due to the fact that after waste water discharges into rivers and water bodies are stopped other contributors to pollution will remain. Among them probably a major source of pollution is snowmelt and rain water running from cities and industrial enterprises. The best way to combat this kind of water pollution is to keep the area perfectly clean. Until the complete solution of this problem is attained one approach is to use settling ponds for the collection of water running from cities.

We see from the above that the problem of the effect of cities and industrial agglomerations on the environment and on a major component, the water balance and also water quality, should be solved in a complicated way with due regard to hydrological, hydrochemical and biological processes and social factors. Such an approach makes it possible to completely understand the regularities in the interrelations between nature and society and to solve them in the light of tasks of constructive geography (Gerasimov, 1973), which play an important progressive part in geographical studies in the USSR and in other countries.

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