Total evaporation from the surface of river catchments in Western Siberia

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Abstract. An important place in determining the water content of the territory in order to plan the optimal management of water resources, as well as in determining the technology of irrigation regimes to obtain sustainable crop yields, is the calculation of total evaporation. Evaporation, being the main element of the hydrological cycle, connects hydrology with meteorology and agriculture. In plant physiology, transpiration is characterized by the transition of water contained in the soil into a vapor state, followed by accumulation in the atmosphere. During transpiration, as with conventional evaporation, it is necessary to take into account such atmospheric elements as radiation, temperature and humidity, soil moisture and wind parameters. Therefore, the value of total evaporation, including transpiration and evaporation from the underlying surface (soil, water, snow, ice, etc.) depends on both zonal and azonal factors of the geographical landscape. Of great importance in determining the total evaporation is the correct choice of calculation method that meets the tasks requirements, taking into account the climatic features and fulfilling the conditions of the required accuracy of the calculation results.

1. Introduction
The territory of Russia, located on two continents and stretching for great distances both from west to east, and from south to north, has a variety of climatic and orographic features, and, therefore, various conditions for the formation of water balance elements. A significant difference in the factors affecting the amount of evaporation was the reason for the appearance of a number of methods for calculating the total evaporation. The most common of them are: the method of hydrological-climatic calculations (GCR) of V. S. Mezetsev, the bioclimatic method of A. M. Alpatiev, the methods of S. I. Harchenko, A. R. Konstantinov, G. K. Lgov, S. P Nevsky and D. A. Shtoyko, each of the methods has its own characteristics to a certain extent, reflecting certain features of the territory that affect the amount of total evaporation.

2. Literature observation
In foreign practice, the calculation models of S.V. Thornthwaite, X. Bleny - V. Blaney, B. Criddle, H. Penman (H. L. Penman) are most often used to determine the total evaporation (evapotranspiration). Since 1990, on the recommendation of the FAO UN (FAO, Food and Agriculture Organization of the United Nations), the Penman - Monteith method (Penman - Monteith, RM) [1], based on the use of standard climatic indicators (solar radiation, albedo, duration of sunshine - actual and possible, etc.). The peculiarity of this model is the definition of evapotranspiration of the “reference” culture (ETO) with the transition to cultures under standard conditions (ETs) and to cultures in vivo (ETs adj) [2].
However, the need for a significant amount of initial data used in the evapotranspiration calculations that are not observed in most meteorological stations limits the application of this method (V. P. Ostapchik) [3]. Unfortunately, despite the existing variety of methods for calculating total evaporation, in practice it is not always possible to choose a universal model that allows mass calculations for the entire territory of Russia. This is confirmed by the fact that the results of calculations by various methods often lead to conflicting indicators. The difficulty in choosing a single method is associated not only with the fact that the total evaporation depends on local factors characteristic of a given natural zone (calculation methods are mostly adapted to regional climatic conditions and are therefore limited for use in other areas), but also the complexity of determining constituent components used in a particular model. Thus, at the present stage, the most optimal for calculating the water-balance characteristics is the use of such models that provide the results as close as possible to the values observed in natural conditions.

3. Materials and methods

To calculate the total evaporation in Western Siberia, the method of hydrological-climatic calculations (GCR) proposed by V. S. Mezentsev is successfully used. The value of total evaporation in this case is determined by solving the equation of connection of water and heat energy balances [4].

\[ Z = \left(\frac{T_z}{L}\right) \cdot \left[1 + \left(\frac{L \cdot (KX \cdot W_1 - W_2)}{T_z}\right)^{-n}\right]^{-1/n} \]  

(1)

where, 
- \( T_z \) - heat energy resources of evaporation, MJ/m²;  
- \( L \) - specific heat of vaporization equal to 2.521 MJ/(m² · mm);  
- \( KX \) - total precipitation, mm;  
- \( W_1 \) - soil moisture at the beginning of the calculation interval, mm;  
- \( W_2 \) - soil moisture at the beginning of the calculation interval, mm;  
- \( n \) - a parameter depending on the physical and geographical conditions of runoff formation.

The practice of using this method to study the laws of the interaction of heat and moisture makes it possible to refine the calculated characteristics of evaporation from the available fields of atmospheric precipitation and heat energy resources, taking into account the orographic, soil-geological, and other structural features of the catchment basin [5]. The main advantage of the method is that only quantities about which mass data are available appear in the equations and can be used for areas that have been little studied and hydrologically unexplored (i.e. the flow regime is determined mainly by climatic data and geographical characteristics).

Western Siberia belongs to a large geographical region of Russia and occupies a significant part of the territory. Located from the Kara Sea to the Kazakh Shoal, it is a relatively flat, slightly drained surface with a flat-lowland relief with elevations of 100-150 m. In some places, the flat character of the relief is disturbed by accumulative-glacial ridges and hills, the marks of which, within the watershed ridges, do not exceed 300 m.

The great length from north to south determines the diversity of climatic conditions that characterize the territory with five natural zones with distinctive climatic and geographical features. In turn, the diversity of climatic characteristics determines different conditions of the territory’s moistening - from wetlands in the north to dry steppes in the south of the territory. Along with climatic factors, the distribution of water resources in time and space is significantly affected by orographic, soil, plant and other features of the catchment basin [6]. In this regard, in the quantitative assessment of the main elements of the moisture circulation, the greatest attention is paid to the heat and energy supply and the features of the underlying surface of the pool.
4. Results and discussion.

The radiation regime of the territory under consideration, as is known, is one of the most significant climate elements that form the heat and energy base of all-natural processes occurring in the river basin [7].

The basic data on the temporal and territorial distribution of radiation characteristics studied on the basis of analysis of long-term observation materials at 22 actinometric stations in Western Siberia and adjacent territories. The numerical values of the characteristics of the radiation regime within the boundaries of the study area are given in Table 1.

Table 1. Climate radiation characteristics of the south of Western Siberia (Q - total radiation, Bc - absorbed radiation, R+ - positive radiation balance, R - radiation balance, MJ / m2 year), geographical latitude (φ, deg), the sum of positive air temperatures above zero (t > 0) and 100C (t> 10).

| Station          | Q  | Bc  | R+ | R  | φ   | t>0 | t>10 |
|------------------|----|-----|----|----|-----|-----|------|
| 1. Ivdel         | 3360 | 2271 | 1563 | 1187 | 60.7 | 1871 | 1422 |
| 2. Alexandrovskoe| 3490 | 2204 | 1525 | 1123 | 60.3 | 1810 | 1440 |
| 3. Kolpashevo    | 3662 | 2355 | 1622 | 1291 | 58.3 | 2020 | 1640 |
| 4. Dubrava       | 3851 | 2732 | 1781 | 1387 | 56.7 | 2156 | 1768 |
| 5. Pamyatinskaya | 4182 | 2870 | 1969 | 1538 | 56   | 2295 | 1943 |
| 6. Tatarsk       | 4190 | 2971 | 1927 | 1529 | 55   | 2300 | 1940 |
| 7. Ogurtsovo     | 4039 | 2899 | 1927 | 1529 | 55   | 2290 | 1940 |
| 8. Omsk          | 4098 | 2996 | 2074 | 1592 | 54.9 | 2333 | 2000 |
| 9. Blagoveshchenka| 4647 | 3331 | 2221 | 1785 | 52.7 | 2430 | 2120 |

When analyzing the territorial distribution of annual values of the radiation balance, attention is drawn to a well-defined latitudinal change in the value of R (increasing from north to south) within the study area. Thus, the numerical values and the territorial distribution of all radiation characteristics are significantly affected by the geographic latitude of the area, which is confirmed by the high communication tightness (Figure 1). The temporal variability of annual sums of radiation characteristics is relatively small and, for example, for the radiation balance, the coefficient of variation is 0.06 - 0.10.

![Figure 1. The dependence of the radiation balance (R, MJ/m²) latitude (φ, degrees.).](image)
At the same time, in cold countries, the use of radiation balance values as energy resources for evaporation does not reveal the energy source of natural processes occurring in the landscape sphere. This is due to the fact that, as a result of cryogenic energy expenditures for heating and thawing in the active layer, the annual heat and energy resources of evaporation turn out to be substantially less than the heat resources of the climate. In this regard, it becomes necessary to determine the thermal energy spent directly on the evaporation processes.

The share of heat and energy resources going to the evaporation process is characterized by the coefficient $\beta_Z = Z/Z_k$ [8], which, depending on moisture, varies within $0 \leq \beta_Z < 1$, approaching zero in conditions of moisture deficiency and to unity at excess moisture. The calculations showed that within Western Siberia this parameter takes values in the range from 0.2 to 0.4, and its territorial distribution has latitudinal zoning. Figure 2 shows the dependence of this parameter on latitude.

![Figure 2](image.png)

Figure 2. Dependence of values of coefficient $\beta_Z$ on geographical latitude ($\phi$, degrees).

The value of the total evaporation is under the decisive influence of both heat resources and moisture resources. The main incoming element of the water balance of the river catchment is precipitation. At present, information on the long-term average values of atmospheric precipitation of the study area has been published in the Climate and Scientific Handbooks. The information provided in the referenced books differs from each other. This is connected with the period for which the data were averaged, as well as with corrections introduced into the measured amounts of precipitation. So, in the scientific and applied reference books, only the correction for wetting was introduced into the amounts measured by the precipitation meter without adjusting the measured amounts to their wind shortage. In this regard, the annual and monthly precipitation amounts in the Scientific and Applied Directories are less than in the Climate Directories. For annual precipitation, the difference is on average about 15%, and for winter precipitation (November-March) more than 20.0%.

Considering the complexity of calculating the total evaporation in the average year and in specific years, as well as their annual distribution by the method of hydrological and climatic calculations, a special program was compiled that satisfies all theoretical limits and takes into account the necessary corrections to atmospheric precipitation. This program is based on the model proposed by G.V. Belonenko [9] and tested in various climatic zones of Russia.

The considered system of coupling equations together with the equation of water and heat energy balances made it possible, in the presence of values of the total moisture and heat energy resources of the climate, to calculate virtually all components of the balance equations, both for the annual and intra-annual periods. To calculate the annual values of the total evaporation, we used data on the humidification and heat resources of 183 points located in Western Siberia; in addition, the conditions of runoff formation were taken into account using various parameters.
The obtained values characterize the study area as follows. The values of total evaporation have latitudinal zonality and decrease southward from 470 mm to 310 mm. This is primarily due to a decrease in the moisture content of the southern part of the study area. The interannual distribution of total evaporation during the warm season is characterized by a maximum in May - June, and a minimum in October. Table 2 shows the information on the annual distribution of heat and moisture resources and the results of calculating the total evaporation for several stations in the study area.

**Table 2.** The intra-annual distribution of the water equivalent of the heat and energy resources of the climate (Zк, mm / year), precipitation (KH, mm) and total evaporation (Z, mm) in the average year.

| Station | IV  | V   | VI  | VII | VIII | IX  | X   |
|---------|-----|-----|-----|-----|------|-----|-----|
| Tobolsk | Zк, MM | 129.7 | 189.7 | 195.8 | 164.3 | 134.9 | 100.4 | 77.6 |
|         | KH, MM | 31  | 50  | 62  | 82  | 72  | 59  | 46  |
| Z, MM   | 51.9 | 84.9 | 99.3 | 77.5 | 61.9 | 43.1 | 31  |
| Ishim   | Zк, MM | 109.9 | 209.4 | 205.5 | 163.9 | 132.5 | 114  | 84.9 |
|         | KH, MM | 25  | 35  | 58  | 76  | 56  | 38  | 36  |
| Z, MM   | 38.3 | 72.4 | 91.6 | 69.5 | 51.3 | 37  | 27.1 |
| Irysh   | Zк, MM | 98.1 | 205.2 | 222.8 | 197.6 | 172.2 | 149.7 | 88.2 |
|         | KH, MM | 26  | 30  | 49  | 66  | 46  | 34  | 32  |
| Z, MM   | 30  | 57.9 | 80.7 | 67.7 | 48.4 | 35.5 | 21.6 |
| Barnaul | Zк, MM | 114.8 | 197.8 | 196.7 | 161.8 | 149  | 127.5 | 98.2 |
|         | KH, MM | 33  | 44  | 56  | 74  | 59  | 43  | 57  |
| Z, MM   | 59.2 | 102.8 | 88.3 | 72.7 | 60.6 | 44.2 | 36.8 |

With an increase in the supply of solar energy in the warm period (from April to October) in the territory under consideration, evaporation increases in May-June by 1.5 - 2 times compared with the values of evaporation in April. The month of July is characterized by a regular decrease in total evaporation, despite significant moisture, which, in turn, is possibly associated with a decrease in the values of heat resources.

The average monthly values of the total evaporation, with sufficient heat and energy resources, are largely determined by the amount of precipitation (figure 3). This is a special characteristic of the southern regions of the West Siberian Plain, where, following the monthly values, annual values of total evaporation tend to annual precipitation.

![Figure 3. Dependence of average annual precipitation and total evaporation, mm.](image-url)
Such a tendency of total evaporation to precipitation indicates a decrease in the proportion of surface runoff in the water balance of the south of Western Siberia and creates additional difficulties in providing water to the population and confirms the need for additional water supply to the root layer in order to obtain a stable crop yield, especially in dry years.

5. Conclusion
Among the variety of methods for determining total evaporation, the most representative data can be obtained using computational models that take into account both zonal and local features of the catchment.

In Western Siberia, the most acceptable method for calculating the total evaporation is V.S. Mezentsev GKR method based on a joint consideration of the laws of interaction of heat and moisture, taking into account the orographic and soil features of the structure of the catchment. The advantage of this method is the ability to calculate the water-balance characteristics of poorly studied and hydrologically unexplored catchments.

The performed calculations show that the annual value of the total evaporation and the value of the intra-annual distribution are closely interconnected with the heat and energy resources of the territory and have latitudinal zonality.

The value of evaporation in the south of the study area is largely determined by precipitation.

The results of calculations of the total evaporation can be used in planning the management of water resources of the study area and determining the irrigation norms, regimes and technologies for land reclamation development.

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