学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

Evaluation of the hydrological environment of peatland by using Peatland Tank Model

（泥炭地タンクモデルを用いた泥炭地水文環境の評価に関する研究）

Peatland is an important ecosystem due to its organic peat soil and unique hydrological environment. The peat soil is characterized by high carbon content, complex structure, and high water-holding capability. In peatland, the groundwater table (GWT) is usually maintained at high level and the hydrological behavior is specific. Consequently, monitoring of GWT fluctuation is indispensable for the investigation of peatland hydrology, and quantitatively and exactly evaluating the peatland hydrological conditions are necessary for the reservation and proper usage of peatland. In this study, we proposed a new method based on Peatland Tank Model (PTM) for evaluating peatland hydrological environment.

The objective of this study is to quantitatively express the shallow GWT fluctuation patterns and to evaluate the changes of hydrological environment. PTM is a simple one dimensional water balance model and its prototype has seven parameters (*C*, *A1*, *A2*, *A3*, *HA1*, *HA2* and *HA3*). To be specific, coefficient *C* represents the GWT increase owing to rainfall. Coefficients *Ai* (*i*: number of plugholes, i = 1, 2, 3) ($0 \leq Ai \leq 1$) and *HAi* are the size and height of the i^{th} plughole, respectively. *C* and *Ai* are unit less. As indicated by the name, PTM models the peatland hydrological as a water storage tank. In this way, the GWT fluctuations of a peatland can be represented by the variations in water levels of a tank.

In this study, the operational platform of PTM is a program using Microsoft Excel's macro function. The operation of PTM only requires time-series data of GWT and rainfall. It does not need a series of parameters representing peat properties and hydraulic characteristics such as bulk density, hydraulic conductivity, specific storage and specific yield. In addition, this model does not need to deal with geographical information such as topographic information, soil type and land use. So, the evaluation method using PTM requires less measurement and the operation can be implemented with very low computational complexity. In the computer simulations based on PTM, GWT fluctuations can be reproduced with a good accuracy of a few centimetres and the subtle variations in GWT fluctuation patterns can be distinguished by configuring the parameters of this model.

The effectiveness and the flexibility of PTM were validated by simulations using the 29-year groundwater data which were collected from Gensekaen of Sarobetsu Mire and Ochiai of Sarobetsu Mire, northern Hokkaido, Japan.

Firstly, in Gensekaen of Sarobetsu Mire, GWT data and rainfall data have been continuously monitored at three sites (E, W and WB) covered by different vegetation communities. The 29-year GWT data were absolute height above sea level because the level survey had been performed here annually from 1983 to 2013. On the basis of the actual computation experience of PTM, four rules and two simulation cases were established and the number of parameters was reduced from original seven to three or two. The fluctuation patterns of GWT can be numerically expressed by the parameters of PTM. The various characteristics of GWT increase could be represented by parameter *C* (a large *C* value indicates a large ratio of GWT increase). The difference in GWT decrease could be described by parameter *Ai* and *HA1* (a large *A1* value or deeper *HA1* indicates greater basic and constant water loss from the peat layer, and a large *A2* value indicates rapid water loss in the upper peat layer). Thus, large values of parameters *C* and *Ai* indicate that the GWT response to rain and dry events had wide variation and large ratios of GWT increase and decrease. Moreover, these parameters could also represent properties of peat soil. A larger C value indicates smaller effective porosity and water storage of peat. A larger Ai and deeper $HA1$ values means that the GWT decreases rapidly so the peat becomes drier during rain-free periods. Long-term variations of the parameters reflect peatland stability. There was drastic variation in the parameters at observation site (WB) dominated by a *Sasa* community from 1991 to 2013, whereas long-term parameter changes were slight at the other two sites (E and W) from 1983 to 2013. Site WB had unstable GWT conditions relative to those at E and W, which mean that the latter two sites were tolerant of annual climate conditions, whereas WB was susceptible to those conditions.

Secondly, in Ochiai of Sarobetsu Mire, three sites (D, M and U) near drainage ditch and peat mining location were observed for collecting rainfall and GWT data, which were measured without certain elevation references or benchmarks (i.e., sea level or ground surface). Through establishing two simulation cases and three rules, such type of GWT data were effectively used for evaluating the changes in GWT fluctuation patterns and site differences in hydrological conditions, even if these GWT data have no common meaning or information in relation to the ground surface or elevation above sea level. Meanwhile, the number of parameters was reduced from the seven to three or two. The simulation results reveal that, wide GWT fluctuations were reflected by large parameter values (parameter C, Ai and $HA2–HA1$). The GWT fluctuation at site (D) near a drainage ditch along the peat mining location was the most drastic: the magnitude of GWT increase in response to rain events was maximum (parameter C) and the amount of water loss was greater than that at the other two sites (Ai and $HA2–HA1$). The water losses from the upper peat layer ($A2$) at the three sites were similar. Furthermore, the variations of $HA2–HA1$ could represent long-term trends of drainage characteristics at each site. The drainage intensity at Site D clearly increased from 1983 to 2013, and the variations of drainage intensity at sites M (at the edge of the peat mining area) and U (in an unused area far from the drainage) were not as significant.

In the validations of the PTM based evaluation method, two types of GWT data were used. The simulation results both achieved the accuracy of less than a few centimeters. However, in the structure of PTM described above, the seasonal response of evapotranspiration and amount of soil moisture in unsaturated peat surface soils were not considered. In the final part of this study, further improvement was made to the proposed method to incorporate the effects of evapotranspiration variations into the algorithm of PTM for more rational and accurate simulation. A new parameter named ETr (the ratio of evapotranspiration used to represent the effect of different vegetation cover on the actual evapotranspiration of the peat) was added and the simulation error was reduced by 17.6%, 23.4% and 30.1% for sites E, W and WB, respectively. Through the modification, the effects of discharge and evapotranspiration that occur at different heights of peat layers with different physical mechanisms are separated. Furthermore, the effects of improvement of simulation were obvious at the peaks and the depletion of the GWT fluctuation curve. This modification did not change the profile of the parameter variations.

In summary, this study proposed a new method based on Peatland Tank Model to quantify and to evaluate the groundwater table fluctuations in peatland. The operation of Peatland Tank Model simply requires time-series data of groundwater table and rainfall. The effectiveness of this method and its applicability for two types of groundwater table data were validated through simulations using the 29-year groundwater table fluctuations in Gensekaen and Ochiai of Sarobetsu Mire, northern Hokkaido, Japan. The fluctuation patterns of groundwater table can be distinguished by using only few parameters. Further structural improvement of this model was made to incorporate the effects of evapotranspiration variations into the algorithm for more rational and accurate simulation. Better simulation accuracy was obtained by this perfection. Comprehensive analyses and discussions were provided for better understanding of this method. The proposed method possesses the merits of simple computational structure, small number of required measurements and high accuracy. It is very meaningful for the research in peatland hydrology, especially when computational complexity is concerned. This model can be expected to play an active role in the basic hydrological study of peatland.