SUG'ORISH SUVLARI TA'SIRIDA YER OSTI SUVLARI SATHI VA MUHITDAGI KONSENTRATSIYA JARAYONLARINI MATEMATIK MODELLASHTIRISH

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Annotatsiya. Mazkur maqolada sug'oriladigan hududlarda sug'orish suvlari ta'sirida yer osti suvlari sathining o'zgarish jarayonlari chuqur tahlil qilingan. Taklif etilgan matematik model orqali suvning konveksiya va diffuziya hodisalari inobatga olinib, sizot suvlarining oqim tezligi hamda konsentratsiya taqsimoti aniqlangan. Modelning ilmiy yangiligi shundaki, unda suvning sho'rlanish darajasi, harorat ko'rsatkichlari va tuproqning namlikka to'yinganlik holati kabi muhim omillarning ta'siri ham hisobga olingan. Shuningdek, muhitning suv o'tkazuvchanlik koeffitsiyentini aniqlashda mazkur parametrlarning qo'llanilishi modelning aniqlik darajasini va prognozlash samaradorligini sezilarli ravishda oshirgan. Tadqiqot natijalari asosida yaratilgan matematik model irrigatsiya tizimlarini samarali boshqarish, suv resurslaridan oqilona foydalanish hamda ularni tejamkor tarzda taqsimlash imkoniyatlarini kengaytiradi. Bundan tashqari, olingan natijalar ekologik barqarorlikni ta'minlash, agrotexnik tadbirlarni to'g'ri rejalashtirish va yerlarning meliorativ holatini yaxshilashda muhim ilmiy-amaliy ahamiyat kasb etadi.

Kalit so'zlar: *Konsentratsiya, yer osti suvlari sathi, to'yinish jarayoni, suvning sho'rligi, tuproqning to'yinganligi, sug'orish suvi, harorat*

MATHEMATICAL MODELING OF GROUNDWATER LEVELS AND CONCENTRATION PROCESSES IN THE MEDIUM UNDER THE INFLUENCE OF IRRIGATION WATER

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Abstract. This article provides an in-depth analysis of changes in groundwater levels under the influence of irrigation water in irrigated areas. The proposed mathematical model accounts for water convection and diffusion processes and determines groundwater flow velocity and concentration distribution. The scientific novelty of the model lies in considering the effects of important factors such as water salinity, temperature, and soil moisture saturation. The use of these parameters in determining the hydraulic conductivity coefficient significantly improves the accuracy of the model and the efficiency of forecasting. The mathematical model developed on the basis of the research results expands opportunities for efficient irrigation system management, rational use of water resources, and their economical allocation. In addition, the obtained results have important scientific and practical significance for ensuring environmental sustainability, proper planning of agrotechnical measures, and improving the reclamation condition of lands.

Keywords: *concentration, groundwater level, saturation process, water salinity, soil saturation, irrigation water, temperature*

Kirish

Bugungi kunda qishloq xo'jaligida suv resurslaridan oqilona foydalanish va ularni samarali boshqarish global muammolardan biridir. Sug'oriladigan maydonlarda yer osti suvlarining sathi va tuzilish xususiyatlari sug'orish tizimlari, gidrogeologik sharoitlar hamda tabiiy-iqlim omillariga bevosita bog'liqdir. Ayniqsa, tuproq qatlamida suvning taqsimlanishi, sho'rlanish darajasi va infiltratsiya jarayonlari agroekotizimning barqarorligiga katta ta'sir ko'rsatadi. Ushbu jarayonlarni chuqur tahlil qilish va matematik modellashtirish suv balansini aniq baholash, meliorativ sharoitlarni yaxshilash va suv resurslarini tejash imkonini beradi. Shu sababli, ushbu tadqiqot sug'orish suvlarining yer osti suvlariga va atrof-muhit konsentratsiyasiga ta'sirini matematik modellashtirishga qaratilgan.

Maqolada sug'orish jarayonlarini boshqarishda qo'llaniladigan integratsiyalashgan gidroiqtisodiy modellarning imkoniyatlari va cheklovlari tahlil qilingan. Mualliflar mavjud modellar fermerlarning haqiqiy qaror qabul qilish jarayonida ikkita muhim jihatni - quduqning suv bilan ta'minlash qobiliyati va mavsumiy sug'orishni rejalashtirish tuzilmasi bilan bog'liq cheklovlarni yetarli darajada hisobga olmasligini ko'rsatdilar. Shu asosda fermerlarning kuzatilgan xulq-atvori asosida sug'orish va suvdan foydalanishga bo'lgan ehtiyojni aniqlash imkonini beruvchi yangi yondashuv ishlab chiqildi [1]. Integrallarni taqribiy hisoblash va optimal kvadratur formulalarni qurish masalasini [2] ishdan topish mumkin.

Maqolada qishloq xo'jaligida sug'orish uchun olinadigan yer osti suvlari miqdorini aniqlash uchun agro-gidrologik model ishlab chiqilgan. Taklif etilayotgan model FAO ko'rsatmalari asosida ekinlarning evapotranspiratsiya jarayonlarini an'anaviy Xin'anjiang (XAJ) gidrologik modeli bilan birlashtiradi. Kalibrlash va sezgirlik tahlillari SCE-UA usuli yordamida amalga oshirildi va natijalar shuni ko'rsatdiki, ko'p maqsadli optimallashtirish usuli daryo oqimi va yer osti suvlari sathi dinamikasini aniqroq aks ettiradi [3].

Maqolada mo'tadil nam iqlim sharoitida sug'orishning yer osti suvlariga ta'siri ko'rib chiqiladi. Tadqiqotda kuzatuv nuqtalarining yetishmasligi sharoitida atrof-muhit izotopik va kimyoviy qidiruv tizimlari yordamida gidrofizik ma'lumotlar to'ldirildi. Natijalar shuni ko'rsatadiki, sug'orish qudug'idan suv olish jarayoni yangi va qadimiy yer osti suvlarining aralashmasini hosil qilgan [4-5].

Maqolada sug'orish amaliyoti ta'sirida sug'oriladigan hududlarda yer osti suvlari sathi va suv sifatining o'zgarishi ko'rib chiqiladi. Natijalar shuni ko'rsatdiki, sug'orish zonasidagi quduqlar o'g'it elementlarining yuqori konsentratsiyasi va suv sathining ko'tarilishi bilan, sug'orish zonasidan tashqarida esa suv sathining pasayishi bilan tavsiflanadi [6-7].

Maqolada sug'orish amaliyotlarining yer osti suvlari oqimiga va daryo haroratining o'zgarishiga ta'siri ko'rib chiqiladi. Tadqiqotda daryo suv balansi, yer osti suvlari oqimi va haroratini baholash uchun yer usti va yer osti suvlari oqimining integral modeli ishlab chiqildi. Uchta ssenariy taqqoslanadi - tabiiy sharoitlar, joriy sug'orish amaliyoti va faqat yer osti suvlaridan foydalangan holda taxminiy sug'orish [8-9].

Maqolada Senegal daryosi deltasi sharoitida sug'oriladigan sholipoyalar tuproqlarining sho'rlanish jarayonlari ko'rib chiqilgan. Tadqiqotning maqsadi sug'orish ta'sirida suv va eritma oqimlari dinamikasini tahlil qilish, maydon darajasida, to'yinmagan zonada va suvli qatlamlarda suv tranzitini monitoring qilish tarmog'ini yaratishdan iborat [10].

O'rganilgan adabiyotlar va ilmiy manbalar tahlili shuni ko'rsatadiki, mavjud tadqiqotlarda qishloq xo'jaligi rekultivatsiya maydonlarida sizot suvlari sathining dinamikasi va ularning meliorativ holatga ta'siri turli usullar yordamida o'rganilgan. Biroq, ushbu ishlarning aksariyati ma'lum cheklovlarga ega bo'lib, birinchi navbatda, mintaqaviy sharoitning o'ziga xos xususiyatlari, infiltratsiya jarayonlarining turli shakllarda namoyon bo'lishi va vaqt o'tishi bilan suv o'tkazuvchanlik koeffitsiyentlarining dinamik o'zgarishlari to'liq yoritilmagan.

Bundan tashqari, mavjud modellashtirish usullari sug'orish jarayonida sodir bo'ladigan qisqa muddatli o'zgarishlarni, suvning diffuziyasi va atrof-muhit bo'ylab tarqalishini aniq ifodalash uchun yetarli darajada takomillashmagan. Bu esa sizot suvlari sathini barqarorlashtirish va optimal boshqarish strategiyasini ishlab chiqishda ma'lum qiyinchiliklarni keltirib chiqaradi.

Shu sababli, muammoning samarali yechimini topish uchun sug'orish sharoitida yer osti suvlari harakatini yanada aniqroq modellashtirish, o'tkazuvchanlik koeffitsiyentining dinamik holatini hisobga oluvchi yangi yondashuvlarni taklif etish va ushbu yondashuvlar asosida optimallashtirish mexanizmlarini ishlab chiqish zarur.

Masalaning qo'yilishi

Sug'oriladigan maydonlar uchun axborot tizimi ishlab chiqilgan bo'lib, unda tuproq parametrlari, yog'ingarchilik va infiltratsiya, harorat va sho'rlanish darajasi kabi ma'lumotlar shakllantiriladi va avtomatik ravishda yangilanadi. Ushbu ma'lumotlar asosida muhitning o'tkazuvchanlik koeffitsiyenti aniqlanadi, Darsi qonuni yordamida g'ovak muhitdagi oqim tezligi hisoblanadi, so'ngra oqim tezliklari va suv bilan to'yinganlikni hisobga olgan holda, konveksiya-diffuziya tenglamasi yordamida sug'orish suvlarining yer ostidagi harakati va suv sathining o'zgarishi bashorat qilinadi. Hisoblashda oshkor chekli ayirmali sxema qo'llaniladi va turg'unlikni ta'minlash uchun Kurant-Fridrixs-Lui (CFL) sharti beriladi. O'zgaruvchan vaqt qadamlari bilan hisoblash samaradorligi oshadi va kerakli funksiyalar barcha vaqt bosqichlarida barqaror natija beradi. Shundan kelib chiqib, sug'oriladigan yerlarda geofiltratsiya jarayonini sonli modellashtirish uchun quyidagi matematik model taklif etildi.

Suvning muhitda taqsimlanishini va to'yingan qatlamdagi sathini aniqlash uchun adveksiya-diffuziya tenglamasi:

$$\frac{\partial C}{\partial t}+(1-H)\left(u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}+w\frac{\partial C}{\partial z}\right)=(1-H)\left(D_x\frac{\partial^2 C}{\partial x^2}+D_y\frac{\partial^2 C}{\partial y^2}+D_z\frac{\partial^2 C}{\partial z^2}\right)+\delta Q,$$

Yer osti suvlari oqimida bosimning taqsimlanishi uchun Darsi tenglamasi asosida:

$$S_{save}\frac{1}{\rho g}\frac{\partial P}{\partial t}=\frac{\partial}{\partial x}\left(k\frac{\partial}{\partial x}\left(\frac{P}{\rho g}+z\right)\right)+\frac{\partial}{\partial y}\left(k\frac{\partial}{\partial y}\left(\frac{P}{\rho g}+z\right)\right)+\frac{\partial}{\partial z}\left(k\frac{\partial}{\partial z}\left(\frac{P}{\rho g}+z\right)\right)$$

Darsi qonuniga ko'ra, g'ovak muhitda suyuqlikning filtratsiya tezligi quyidagi munosabat bilan aniqlanadi:

$$u=-\frac{k}{\mu}\frac{\partial P}{\partial x},\ v=-\frac{k}{\mu}\frac{\partial P}{\partial y},\ w=-\frac{k}{\mu}\frac{\partial P}{\partial z}.$$

Vaqtning boshlang'ich lahzasida () jarayonni boshlash uchun zarur bo'lgan boshlang'ich shartlar aniqlanadi, ular keyingi iteratsiyalar uchun asos bo'lib xizmat qiladi:

$$C(x,y,z,t)\big|_{t=0}=C_0(x,y,z),\ \ P(x,y,z,t)\big|_{t=0}=P_0(x,y,z),$$

Chegaraviy nuqtalardagi konsentratsiya va bosim qiymatlari quyidagi shartlar bilan aniqlandi. Konsentratsiyani ifodalovchi funksiyani quyidagicha yozish mumkin:

$$x=0\ ,\ C(0,y,z,t)=C(x+\Delta x,y,z,t)+\big(C(x+\Delta x,y,z,t)-C(x+2\Delta x,y,z,t)\big),$$

$$x=L_x\ ,\ C(x,y,z,t)=C(x-\Delta x,y,z,t)+\big(C(x-\Delta x,y,z,t)-C(x-2\Delta x,y,z,t)\big),$$

$$y=0\ ,\ C(x,0,z,t)=C(x,y+\Delta y,z,t)+\big(C(x,y+\Delta y,z,t)-C(x,y+2\Delta y,z,t)\big),$$

$$y=L_y,\ C(x,y,z,t)=C(x,y-\Delta y,z,t)+\big(C(x,y-\Delta y,z,t)-C(x,y-2\Delta y,z,t)\big),$$

$$z=0,\ C(x,y,0,t)=C(x,y,z+\Delta z,t)+\big(C(x,y,z+\Delta z,t)-C(x,y,z+2\Delta z,t)\big),$$

$$z=L_z,\ C(x,y,z,t)=Q_{Lz}.$$

Chegaraviy nuqtalarda bosim funksiyasining qiymatlari quyidagi chegaraviy shartlar asosida hisoblandi:

$$x=0,\ P(x,y,z,t)=P(x+\Delta x,y,z,t)+\big(P(x+\Delta x,y,z,t)-P(x+2\Delta x,y,z,t)\big),$$
$$x=L_x,\ P(x,y,z,t)=P(x-\Delta x,y,z,t)+\big(P(x-\Delta x,y,z,t)-P(x-2\Delta x,y,z,t)\big),$$
$$y=0,\ P(x,y,z,t)=P(x,y+\Delta y,z,t)+\big(P(x,y+\Delta y,z,t)-P(x,y+2\Delta y,z,t)\big),$$
$$y=L_y,\ P(x,y,z,t)=P(x,y-\Delta y,z,t)+\big(P(x,y-\Delta y,z,t)-P(x,y-2\Delta y,z,t)\big),$$
$$z=0,\ P(x,y,z,t)=P(x,y,z+\Delta z,t)+\big(P(x,y,z+\Delta z,t)-P(x,y,z+2\Delta z,t)\big),$$
$$z=L_z,\ P(x,y,z,t)=P(x,y,z-\Delta z,t)+\big(P(x,y,z-\Delta z,t)-P(x,y,z-2\Delta z,t)\big),$$

bu yerda: $u(x,y,z,t)$, $v(x,y,z,t)$, $w(x,y,z,t)$- yo'nalish bo'yicha adveksiya tezligi elementlari; $C(x,y,z,t)$ - muhitning suv konsentratsiyasi darajasi; Q - sug'orish paytidagi infiltratsion suv miqdori; $D_x(x,y,z,t),\ D_y(x,y,z,t),\ D_z(x,y,z,t)$ - tarqalish tezligi koeffitsiyentlari [11-12].

$$\delta=\begin{cases}0, & x\neq x_0, y\neq y_0\ , z\neq z_0, t\neq t_0;\\ 1.\end{cases}$$

bu yerda δ - Dirakning delta funksiyasi.

Suv sathi funksiyasini topish uchun quyidagi munosabatdan foydalaniladi [11]:

$$H(x,y,z,t,C)=\begin{cases}1, & \begin{cases}C_{max}(x,y,z',t)-C(x,y,z',t)\le\varepsilon\ \forall z'\le z,\\ C_{max}(x,y-\Delta y,z-\Delta z,t)-C(x,y-\Delta y,z-\Delta z,t)\le\varepsilon,\\ C_{max}(x,y+\Delta y,z-\Delta z,t)-C(x,y+\Delta y,z-\Delta z,t)\le\varepsilon,\\ C_{max}(x-\Delta x,y,z-\Delta z,t)-C(x-\Delta x,y,z-\Delta z,t)\le\varepsilon,\\ C_{max}(x+\Delta x,y,z-\Delta z,t)-C(x+\Delta x,y,z-\Delta z,t)\le\varepsilon.\end{cases}\\ 0 & .1\ \text{d a}\end{cases}$$

O'tkazuvchanlik koeffitsiyentining qiymati quyidagi formula yordamida hisoblanadi [13]:

$$k(x,y,z,t)=k_0\frac{T(x,y,z)}{T_0}\left(1-\frac{S(x,y,z,t)}{S_0}+\frac{P(x,y,z,t)}{P_0}\right)\big(1-F(x,y,z,t)\big).$$

Tuproqning namlik bilan to'yinishining ortishi va uning muvozanatga qaytishini tavsiflash uchun logistik o'sish funksiyasi qo'llaniladi:

$$F(x,y,z,t)=F_{max}(x,y,z)\frac{1}{1+e^{-k_F(t-t_0)}}.$$

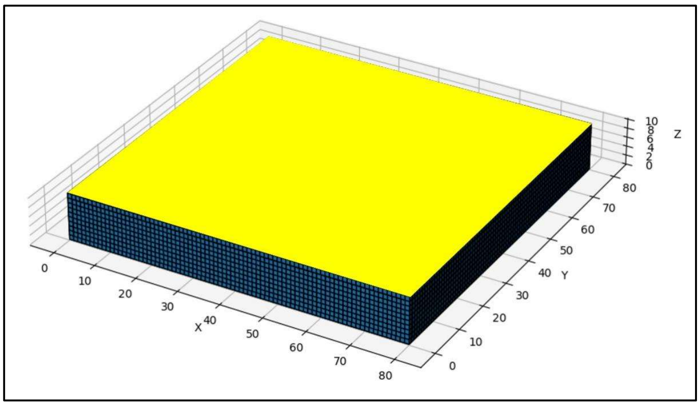
Suvning sho'rlanish darajasining vaqt bo'yicha o'zgarishi quyidagi funksiya bilan ifodalanadi [7; 47-48-b]:

$$S(x,y,z,t)=S_0(x,y,z)\ e^{-k_S t}.$$

Natijalar va muhokama

Matematik hisob-kitoblar jarayonida aniq chekli ayirmali sxemadan foydalaniladi. Ushbu yondashuv hisob-kitoblarning soddaligi va algoritmik samaradorligi bilan ajralib turadi. Lekin sxemaning turg'unligi muhim omil bo'lgani uchun Kurant-Fridrixs-Li (KFL) sharti albatta hisobga olinadi. CFL sharti vaqt qadamini fazoviy diskretlash o'lchamlariga mos ravishda tanlashni ta'minlab, hisoblash natijalarining barqarorligini kafolatlaydi. Hisob-kitoblarda o'zgaruvchan vaqt qadamlaridan foydalanish jarayonning murakkab dinamikasini aniqroq ifodalash va hisob-kitoblar samaradorligini oshirishga xizmat qiladi. Natijada, izlanayotgan funksiyalarning barcha vaqt bosqichlarida barqaror va fizik jihatdan ma’noli yechimlar olinadi.

Zamonaviy elektron hisoblash mashinalarida yer osti suvlari harakati jarayonlarini o‘rganish, suv sathini kuzatish va bashorat qilish uchun ishlab chiqilgan matematik dasturiy ta’minot yordamida sonli hisoblash sinovlari o‘tkazildi [14]. Olingan ma’lumotlarning eksperimental hisob-kitoblari H orqali aks ettirilgan C_{max} sath funksiyasi va C haqiqiy konsentratsiya ko‘rsatkichlari. Ushbu eksperimental hisob-kitoblar natijalari 1 va 2-rasmlarda grafik tarzda ifodalangan.



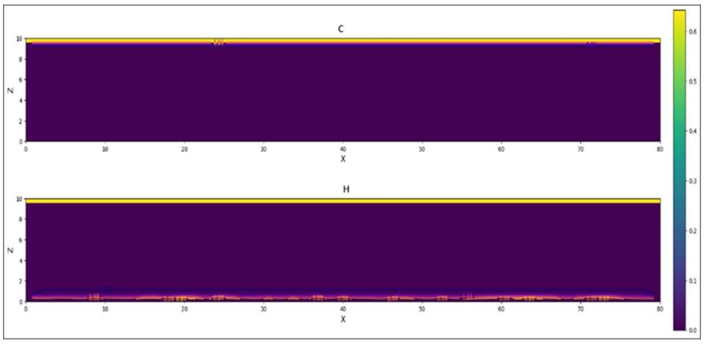
1-rasm. Birinchi chegaraviy shart uchun hududni suv bilan ta’minlash

Eksperimental hisob-kitoblar asosida shakllantirilgan natijalar uch o‘lchamli (3D) fazoviy model doirasida ko‘rib chiqildi va quyidagi ko‘rsatkichlar bilan ifodalandi:

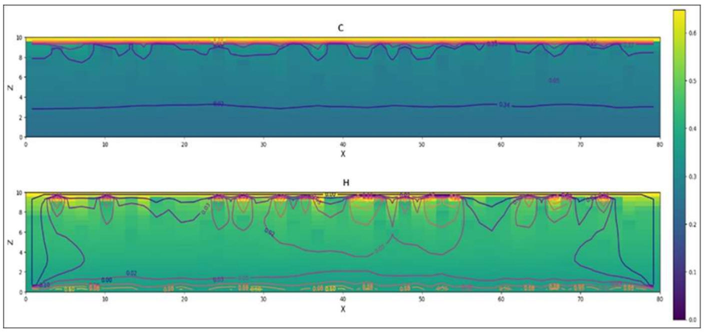
$$N_x = N_y = 200,\ N_z = 20,\ L_x = 80[m], L_y = 80[m], L_z = 10[m],\ k_0 = 0.03[m^2/s],$$

$$\Delta x = \Delta y = 0.4[m], \Delta z = 0.5[m],\ P_0 = 101.325[kpa],\ T_0 = 20[\text{degree Celsius}],\ S_0 = 0.01,\ F_{max} = 0.45,$$

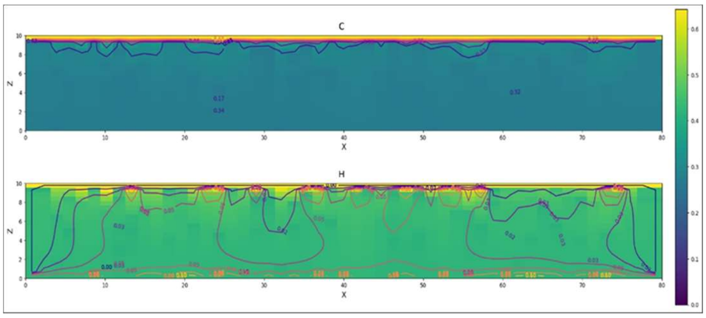
$$Q_s = 0.05,\ \Delta t_0 = 0.1[\text{hour}],\ L_{xs_0} = 0, L_{xs_1} = 80, L_{ys_0} = 0, L_{ys_1} = 80.$$



t=0



t=50



t=140

2-rasm. a), b), v) Yer osti suvlari sathi, konsentratsiya ko'rsatkichlari.

1-rasm: $t = 0$ da muhit tomonidan yutilgan suv massasining to'yinishi va muhitning yetarlilik darajasi bir tekis taqsimlangan. Bu boshlang'ich sharoitlar sug'orishning boshlang'ich holatidir.

Berilgan va vaqt oraliqlari uchun muhitga tushayotgan suv konsentratsiyasi $t = 50$ va $t = 140$ muhitdagi maksimal sathning o'zgarish dinamikasi berilgan. Bu jarayon yer osti suvlarining sug'orish davridagi harakati va atrof-muhitda taqsimlanishini ifodalaydi. Shu bilan birga, suvning muhitga kirib borishi va diffuziya jarayonlari natijasida vaqt o'tishi bilan konsentratsiya va to'yinish ko'rsatkichlari o'zgaradi.

Xulosa

Olib borilgan tadqiqotlar natijalari sug'oriladigan maydonlarda yer osti suvlari harakatini modellashtirish jarayonida taklif etilgan matematik modelning samaradorligini tasdiqlaydi. Modelda suvning konveksiya va diffuziya jarayonlari bilan bir qatorda tuproqning sho'rlanish darajasi, harorat ko'rsatkichlari, namga to'yinganlik darajasi kabi muhim parametrlar hisobga olinishi natijasida hisoblash aniqligi va prognozlash imkoniyatlari sezilarli darajada oshdi. Ushbu yondashuv nafaqat yer osti suvlari sathini monitoring qilish va bashorat qilish, balki sug'orish tizimlarini boshqarish uchun ham muhimdir. Taklif etilayotgan model yordamida sug'orish suvlarini taqsimlanishini samarali boshqarish, suv resurslaridan oqilona va tejamli foydalanish imkoniyati yaratilgan. Shuningdek, model asosida olingan natijalar agrotexnik tadbirlarni to'g'ri rejalashtirish, yerlarning meliorativ holatini yaxshilash va ekologik barqarorlikni ta'minlashda muhim ilmiy-amaliy ahamiyat kasb etadi. Natijada, ishlab chiqilgan modeldan suv resurslarini boshqarish va ularning kelajak avlodlar uchun barqarorligini ta'minlashda ishonchli vosita sifatida foydalanish mumkin.

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