Simulation of Eco-hydrological Process in Hani Terrace wetland

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Abstract

Hani terrace is a precious legacy which Hani people created from generation to generation; it has been in good running for over thousand years. It is a complete new attempt to reveal the good running mechanism of Hani terrace from the eco-hydrological process, which is to reveal the terrace’s interactive influence relationship with local ecological effect from the core of its hydrological element. In this article, on the basis of eco-hydrology process, the paper initially constructs a rainfall interception model, evapotranspiration model, plant-soil moisture transmission model, groundwater model, and eco-hydro-chemistry process simulation model, finally finds out initially ecological effect of Hani terrace wetland based on all models.

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1. Introduction

The wetlands of china covers an area 6.594×105km\textsuperscript{2}, holds the fourth place of the world, accounting for 6.5% of territory, in which rice and other wetlands areas reached 3.8×105km\textsuperscript{2}, accounting for 57.63% of the wetlands of china. The artificial terrace wetlands which located in southern red river, is the most famous one. Hani terrace wetland extremely perfect integrated with nature. Terrace wetland is a naturalized artificial eco-system, which plays a wide functional role for a long time. The research of Hani
terrace began in the 1980s, mainly in its historical origins, rituals rice terraces, terraced farming methods and ways of management[1]. After 2000, as reported by many international media, especially, it was listed as preparatory world inheritance to UN by China's government; many foreign experts and scholars went there and made related research. JIAO YUAN- MEI[2], starting from the concept of landscape, studied the cultural landscape features, structure, function and protection measures on Hani terraced. YAO MING[1] analyzed and compared the similarities and differences in the structure, function and value among Hani terrace wetland, plain rice field, and natural wetland, highlights further the vertical characteristics of Hani terrace wetland. RAO BI-YU[3] established a reasonable water resources allocation model, which suitable for Hani terraced fields, based on analysis of balance between supply and demand, finally, obtained rational allocation of water resources program in different frequencies and level. REN HUA-LI[4] analyzed distribution of heavy metals in surface paddy soil, and evaluated the potential ecological risk of heavy metals in sample area. But there are a few studies in coupling of water behavior and ecology behavior in Hani terraced filed from eco-hydrological. Hani terrace is a precious legacy which created by generations, and it runs well for thousands of years. How to protect and continuous develop Hani terrace, that is the world and researchers are focused on. It is a new attempt to reveal the good performance of Hani terrace from eco-hydrological processes. Starting from the core elements-hydrological of Hani terrace, it reveals the mutual influence relationship between local ecological effects. It helps to deeper understand of Hani terraced ecosystem.

2. Situation of study area

Hani terrace wetland, located in southern Yunnan province, the southern section of Ailao Mountains in the south bank of Red River. it is a subtropical monsoon climate zone, the annual average temperature is 16.4 degrees Celsius(℃), maximum temperature of 32.4 degrees Celsius(℃), minimum temperature of -2.6 degrees Celsius(℃), frost-free period 363.5 days. due to geographical and topographical conditions, three-dimensional climate was obvious. the following elevation 1200m, it is valley, frost-free round, abundant rainfall, amount of evaporation, hot weather; between elevation 1200 ~ 1700m, it is called lower and middle mountain, relatively abundant rainfall, a moderate climate. Hani terrace has a unique natural landscape and cultural landscape, and declared world heritage area in 2006 ~ 2007 year.

3. Simulation of eco-hydrological physical processes in Hani terrace wetland

Water is the soul of Hani terrace, the most basic reasons which make Hani terrace rich and beautiful, is that adequate water and good water running behavior. Hani terrace wetland has a high water content, especially keeping water year round in the upper of the forest and high altitude terraces, the depth of water is about 0.25 to 0.3m. the thickness of sediment is about 0.25m, moisture content of sediment is more than 90%. Hani terrace wetland is equivalent to a small natural reservoir which provide a steady stream of water to Hani terrace wetland. According YAOMING calculated to Hani terrace wetland, the water storage capacity of 5050 m³/hm²[1]. The eco-hydrological physical processes in Hani terrace wetland, mainly from the vegetation rainfall interception, evapotranspiration, plants-soil water transport, runoff to study. The water is Hani inherent power, the external power of its eco-hydrological physical processes is that vegetation cover and land use patterns and habits of local residents.

3.1 Rainfall interception model of Hani terrace wetland vegetation

When atmospheric precipitation was into Hani terrace wetland ecosystem, the first to reach the vegetation canopy, then precipitation being re-allocated when it down to ground. The each link of
distribution is accompanied by the loss of liquid water and gaseous water generation and divergence. After rainfall interception, some rainfall shaped stem-flow and rain through the crown, the other evaporate back into the atmosphere, therefore, the rainfall interception by vegetation canopy is a way of wetland water loss. HE DONGJIN and HONG WEI[5] proposed a formula of the rainfall interception based on the improvement in the previous one.

\[ E_i = \begin{cases} 1 - (\text{veg} / \text{LAI})^\alpha \cdot P, & P \leq P^* \\ E_i^*, & P > P^* \end{cases} \] (1)

\[ E_i^* = \alpha \cdot \text{LAI} \left[ 1 - (\text{veg} / \text{LAI})^\alpha \right] \] (2)

\[ P^* = \alpha \cdot \text{LAI} \] (3)

in the formula: LAI is leaf area index, value of 0.2[6], P is rainfall, P* is critical rainfall when it reach maximum that the rainfall interception by vegetation, veg/LAI represents the ratio of vertical projection and leaf area of vegetation in sample area, veg value of 0.69 through the investigation, \( \alpha \) is the average maximum draft of the leaf surface, change in range is about 0.1-0.3mm, value of 0.2. EI* is the maximum interception.

By calculating, the critical rainfall of vegetation in Hani terrace wetland is 0.8mm.0.56mm maximum interception. The results can be seen that there is a little interception in Hani terrace wetland, this is because the terraced crop leaf area index on the small.

3.2 The evapotranspiration model of Hani terrace wetland

The evapotranspiration is the main way of wetland losing water, and the impact of vegetation on hydrological processes in wetland mainly on the process of evapotranspiration. As an important hydrological characteristics of wetland ecosystems, directly affect its material and energy recycling. Penman-Monteith by FAO recommended suit for the actual situation in china, especially large-scale, complex topography region the best.

\[ ET_{0(P-M)} = \frac{0.408\Delta(R_s - G) + \gamma \frac{900}{T + 273} U_2(E_s - E_a)}{\Delta + \gamma (1 + 0.34U_2)} \] (4)

\[ R_s = R_{so} - R_d \] (5)

\[ R_{so} = (1 - a)(a + bn / N)R_s \] (6)

\[ R_d = 2.45 \times 10^{-9} \cdot (1.35 \frac{0.25 + 0.5}{N} - 0.35) \cdot (0.34 - 0.14) \cdot (0.34 - 0.14) \cdot (T^4 - T_n^4) \] (7)

in the formula: ET0(P-M) is the reference crop evapotranspiration(mm / d).G is soil heat flux[MJ / (m·d)]. When calculation time in 10-30d, the daily average soil heat flux is negligible, in daily or long-term estimation, G value is usually very important. U2 is 2m height wind speed, when it is the wind speed with conventional height of weather station, to be multiplied by 0.72. \( \Delta \) is the slope of saturation vapor pressure curve(kPa / °C). \( \gamma \) is the psychrometer constant(kPa / °C).T is the average temperature 2m height. Es is the saturation vapor pressure(kPa), Ea is the actual water vapor pressure(kPa), Rn is the net radiation for the crop surface(MJ / (m·d)). Rns is the net shortwave radiation for the crop surface(MJ / (m·d)). Rnl is the net long-wave radiation for the crop surface(MJ / (m·d)). n is actual sunshine hours(h), N is the maximum number of hours of sunshine(h).

This article selected related date of hydrological station in Yuanyang County xinjiezhen, (such as tab
1), using the above model to calculate potential evaporation, and then draw monthly evaporation. By comparing the local hydrological station evaporation data, such as (Figure 1), indicated that the model can better simulate the evapotranspiration process in Hani terrace wetland.

### Tab1. the part of meteorological data, xinjiezhen, 1978-1996

|       | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| TEMP(℃) | 10  | 12  | 15  | 19  | 20  | 21  | 21  | 19  | 17  | 14  | 11  |     |
| PRCP (mm) | 33  | 46  | 47  | 88  | 219 | 201 | 195 | 164 | 164 | 100 | 113 | 30  |
| SUNS(h)  | 148 | 142 | 189 | 263 | 192 | 121 | 120 | 127 | 119 | 115 | 124 | 155 |
| EVAP(mm) | 87  | 120 | 189 | 205 | 182 | 131 | 119 | 125 | 101 | 83  | 72  | 82  |

Figure 1. comparison chart among rainfall, the actual evaporation and calculation of evaporation

### 3.3 The groundwater flow model of Hani terrace wetland

Through arranged pumping well and observation well in Hani terrace wetland, we can see that the dive of hani terrace wetland mainly occur in the loose layer of Quaternary, and the middle diving in the study area no continuous impermeable layer, so can be regarded as a unified group of aquifer.

Groundwater supplied of Hani terrace wetland mainly from precipitation and the groundwater runoff on the mountain which above the wetland. The west side of study area is mountains, east is the terrace, formed a unique the natural landscape about the “village – terrace – the river” which from west to east elevation decreasing, also the direction of runoff is west to east, diving excretion mainly be in the form of evaporation and runoff.

According to the above conditions, groundwater flow model to establish the following:

\[
\frac{\partial}{\partial x} (K \frac{\partial h}{\partial x}) + \frac{\partial}{\partial y} (K \frac{\partial h}{\partial y}) = \mu \frac{\partial h}{\partial t} \quad (x, y \in \Omega; \quad t > 0)
\]  \hspace{1cm} (8)

\[ h(x, y, 0) = h_0(x, y) \quad (x, y \in \Omega) \]  \hspace{1cm} (9)

\[ h(x, y, t)|_{\Gamma_w} = h_0(x, y, t) \quad (x, y \in \Gamma_w ; \quad t > 0) \]  \hspace{1cm} (10)

\[ h(x, y, t)|_{\Gamma_e} = h(x, y, t) \quad (x, y \in \Gamma_e ; \quad t > 0) \]  \hspace{1cm} (11)

\[ K \frac{\partial h}{\partial x} |_{\Gamma_w} = q_1 \quad (x, y \in \Gamma_w ; \quad t > 0) \]  \hspace{1cm} (12)

\[ h(x, y, t) = H(x, y, t) - B(x, y) \quad (x, y \in \Omega ; \quad t > 0) \]  \hspace{1cm} (13)

In the formula: h is groundwater height, H is groundwater elevation. B is the aquifer bottom elevation; K is the permeability coefficient, μis the specific yield of aquifers. Ω is the scope of the study area. ΓW
and ΓE respectively east and west side of the head of the study area boundary, q1 is the single-wide infiltration of groundwater on the upper terrace.

As the unique topography of Hani terrace wetland that west to east, the elevation progressively decreasing. The border infiltration of north and south is very little; there is negligible. The boundary head of model was obtained by the observation well in the study area. Infiltration was calculated by the measured flow. As the aquifer thickness and the depth of disturbed small, so think it is ground floor under the ground 20m. In this paper, using this formula, calculated the permeability coefficient K of wetland is 128.7 m/d.

To compare the model, using pumping test data (such as Figure 1-1), draw Q-S curve, then chose pressure integrity of wells with two observation holes to calculate by the follow:

\[ K = 0.336 \frac{Q\log r/r_1}{M(S_1 - S_2)} \]  

(14)

In the formula: Q is the water inflow. M is the thickness of the aquifer. r1 is the distance that observation 1 to pumping well, r2 is the distance that observation 2 to pumping well.

By calculating, the permeability coefficient K is 63.5 m/d. It differs from the previous; this is because the pumping test data to draw the Q-S curve itself has large errors. And the test is the easiest stability pumping test of single hole, and assumptions have limited the accuracy of the value of K. By compared, showed that the value of K which derived from previous model was closer to the actual situation.

Tab 2. Part of the data of the pumping well

| INFLOW Q(m³/h) | DRAWDOWN S(m) | Well-1 S(m) | Well-2 S(m) | Well-3 S(m) | Well-4 S(m) | Well-5 S(m) | Well-6 S(m) |
|----------------|---------------|-------------|-------------|-------------|-------------|-------------|-------------|
| 186            | 3.78          | 2.1         | 1.01        | 0.83        | 1.36        | 0.78        | 0.65        |
| 132            | 2.59          | 1.37        | 0.53        | 0.42        | 0.85        | 0.39        | 0.38        |
| 78             | 1.5           | 0.87        | 0.35        | 0.17        | 0.24        | 0.23        | 0.3         |

3.4 Eco-hydro-chemistry process model of Hani terrace wetland

Wetland has a strong ability to degrade and transform pollutants. It uses the triple coordination which formed by the physical, chemical and biological processes in the ecosystem. Through filtration, adsorption, precipitation, plant uptake, microbial degradation to achieve the efficient decomposition and purification on pollutants [7]. Hani terrace wetland is a typically artificial wetland, in order to avoid man-made factor as little as possible impacted, track and monitor water quality in fallow season, and so the water quality of terrace limited only by the impact of sewage. In study area, there are seven long-term water quality sampling points (Bailongquan elevation 1663m, Xicaikou elevation 1650m, Cunkoupaiguowu elevation 1650m, Henggouw elevation 1557m, zhonggou elevation 1550m, Kakouzhan elevation 1540m). In the 1650m, set comparison. By tracking and monitoring the water quality of the experimental points, found that the water quality in study area changes with elevation and shows a significant variation. Figure 2 shows, the water quality is well in the living area above, this is because above the Hani terrace wetland there is a large expanse of forest, and less affected by human disturbed. But when runoff flows to the village and used by local residents, water quality decreased. Then the water flows to terrace, by the experimental data of kakou, can be seen the water quality return to a better level.
By regression analysis of the experiment data, obtained the concentration regression equation of each index which decrease exponentially with altitude.

Tab 3. The regression equations of water quality indicators

| WATER QUALITY INDICATOR | REGRESSION EQUATION          |
|-------------------------|-----------------------------|
| TN                      | $\text{Y}=1.6105e^{-0.138x}$, $R^2=0.139$ |
| TP                      | $\text{Y}=0.1668e^{-0.102x}$, $R^2=0.1078$ |
| N-\text{NH}_3           | $\text{Y}=1.5701e^{-0.063x}$, $R^2=0.1497$ |
| N-\text{NO}_3           | $\text{Y}=0.7066e^{-0.042x}$, $R^2=0.0588$ |

Figure 2. The curve of TN, TP, N-NH$_3$, N-NO$_3$ with elevation

4. Ecological effects of Hani terrace wetland

Hani terrace fields has a thousand years of history, it is the industrious and intelligent people to create wetland, combined with local topography in the Ailao mountain area where it has no wetlands. Since the birth of Hani terrace, greatly improving the ecological environment of this region, so it is a healthy created wetland of artificial, and brings a significant ecological effects to the local.

Hydrological processes controlled the migration and conversion of nutrients, contaminants, minerals and organic matter in ecosystem. Deterioration of water quality, water level changes, water chemistry characteristics and its changes, that all impact on plant community structure, dynamics, distribution and succession. Therefore, dynamics of vegetation can be controlled by adjusting the hydrological process [5]. Hani terrace wetland is a model of wetland, its good ecological effects is inseparable with hydrological processes. When coupled the entire previous model, it initially formed the eco-hydrological model of Hani terrace wetland.

There is a large area of forest above Hani terrace fields, due to old bylaws, felling water forest has been forbidden, especially the shengzhailin. The old bylaws played a very good protective effect on the local water resources. Rainfall, after intercepted and storage by the forest, flows through the village, terrace in the form of spring or stream. That provides a steady stream for Hani terrace wetland. From the rainfall data of xinjiezhen 1968-1996, it can be seen that rich precipitation in Hani terrace wetland and average annual precipitation reached 1403.6m. From figure 1, can be seen evaporation greater than precipitation in January to May and December, in June to November, it is contrary. For the full year precipitation basically keep the same with evaporation, this is the description of water balance in Hani terrace ecosystem. From the previous study shows the water quality has dropped significantly after water has been used by the village. At the same time poultry, livestock manure and human waste consisting of
“manure” that is not only increased the terrace fertility, improve soil fertility, but also reduced the pollution of the local environment. So Hani terrace wetland constitutes a healthy self-cleaning system. Hani terraced wetlands also can maintain soil erosion. These above mentioned have all brought good ecological effects to Hani terrace fields.

5. Conclusion

(1) The Penman-Monteith formula is also applicable in Hani terrace wetland; the evaporation is calculated by the 1978-1996 meteorological data of Xinjie town and the evaporation of the local meteorological data, between which the deviation was controlled within 2%; the model can well simulate the Hani terrace wetland evapotranspiration process.

(2) Through comparing the groundwater permeability coefficients calculated by model and by pumping test drawing q-s curve, the value from the model was more close to the actual situation; the permeability coefficient K of Hani terrace wetland obtained was 128.7m/d.

(3) The indicators of water quality used in this paper, total nitrogen, total phosphorus, ammonia nitrogen, nitrate nitrogen, first increased then decreased along with elevation. This was because of the ecosystem’s spatial structure of Hani terrace and the utilizing form of water resource; Hani terrace wetland itself is a self-purifying system.

(4) Hani terrace precipitation and evaporation are basically the same level, which shows that Hani terrace wetland is a positive ecological water circulation system.

The establishment of Hani terrace eco-hydrological model provides theory support for the future eco-hydrological research; but except the evapotranspiration model and the chemistry process model were fitted out from actuality, other models had no fitting with the Hani terrace actual situation. This is also the next job needing to be done in the eco-hydrological research, through hydrological data and experimental data to validate, fit, adjust and improve the model; and the coupled model of hydrological process and ecological process also needs further in-depth research, establishing corresponding ecological indicators in response to the hydrological process.

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