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Remediation effect of contaminated water by water hyacinth (*Eichhornia crassipes* (Mart.) Solms)

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ABSTRACT

Based on the results of laboratory and field experiments, the remediation effect of water hyacinth (*Eichhornia crassipes* (Mart.) Solms) on contaminated water was analyzed in this paper. The selected plant was purchased at the local market in Zhengzhou city, central district in China. Water sample group S-A was collected from river through the city while Groups S-B and S-C were confected by adding carbon source, nitrogen and phosphorus to river water. Removal efficiency of COD, total phosphorus (TP), total nitrogen (TN), and ammonia nitrogen (NH_3-N) attained to 66–75%, 64.65–91.72%, 37.55–79.89%, and 61.27–97.58%, respectively, within 18 d. Individual variance existed at purifying these pollutants by water hyacinth. Removal dynamic process of COD, TP, TN, and NH_3-N were corresponded with first-order-reaction kinetics equation. The elimination rates of COD, TP, and NH_3-N were kept high for six days while that of TN lasted for 12 d, and then removal efficiency increased gently. Compared with COD and TP, the elimination of TN was a related slow process. Under the experimental condition, the fresh weight of the plant had doubled within 18 d but overgrowth phenomenon did not happen. The results showed that water hyacinth could be used for restoring the contaminated water in Zhengzhou city, without bringing about significant negative ecological consequences during phytoremediation.

Keywords: Phytoremediation; Water hyacinth; Contaminated water; Purifying effect

1. Introduction

With social economical development and population growth, the discharge volume of industrial waste and domestic sewage multiplies daily. There are more and more pollutants in water body while wastewater treatment lags behind. The proportion of 110 emphasized river segments in seven big rivers and continental rivers according with Grade I and II, Grade III, Grade IV, and V of environmental quality standards for surface water in China (GB3838-2002), was 32, 29, and 39%, respectively [1]. Water eutrophication and organic pollution have become global problems [2,3].

Purifying water technology was developed broadly owing to the seriousness of water pollution [4–6]. Bioremediation was an important purification method and phytoremediation was a potential green technology [7,8].

As a kind of aquatic plant which was studied deeply with a long history and extensively used in ecological restoration project, water hyacinth (*Eichhornia*

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crassipes (Mart.) Solms) could effectively remove nitrogen and phosphorus, reduce BOD, and absorb many kinds of heavy metals and toxic compounds [4,9,10]. It had been used to treat water body such as eutrophication lakes, polluted riverway, breeding wastewater, industrial wastewater, rubbish percolate, and so forth [11–13]. The manuscript studied the remediation effect of water hyacinth (*E. crassipes* (Mart.) Solms) on contaminated water, thus to provide theoretical basis for application.

2. Material and methods

2.1. Experimental material

Water hyacinth was purchased from local flower market. Water sample was collected from downstream of Eighteen River which was a mainly riverway through Zhengzhou city, China. The total of 50 L water sample was collected every 10 m alone the river (four representative sites were chosen), which was partly used as the experimental sample S-A. The sample S-B was prepared by adding 2.32 g sucrose to 1 L initial water sample, and the sample S-C with 0.80 g sucrose, 0.27 g ammonium nitrate, 0.035 g monopotassium phosphate to 1 L initial water sample.

2.2. Sample treatment and analyses

The samples were classified into four groups in triplicate. Group 1–3, where water hyacinth was planted, held 8 L water sample S-A, S-B, and S-C, respectively. Group 4 held 8 L tap water without water hyacinth was used as control group for determining evaporation volume of water.

The experiment was carried out from end of April to mid-May. COD, total phosphorus (TP), total nitrogen (TN), ammonia nitrogen (NH_3-N), fresh weight of water hyacinth were measured every six days. The evaporated water volume was replenished by distilled water before sampling. COD, TP, TN, and NH_3-N were analyzed, respectively, by potassium permanganate index method, ammonium molybdate spectrophotometric method, alkaline potassium persulfate digestion-ultraviolet spectrophotometry, and Nessler's reagent spectrophotometry according to GB3838-2002.

3. Result and discussion

3.1. Pollution feature analysis of water sample

Water quality of three groups (S-A, S-B, S-C) overstepped Grade V of surface water quality standards which was the lowest standard and had basic water quality function (Table 1). COD was 7–8 times of the limitation value (15 mg/L) and TN was 6–9 times of the value (2.0 mg/L) to all the samples. TP of Group S-C was greater than the limitation value while that of Groups S-A and S-B met the standard requirement. Water quality of all the groups was worse than Grade V as a whole.

The nutrition state was evaluated with eutrophication index by COD, TP, and TN for water samples. Three groups of sample were at eutrophication level according to the widely used eutrophication index standard (Table 1) [14,15].

3.2. Purification effect of water hyacinth

3.2.1. Removal effect of water hyacinth on COD

COD dropped dramatically with the effects of water hyacinth in 18 d which decreased from above 100 to 30 mg/L (Fig. 1). Data fitting and trend analysis based on S-A2, S-B2, and S-C3 showed that COD in water sample were exponentially related to time (Fig. 2). The equation was $y = 113.46e^{-0.0738t}$ ($R^2 = 0.9781$) for S-A2, $y = 111.06e^{-0.0726t}$ ($R^2 = 0.968$) for S-B2 and $y = 110.73e^{-0.064t}$ ($R^2 = 0.9753$) for S-C3, respectively.

The removal efficiency of COD by water hyacinth surpassed 30% and the highest removal efficiency was 45% in six days. Most of the removal efficiency of

Table 1
The main index value of water sample

	COD (mg/L)	TP (mg/L)	TN (mg/L)	NH_3-N (mg/L)
Sample A	105.53 ± 10.51	0.351 ± 0.042	19.227 ± 0.707	0.635 ± 0.207
Sample B	117.07 ± 10.48	0.351 ± 0.038	13.653 ± 5.064	0.536 ± 0.110
Sample C	113.46 ± 4.27	0.842 ± 0.220	18.127 ± 1.054	1.634 ± 0.809
Grade V[a]	15	0.4	2.0	2.0
Eutrophication level[b]	10	0.2	2.0	

[a]Grade V were one of 5 grades in environment quality standards for surface water in China (GB3838-2002).
[b]Eutrophication level was one of 6 level in eutrophication index standard referred by Shu in 1990 [14].

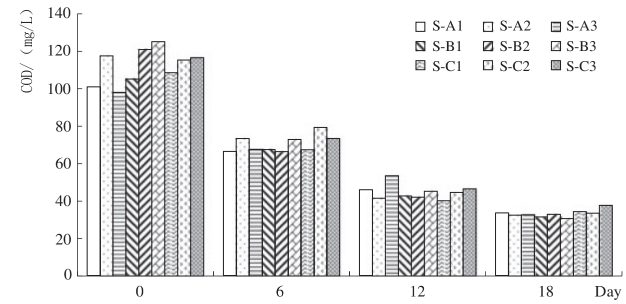

Fig. 1. Purification effect of water hyacinth on COD.

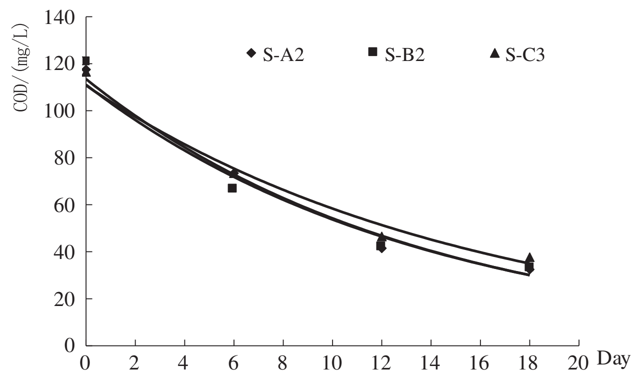

Fig. 2. Purification trend analysis of COD by water hyacinth.

COD reached 60% in 12 d with the minimum value of 45% and the maximum value of 65%. After 18 d, the removal efficiency ranged between 66 and 75%. Experimental time was lengthened because COD in 18 d was at a higher level (Fig. 1). Nonetheless, the removal efficiency of COD in 30, 40, and 50 d was basically maintained at 70–80%, indicating lower average elimination rates for individual sample than the former stage (Table 2). COD value in some water samples had a transitory rise period after 34 d (for instance, S-B3 and S-C2), demonstrating that COD rose temporarily and the removal efficiency by water hyacinth was lessened in related study where COD lingered about 20 mg/L for several months [16]. To the average removal efficiency, which reached to 70.12% in 18 d while 75.67% in 54 d and only improved by 5%. The removal efficiency of COD by water hyacinth grew more slowly during the prolonged period.

3.2.2. Removal effect of water hyacinth on TP

TP of Group S-A, S-B, and S-C was significantly reduced in 18 d although phosphorus was added into S-C. TP of S-A, S-B dropped below 0.1 mg/L (0.084–0.025 mg/L) from initially more than 0.3 mg/L (0.394–0.321 mg/L) while that of S-C below 0.3 mg/L (0.08–0.292 mg/L) from initially more than 0.6 mg/L (0.631–1.07 mg/L) (Figs. 3 and 4). Data fitting and trend analysis based S-A2, S-B2, and S-C2 showed that TP in water sample presented exponential relation with time (Fig. 4). The equation was $y = 0.3462e^{-0.0897t}$ ($R^2 = 0.9077$) for S-A2, $y = 0.2656e^{-0.1098t}$ ($R^2 = 0.8825$) for S-B2, and $y = 0.7752e^{-0.0534t}$ ($R^2 = 0.9387$) for S-C2, respectively.

Except for S-A1, the removal efficiency of TP by water hyacinth surpassed 40% in all the samples where the highest value attained above 80% (S-A3) and the average value was 56.04% in six days. Then, the average removal efficiency of TP reached 74.9% in 12 d where the minimum value was 45.64% (S-C2) and the maximum value was 87.42% (S-A3). For S-A1, the growth rate of removal efficiency, from 10.93% in 6 d to 70.93% in 12 d, was the fastest among all the samples. At the end of the experiment, the average removal efficiency of TP reached 80.63% in 18 d. S-A3 had the highest removal efficiency while S-C2 had the lowest removal efficiency. Our results suggested that water hyacinth had strong individual variation, and the well-grown water hyacinth would keep a better purification capacity with time; in contrast, the weak grown plants would have a poor purification capacity. Based on the average value (56.04%) at the initial 6 d,

Table 2
Removal efficiency of COD by water hyacinth with time (%)

Day	S-A1	S-A2	S-A3	S-B1	S-B2	S-B3	S-C1	S-C2	S-C3	Mean ± SD
6	34.17	37.56	31.09	35.84	45.05	41.73	37.93	31.16	37.02	36.84 ± 4.56
12	54.62	64.72	45.42	59.40	65.18	63.83	62.98	61.29	60.08	59.73 ± 6.28
18	66.90	72.37	66.67	70.00	72.77	75.48	68.36	70.90	67.66	70.12 ± 3.02
34	79.72	76.01	59.88	–	76.01	84.73	65.09	67.38	70.48	72.41 ± 8.20
44	79.72	76.60	67.84	65.31	77.25	69.94	69.70	60.27	74.17	71.20 ± 6.29
54	81.63	77.26	69.78	73.15	79.03	78.09	78.44	69.12	74.57	75.67 ± 4.30

Note: SD, standard error.

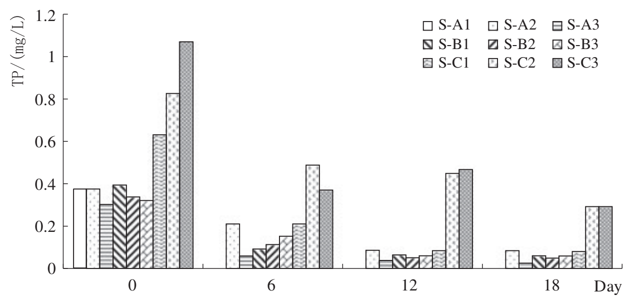

Fig. 3. Purification effect of water hyacinth on TP.

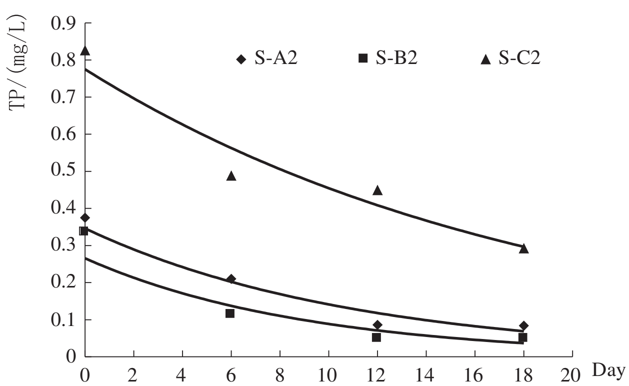

Fig. 4. Purification trend analysis of TP by water hyacinth.

the removal efficiency increased to 18% during 6–12 d and 6% during 12–18 d, respectively. The elimination rates of TP by water hyacinth rapidly lowered with time (Table 3).

Previous research showed that the removal efficiency of TP by water hyacinth decreased with its concentration. Under the condition of 0.0155, 0.031, 31, and 155 mg/L, the efficiency was 87.1, 64.52, 54.84, and 24.71%, respectively, in 15 d [17]. The concentration of TP was between 0.3 and 1.0 mg/L in the experiment. The efficiency reached 80% in 18 d, more than the value by the reference [17]. The purification trend of TP by water hyacinth became gentle after 12 d in both research results. The increase trend of removal efficiency with time was mainly due to water hyacinth assimilating abundant phosphorus for growth at initial time, which made TP rapidly reduce. The low absorption rate after some time, however, was due to falling demand and redistribution in water hyacinth body for phosphorus.

3.2.3. Removal effect of water hyacinth on TN

To all the samples except S-B1, TN was observably lessened by water hyacinth in 18 d which decreased from initial nearly 20 mg/L to below 6.5 mg/L (Fig. 5). Data fitting and trend analysis based S-A1, S-B2, S-C2 showed that TN in water sample present exponential relation with time. The equation was $y = 19.623e^{-0.0749t}$ ($R^2 = 0.8965$) for S-A1, $y = 9.5088e^{-0.0934t}$ ($R^2 = 0.9508$) for S-B2, and $y = 17.821e^{-0.0705t}$ ($R^2 = 0.941$) for S-C2 (Fig. 6), respectively.

The average removal efficiency of TN in 6, 12, and 18 d were 28.67, 60.53, and 67.38%, respectively. The efficiency in 6–12 d was double than that of 0–6 d. The increasing rate of the efficiency for TN attained the maximum in 6–12 d. Whereas, the eigenvalues for COD and TP attained the maximum in 0–6 d after rapid decreasing. Compared with COD and TP, TN maintained a relatively rapid decline and its removal was a correspondingly slow process in 12 d. The maximum removal efficiency was almost 80% (S-A2 and S-B2), while the minimum value was only 37.55% (S-B1) in 18 d. There was a higher increase of removal efficiency of TN in 12–18 d for S-B1, which explained TN could be lowered to a large extent if continued remediation was done (Table 4). At the end of experiment, the removal efficiency was close to the previous results [17].

3.2.4. Removal effect of water hyacinth on NH_3-N

The average value of NH_3-N was reduced from 0.94 mg/L (0.40–2.52 mg/L) to 0.23 mg/L (0.02–0.98 mg/L) in 18 d. The final values were far lower than the initial value except for S-C2 and S-C3 (Fig. 7). The exponential relations between NH_3-N and time from fitted curve were expressed as follow, $y = 0.39e^{-0.1677t}$

Table 3
Removal efficiency of TP by water hyacinth with time (%)

Day	S-A1	S-A2	S-A3	S-B1	S-B2	S-B3	S-C1	S-C2	S-C3	Mean ± SD
6	10.93	44.00	80.46	76.65	66.57	52.65	66.72	40.92	65.42	56.04 ± 21.66
12	70.93	77.07	87.42	83.76	84.91	81.31	86.69	45.64	56.36	74.90 ± 14.73
18	79.73	77.60	91.72	84.77	85.50	81.62	87.32	64.65	72.71	80.63 ± 8.20

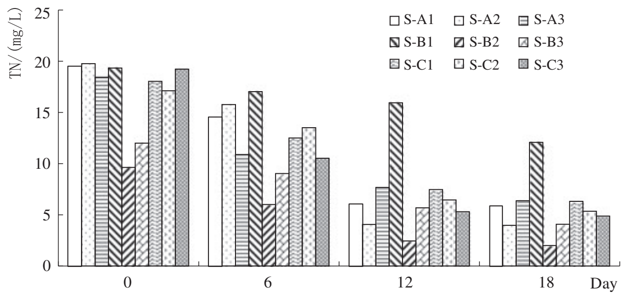

Fig. 5. Purification effect of water hyacinth on TN.

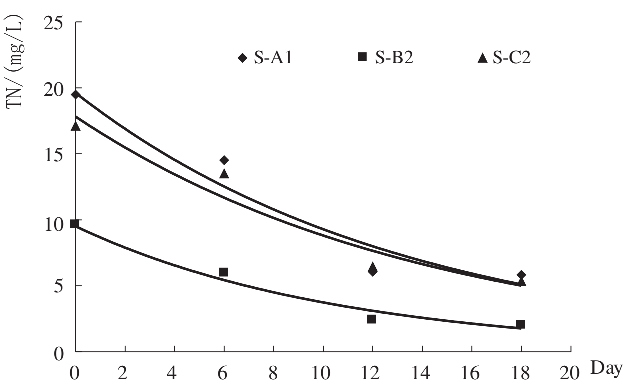

Fig. 6. Purification trend analysis of TN by water hyacinth.

($R^2 = 0.9919$) for S-A2, $y = 0.336e^{-0.1189t}$ ($R^2 = 0.8934$) for S-B2, and $y = 1.5421e^{-0.0612t}$ ($R^2 = 0.8771$) for S-C2 (Fig. 8).

NH_3-N was evenly removed 54.34% in six days, which had the minimum removal efficiency of 26.28% for S-C2 and the maximum removal efficiency of 76.61% for S-B2. The Group S-B had higher removal efficiency than other groups in six days. The average removal efficiency of NH_3-N in 12 and 18 d reached 69.99 and 81.63%, respectively. The value added for average removal efficiency of NH_3-N every six days at later stage surpassed 10%, which showed that NH_3-N of water sample underwent steady and fast elimination. S-C2 had the minimum removal efficiency while S-B3 and S-A2 had larger removal efficiency rather than S-B2 in 6–12 d and 12–18 d. All the Group B samples revealed higher removal efficiency during the experiment time (Table 5).

3.2.5. *Comprehensive analysis of water hyacinth remediation effect*

TP and NH_3-N in water samples were consistent with Grade V of surface water quality standards and eutrophication index standard cited in previous section. COD and TN, however, are inconsistent with these standards. Even after water hyacinth remediating for 54 d, COD still exceeded these standards (Tables 1 and 6). The main possible reasons could be higher initial concentration and shorter remediation time. Other possible reason could be due to lower air temperature at the late time causing water hyacinth to grow tardy. Except for TN, all the measured indicators for Group S-B which had larger plant, had higher removal efficiency than Group S-A and S-C.

Removal dynamic process of COD, TP, TN, and NH_3-N in water samples was consistent with first-order-reaction kinetics equation. On account of sufficient nutrient substance in water sample at the initial six days, water hyacinth could absorb large amounts of carbon, nitrogen, and phosphorus, and so forth. The elimination rates of COD, TP, and NH_3-N kept fastest in six days while that of TN did in 12 d. As a whole, water hyacinth remediation attained the same good effect as before, thus proving that this kind of plant could be used for treating polluted water [18]. Some research showed that water hyacinth with high protein and high fat had not only a good tolerance and remediation effect to organic pollutant, nutrient substance, and heavy metal of water body, but also higher values in making paper, feeding stuff, and other industry [19,20].

3.3. *Study on water hyacinth growth rhythm*

In this experiment, each selected group of water hyacinth with similar weigh. For Group S-A, the

Table 4
Removal efficiency of TN by water hyacinth with time (%)

Day	S-A1	S-A2	S-A3	S-B1	S-B2	S-B3	S-C1	S-C2	S-C3	Mean ± SD
6	25.51	20.20	40.98	11.94	37.62	24.75	30.68	21.13	45.27	28.67 ± 10.87
12	68.90	79.42	58.31	17.60	74.55	52.63	58.61	62.32	72.39	60.53 ± 18.31
18	70.06	79.89	65.39	37.55	79.17	66.02	64.99	68.76	74.62	67.38 ± 12.54

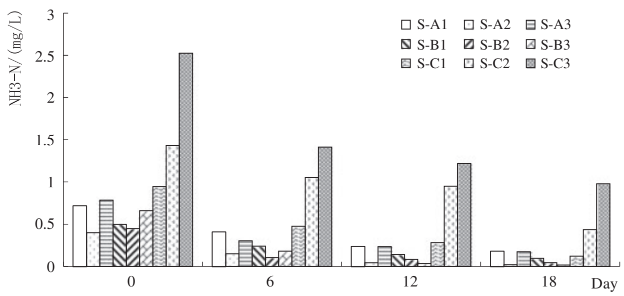

Fig. 7. Purification effect of water hyacinth on NH_3-N.

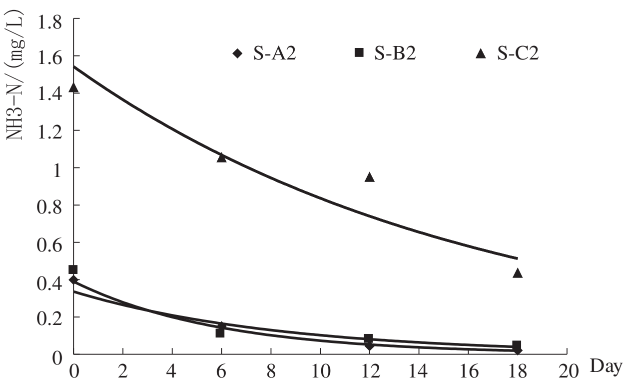

Fig. 8. Purification trend analysis of NH_3-N by water hyacinth.

average fresh weight of the plant in 18 d increased from 18.46 to 33.17 g, by adding 14.71 g and the rate of 79.7%. For Groups S-B and S-C, the average fresh weight increased from 24.30 to 53.33 g by adding 29.03 g and the rate of 119.5%, and from 12.60 to 25.00 g by adding 12.4 g and the rate of 98%, respectively (Table 7). The order of increase rate was S-B > S-C > S-A. S-B could offer more carbon source to make water hyacinth grow well, which explained, to some extent, purification different of COD, TP, TN, and NH_3-N among groups.

As we know, water hyacinth has strong fecundity, seizing surrounding water in the short time, and forms large area of single plant community. In our experiment, water hyacinth did not show vigorous growth or overgrowth. The fresh weight of the plant had doubled in 18 d. The "slow" growth could be due to the climate in Zhengzhou city (central China), different from southern city where overgrowth phenomenon of water hyacinth occurred very commonly [21]. Because appropriate temperature and enough illumination were very important to plant growth, water hyacinth was also influenced by weather change in the process. In addition, when water hyacinth was weighed, its biological tissue could be damaged by temporary departure from water, thus affecting purification action.

Though Zhengzhou city is located in subtropical and warm temperate regions and is suitable for water

Table 5
Removal efficiency of NH_3-N by water hyacinth with time (%)

Day	S-A1	S-A2	S-A3	S-B1	S-B2	S-B3	S-C1	S-C2	S-C3	Mean ± SD
6	43.91	62.41	61.40	51.90	76.61	72.73	49.79	26.28	44.04	54.34 ± 15.73
12	67.59	88.97	69.94	71.54	81.51	94.85	70.19	33.61	51.72	69.99 ± 18.63
18	75.62	94.74	77.96	80.76	89.98	97.58	87.21	69.53	61.27	81.63 ± 11.93

Table 6
Parameter values of water sample in 18 d (mg/L)

	Sample A		Sample B		Sample C	
	Mean ± SD	RE[b] ± SD	Mean ± SD	RE ± SD	Mean ± SD	RE ± SD
COD[a]	24.97 ± 5.72	76.22 ± 5.99	27.00 ± 1.49	76.76 ± 3.16	29.55 ± 6.10	74.04 ± 4.68
COD	32.86 ± 0.53	68.65 ± 3.23	31.72 ± 1.13	72.75 ± 2.74	35.20 ± 2.19	68.97 ± 1.70
TP	0.06 ± 0.03	83.02 ± 7.61	0.06 ± 0.01	83.96 ± 2.06	0.22 ± 0.12	74.89 ± 11.49
TN	5.40 ± 1.26	71.78 ± 7.40	6.05 ± 5.32	60.91 ± 21.27	5.51 ± 0.73	69.45 ± 4.85
NH_3-N	0.12 ± 0.09	82.77 ± 10.43	0.05 ± 0.04	89.44 ± 8.42	0.51 ± 0.43	72.67 ± 13.25

[a]COD value in 54 d.
[b]RE, Removal efficiency mean (%).

Table 7
The average fresh weigh change of water hyacinth with time (g)

Day	S-A	S-B	S-C
0	18.46	24.30	12.60
6	25.67	38.57	18.07
12	30.33	47.50	22.50
18	33.17	53.33	25.00

hyacinth growth, it could not make the plant overwinter. So it was viable to use water hyacinth for treating polluted water and control its overgrowth in the city.

4. Conclusions

Polluted water remediation with water hyacinth was studied by experiment in this study. Main results were as following:

(1) Removal dynamic process of COD, TP, TN, and NH_3-N by water hyacinth was corresponded with first-order-reaction kinetics equation.
(2) Removal efficiency of COD, TP, TN, and NH_3-N were 66–75%, 64.65–91.72%, 37.55–79.89%, and 61.27–97.58%, respectively, in 18 d. The average removal efficiency of these parameters was 70.12, 80.63, 67.38, and 81.63%, respectively.
(3) The elimination rates of COD, TP, and NH_3-N with time were the fastest in six days while that of TN kept the relative fast speed in 12 d. Then the removal efficiency increased gently. Compared with COD and TP, the elimination of TN was a relatively slow process.
(4) Under the experimental condition, the fresh weight of the plant had doubled in 18 d without overgrowth. Individual variance existed at purifying COD, TP, TN, and NH_3-N by the plant. The results showed that water hyacinth could be used for polluted water remediation in Zhengzhou city without overgrowth.

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