

1 **Impact of Drought on the Quality of Surface Water in**

2 **Basins**

3

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10

11 **Abstract**

12 Under the background of climate change and manmade alterations to the environment , there
13 has been an increase in the frequency of droughts and the range of their impact. Droughts
14 may give rise to a series of resource, environmental and ecological effects, i.e., water
15 shortage, water quality deterioration, as well as the decrease in the diversity of aquatic
16 organisms. This paper, above all, identifies the impact mechanism of drought on the surface
17 water quality of the basin, and then systematically studies the laws of generation, transfer,
18 transformation and degradation of pollutants during the drought, finding that the alternating
19 droughts and floods stage is the critical period during which the surface water quality is
20 affected. Secondly, through employing indoor orthogonality experiments, serving drought
21 degree, rainfall intensity and rainfall duration as the main elements and designing various
22 scenario models, the study inspects the effects of various factors on the nitrogen loss in soil,
23 as well as the loss of non-point source pollution and the leaching rate of nitrogen under the
24 different alternating scenarios of drought and flood. It comes to the conclusion that the
25 various factors and the loss of non-point source pollution are positively correlated, and under
26 the alternating scenarios of drought and flood, there is an exacerbation in the loss of
27 ammonium nitrogen and nitrate nitrogen in soil, which generates the transfer and
28 transformation mechanisms of non-point source pollution from a micro level. Finally, by

1 employing the data of Nenjiang river basin, the paper assesses the impact of drought on the
2 surface water quality from a macro level.

3

4 **1 Introduction**

5 Drought is a natural phenomenon when there is an abnormal climate, and it's also a normal
6 order under long-term climate regulation (Wilhite, 2000). Drought gives rise to a series of
7 resource, environmental and ecological effects, i.e., water shortage, water deterioration, as
8 well as the decrease in the diversity of aquatic organisms. With the rapid development of a
9 social economy, people's demands for water resources gradually increase. Presently , under
10 the competitive situation of water use, water demand issues will become critical during a
11 drought . Under the same natural conditions, a drought will worsen the situation.

12 Historical monitoring data and the assessment reports of IPCC make it clear that the
13 occurrence of drought in some areas becomes more frequent and the duration increases at the
14 same time. In China, runoff volume in some rivers and lakes has decreased noticeably (Liu,
15 1997; Zhang, 2008). For years, scholars in China and internationally have made a great
16 number of discoveries focusing on the impact of drought on water environments. These
17 discoveries consist of three different stages: the embryonic stage, the growth stage and the
18 development stage. Rudimentary stage (before 21st century): most scholars conducted studies
19 on the water environments of the drought periods, as well as the drought areas, mainly
20 focusing on the physicochemical property of water bodies during the drought and the water
21 environments in drought areas; meanwhile, they briefly explored the causes of water
22 deterioration in the drought periods (Whitehead,2009; Margarida, 1995; Peter, 2007). Their
23 studies were mainly qualitative (Chang, 1999; Bishay,1995; Gomez,1996; Wang, 1998).
24 Growth stage (2000-2006): researchers, from the perspective of climatic change, studied the
25 changes in physical, chemical and biological indexes of water quality, which were caused by
26 the variations of the climatically hydrological factors (temperature, rainfall, river flow, etc.) in
27 order to identify the impact mechanism of drought on the water environments (Caruso,2002;
28 Mimikou, 2000; Zhan, 2005; Senhorst, 2005; Zwolsman, 2007). Development stage (from
29 2007 to now): researchers began to analyze the impact of drought on water environments at
30 the mechanism level. They have been carrying out different studies on the surface water
31 quality of water bodies in actual drought situations, and combining regional characteristics
32 into their studies , they have tried to analyze the transformation features of the pollutants

1 among the water bodies under the scenario of drought as well as the affects on the water
2 environments(George, 2007; Lunchakorn, 2008; Verweij, 2010; Delpla, 2009; Harmke, 2006;
3 Zowlsman,2008). To sum up, current research focuses on the impact of drought on water
4 quality, the relationship between drought and pollutants in water bodies as well as the
5 physical and chemical reactions in water bodies during the drought. However, research in the
6 following areas, such as the changing mechanisms of surface water quality during the
7 drought, the identification of the main factors that affect the loss of non-point source
8 pollution, and the alleviation of impact of drought on water environments, are badly needed.

9 This paper, at the very beginning, identifies the impact mechanism of drought on the surface
10 water quality of the basin, analyzes the impact of rainfall on the surface water quality before
11 and after a drought, studies the laws of how pollutants are formed, how they enter the rivers
12 and how they are transferred and transformed in the river channels. Then drought severity,
13 rainfall intensity and rainfall duration are chosen as the main elements; at the same time,
14 orthogonality experiments are conducted to simulate the dynamic changing process of
15 nitrogen in the agricultural topsoil under the different scenarios of dry-and-wet processes. The
16 paper also examines the transformation mechanisms of non-point source pollution during the
17 alternating periods of drought and flood, and analyzes how much impact the various factors
18 and scenarios have on the river water quality. Finally, by using the observed data of Nenjiang
19 river basin, the paper assesses the impact of drought on the surface water quality of the basin
20 from the level of river basin.

21

22 **2 Identifications of the basic impact mechanisms of drought on surface water** 23 **quality of the basin**

24 Water is the carrier of the basin substances and energy flow. The process of water cycle is
25 accompanied with the transfer and transformation of pollutants. Drought is the extreme
26 process of water cycle. Hydrological extreme events, droughts for instance, affect the runoff
27 generation and confluence mechanism of the basin, and change the pollutants transformation
28 and the dilution capacity of water bodies. hHuman activities (such as taking, supply, using,
29 consumption, drainage, etc.) interfere with the cycling process of natural water. For example,
30 using water will change the water volume, and drainage will change the water quality. Under
31 the background of the climate change and human activities, changes could take place in the
32 laws of generation, transfer and diffusion of river basin pollutants. In the first place, the

1 deficiency of rainfall during the drought damages the balance of the surface water, giving rise
2 to the reduction of the water supply, the aggravation of evaporation, the drop of water table
3 levels and the shrink of river and lake basins. Secondly, during the drought, the increase in
4 the concentration of nutrition elements (i.e. nitrogen, phosphorus, etc.), the weakening of the
5 hydrodynamic conditions and the extension of the dwell time will provide sufficient nutrition
6 for algae's rapid multiplication, leading to the aggravation of eutrophication, the disorder of
7 the aquatic ecosystem, the reduction of the living species and the damage to the diversity of
8 organisms. Finally, the mechanism of runoff generation and confluence is altered during the
9 drought, leading to the variations of the total number, components and diffusion of pollutants
10 in the river basin. The rainfall after the drought, in particular, will bring the accumulated non-
11 point source pollution into the water body, resulting in the deterioration of water quality.
12 Therefore, if we want to know exactly how drought impacts the surface water quality by
13 studying the impact of drought on the generation, transfer and degradation rules with regards
14 to water content and pollutants, climate change and human activities must be taken into
15 consideration.

16 **2.1 Impact of drought on pollution sources and pollutant generation quantity**

17 The surface water quality of the basin is affected by both the point source pollution (industrial
18 waste water and domestic sewage) and non-point source pollution. With the point source
19 pollution being reduced gradually, the non-point source pollution has become the main factor
20 of the surface water degradation in China. Urban runoff and agricultural runoff are the two
21 types of non-point source pollution, while surface runoff and interflow are the carriers that
22 make the non-point source pollution enter into the water body. During the drought, due to the
23 decrease of rainfall and runoffs, non-point source contaminants that flow into the surface
24 water become less. As a result, pollutants of surface water body during the drought mainly
25 belong to the point source pollution.

26 During the dry period, for a lack of formation process of runoff, domestic refuse, wastes and
27 non-point source contaminants alike are piled up in the earth's surface and soil. When the rain
28 falls, they will fall into the receiving water body along with runoffs. The dry-wet alternation
29 from drought to rainfall will promote the decomposition of the organic matters in soil and
30 increase the load of nutrients in water, which lead to a rapid deterioration of surface water
31 quality in a short time (the major exceeding items are nutrient salt and suspended solids).
32 Compared with the drought season, the precipitation events after the drought exert a greater

1 influence on the water quality. Therefore, the alternating drought and flood stage is the most
2 important one that affects the surface water quality of a basin.

3 **2.2 Impact of drought on the transformation process of pollution**

4 The contaminants finish their process of transfer and transformation in atmosphere-soil-water
5 through water cycle. The impact of drought on the migration and transformation of
6 contaminants in various mediums are as follows:

7 (1) Atmosphere

8 During the drought, temperatures rise and evaporation amount increases. As a result, there is
9 an increase of pollutants that enter the atmosphere through evaporation, while pollutants that
10 return to the water and soil through precipitation drop. When it rains for the first time after
11 the drought, the pollutants in the air will fall onto the earth's surface, resulting in an increase
12 of them in the runoffs.

13 (2) Soil

14 The main transformation process of contaminants in the soil consists of absorption,
15 desorption, diffusion, evaporation and degradation. Drought exerts an impact on the soil
16 moisture, solute transfer and temperature, which alters the transfer law of the pollutants in the
17 soil. The temperature of soil affects the edaphon and enzymatic activity, the speed of soil
18 reaction and the rate of soil respiration. A rise in the temperature promotes the decomposition
19 of organic contaminants in the soil. If there is less soil moisture, there will be more organic
20 contaminants that are absorbed into the soil particles and reside in the soil in the solid form.
21 Whenever it rains after a drought, the organic contaminants that have accumulated for a long
22 time during the drought will migrate with the runoffs.

23 (3) Water

24 On account of a shortage of precipitation and runoffs during the drought period, pollutants
25 accumulate in the soil and the earth's surface. When it rains, the pollutants flow into the river
26 channels in the wake of surface and subsurface runoffs. Along with the the waterflow, the
27 pollutants in the river channels lessen the density of the pollutants through physical, chemical
28 and biological actions, as well as their own dispersion, attenuation and transformation. When
29 there is a drought, there will be a decrease in the discharge of water in the river channels, a
30 gradual worsening of the hydrodynamic condition, a reduction in the velocity, a deposition of

1 sediments and contaminants, as well as an increase of resident time of the pollutants in the
2 water body. All these will lead to the reduction of water quality.

3 **2.3 Impact of drought on the channel pollutants and surface water quality**

4 During the drought, a decrease in the channel flow and velocity as well as the capacity of
5 diluting and transferring is common. At the same time, the increase of the density of nutrition
6 elements (i.e. nitrogen, phosphorus, etc.), the weakening of the hydrodynamic conditions and
7 the extension of the dwell time will provide sufficient nutrition for algae's rapid
8 multiplication, leading to an aggravation of eutrophication, a disorder of the aquatic
9 ecosystem, a reduction of the living species and a damage to the diversity of organisms. A
10 large quantity of sediments and pollutants are accumulated in the bottom of the river, which
11 breaks the balance of the deposition and suspension of the downriver sediments and increases
12 the oxygen consumption of suspended particles and pollutants, leading to a decrease in the
13 pollutant carrying capacity and an increase in the density of pollutants.

14 The decomposition of the organics by microorganisms consumes the dissolved oxygen in the
15 water. As a result, with the level of the dissolved oxygen decreasing, toxic materials enter the
16 aquatic organisms, resulting in their deaths. Therefore, more dissolved oxygen is needed to
17 decompose their bodies. The entry of nutrients into the water body causes the algae and other
18 plankton to multiply rapidly. They gradually take up the surface of the water and consume a
19 great amount of dissolved oxygen. When the dissolved oxygen in water is used up, the
20 organisms begin their anaerobic decomposition, which produces some unpleasant gases such
21 as hydrogen, mercaptan, etc., and deteriorate the water quality.

22 A rise in temperature during the drought, at first, affects the physical and chemical property of
23 the water bodies, for example, the solubility of a gas, the speed of chemical and biochemical
24 reaction, and the impacts of water temperature on the activities of microorganisms. Secondly,
25 it affects the inner process of the water body; for instance, the process of diffusion,
26 mineralization and vertical mixing changes the temperature between the metalimnion and the
27 stratosphere, which can easily generate the stratification of the water body. It also speeds up
28 the oxic reaction, leading to the decrease of the dissolved oxygen. The levels of ammonia
29 nitrogen, nitrite and phosphate rise, while there is a drop in nitrates. Besides, it reactivates the
30 toxic organisms, which will cause extra pollution to the water body. Finally, it makes the

1 algae multiply rapidly, which in turn will destroy the ecological balance of water and cause
2 the water eutrophication.

3 **3 Experimental materials and designs**

4 **3.1 Design of drought scenario**

5 By employing the indoor orthogonality experiments, serving the drought severity, rainfall
6 intensity and rainfall duration as the main factors, the study examines the impact of various
7 factors on the nitrogen loss in soil, as well as the loss of non-point source pollution and the
8 leaching rate of nitrogen under the different alternating scenarios of drought and flood.

9 The soil was collected by no bottom stainless steel box (50*40*20cm) at Daxing
10 Experimental Base in 2011. The soil used for experiment was taken from the surface of corn
11 experimental field at Daxing Experimental Base. Every soil sample was collected in 100
12 acres. Every soil sample was collected about 9 to 20 points. The collection depth of the
13 sample was about 20 cm. In the sample collection, it must take by random, equal quantity and
14 mixed by multiple points principles. The sample collected by S and X line. The field not
15 fertilized recently. It's a sunny day that we collected the sample. Table 4 showed the soil
16 basic physical and chemical properties.

17 The leakage water was collected by the steel plate water collector under the experiment
18 device, and collected until no more water was flowed from the soil sample.

19 In order to keep the actual drought process of the soil in the study area, the soil sample
20 collected from the field was put into the incubator (LHS-250SC). The temperature of the
21 incubator was kept at 26.9°C(mean monthly maximum temperature in Daxing Region,
22 Beijing) and the humidity was kept at 69% (mean yearly relative humidity in Daxing Region,
23 Beijing). The temperature of the soil and rainfall water held constant in 26.9°C.The relative
24 soil moisture (W) was served as the criterion to appraise the soil drought severity (see Table
25 1). The soil moisture content was monitored continuously, and the soil in the light of the four
26 drought scenarios (i.e. mild, moderate, severe and extraordinary) was cultivated respectively.
27 We simulate different soil moisture by different rainfall duration or no rainfall time. The Tab.
28 1 was designed by standard of classification for drought severity in China (SL424-2008). The
29 date in the research came from the experiment. The pre-treatment of the date used by Excel,
30 and then plotted the date by Origin8.0.

1 The calculating formula of the relative soil moisture (W)—see equation 1.

$$2 \quad W = \theta / F_c \times 100\% . \quad (1)$$

3 θ —average weight water content of soil (%)

4 F_c —field moisture capacity of soil (%)

5 Table 1 Drought degrees of the relative soil moisture

Degree	Mild	Moderate	Severe	Extraordinary
Relative soil moisture W	$50 < W \leq 60$	$40 < W \leq 50$	$30 < W \leq 40$	$W \leq 30$

6 3.2 Design of rainfall scenario

7 The soil of the previous four drought scenarios was watered and dealt with simulated rainfall.

8 The alternating scenario of drought and flood was simulated in order to find out how rainfall

9 duration affects the nutrients contents in soil of the different drought degrees (see Table 2).

10 Through designing different kinds of rainfall intensity, we simulated how the different kinds

11 of rainfall intensity led to the nitrogen loss of the drought soil and the soil belonging to

12 different drought severity by the same rainfall intensity (see Table 3). The leakage water from

13 the lateral side of the soil sample was collected after the rainfall, and then it was tested, along

14 with the content of the ammonia nitrogen and nitrate nitrogen.

15 Table 2 Simulation test of rainfall duration

Rainfall duration	0.5h	1h	2h	4h	8h
Drought degree					
Mild	D ₁₁	D ₁₂	D ₁₃	D ₁₄	D ₁₅
Moderate	D ₂₁	D ₂₂	D ₂₃	D ₂₄	D ₂₅
Severe	D ₃₁	D ₃₂	D ₃₃	D ₃₄	D ₃₅
extraordinary	D ₄₁	D ₄₂	D ₄₃	D ₄₄	D ₄₅

16 Table 3 Simulation test of rainfall intensity

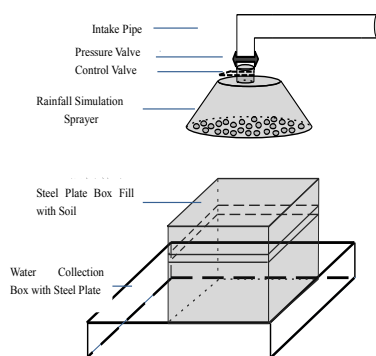
Rainfall duration	Mild	Moderate	Severe	Extraordina ry
Drought degree				
2mm/min	P ₁₁	P ₁₂	P ₁₃	P ₁₄
2.5mm/min	P ₂₁	P ₂₂	P ₂₃	P ₂₄

1 3.3 Experimental materials and equipment

2 The experiment was carried out at Daxing Experimental Base (China Institute of Water
3 Resources and Hydropower Research) in Beijing. The surface soil used for testing was taken
4 from the maize planting area at Daxing Experimental Base. The soil type was fluvo-aquic
5 soil. See Table 4 for its basic physical and chemical properties. See Figure 1 for rainfall
6 simulator. The water speed and volume are controlled by a control valve, while the outfall
7 intensity of the sprinkler used for rainfall simulation was controlled by a pressure valve. The
8 rainfall simulator can simulate a heavier rainfall at a relatively authentic level.

9 Table 4 Basic soil property

Soil type	Unit weight (g/c m ³)	Total porosity (%)	pH	Organic matter (g/kg)	Soil capacity (%)
fluvo-aquic	1.40	50.3	8.00	11.05	23.6



10 (a)

11 (b)

12 Figure 1 Experimental equipments

13 3.4 Calculation of the leaching rate of nitrogen and pollution-yield rate

14 At the beginning of the rainfalls, the surface soil moisture reaches its saturation rapidly as a
15 result of plant interception and soil infiltration. The transfer of nitrogen is an associated
16 process of water cycle. The experiment simulates the generation of runoffs under the different
17 alternating scenarios of drought and flood, and calculates the leaching rate (LR) of nitrogen
18 and pollution-yield rate (PR). See Formulas 2 and 3 for the calculating methods.

$$1 \quad LR = \frac{N_w}{N_s} \quad (2)$$

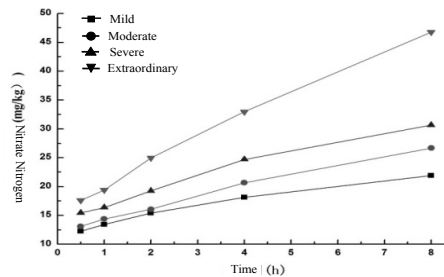
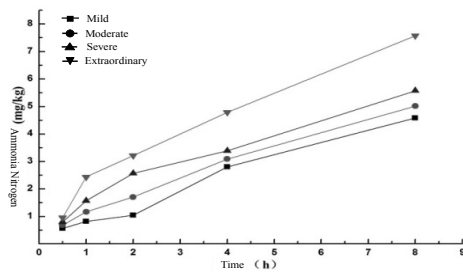
$$2 \quad PR = \frac{N_w}{N_L} \quad (3)$$

3 N_w — content of NO₃-N and NH₄-N in leakage liquid

4 N_s — content of NO₃-N and NH₄-N in soil before the rainfall

5 N_L — loss of NO₃-N and NH₄-N in soil after the rainfall

6 3.5 Results and discussions



7

(a)

(b)

9 Figure 2 Impact of rainfall duration on the [ammonia nitrogen](#) and nitrate nitrogen loss in soil

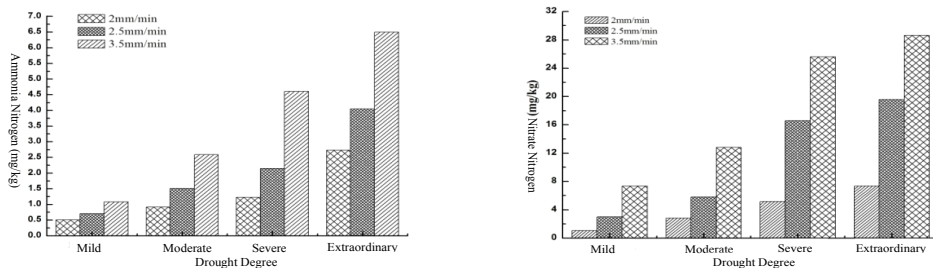
10 The impact of rainfall duration on the nitrogen loss in the soil is shown in Figure 2. As is
 11 shown in the figure, when the soil moisture contents are identical, in other words, when the
 12 drought degrees are identical, the longer the rainfall duration is, the more ammonia nitrogen
 13 and nitrate nitrogen loss in the soil will be. When the rainfall durations are the same, the
 14 higher drought degree leads to greater loss of ammonia nitrogen and nitrate nitrogen.
 15 Compared with ammonia nitrogen, nitrate nitrogen is more significantly affected by the
 16 rainfall duration.

17 The experiment shows that droughts aggravate the loss of ammonia nitrogen in the surface
 18 soil. With the aggravation of the drought severity, an increased mineralization of nitrogen in
 19 the soil and a rise in the ammonia nitrogen content. Higher soil moisture content and better
 20 soil ventilation will enhance the microbiological activities, which reinforces the
 21 transformation from urea nitrogen to ammonium nitrogen. The formation of runoffs and
 22 partial infiltration of soil moisture are the two major ways that cause the loss of ammonia

1 nitrogen in the soil. The during-after rainfalls result in an increase of ammonia nitrogen loss
2 in surface water.

3 Rainfall duration worsens the loss of nitrate nitrogen existing in surface soil. Besides, as the
4 drought degree gears up, this impact increases. Nitrate nitrogen is the main residue of
5 fertilizer N that permeates the soil but is not absorbed by plants, and it moves along with the
6 water flow. To the soil of lower drought severity, its infiltration capacity is strong; therefore, a
7 large amount of nitrate nitrogen infiltrates into the deep subsoil in the wake of moisture(Cui,
8 2013). The soil of severe drought degree will become hardened and impervious. The heavy
9 runoff during the rainfall results in a mass loss of nitrate nitrogen in the field surface soil.

10 3.5.1 Impact of rainfall intensity on the nitrogen loss in the soil of 11 various drought degrees



12 (a)

13 (b)

14 Figure 3 Impact of rainfall intensity on the nitrogen loss in the soil

15 Impact of rainfall intensity on the leaching amount of agricultural non-point source pollution
16 is demonstrated in Figure 3. As is shown in Figure 3, when the soil moisture contents are
17 identical, if the rainfall intensity is greater, more ammonia nitrogen and nitrate nitrogen in the
18 soil will be lost. When the rainfall intensity is the same, the higher drought severity leads to
19 greater loss of ammonia nitrogen and nitrate nitrogen. Compared with ammonia nitrogen,
20 nitrate nitrogen is more significantly affected by the rainfall intensity.

21 The impact mechanism of rainfall intensity on the nitrogen loss in the soil is identical to the
22 one of rainfall duration. In addition, rainfalls of high intensity aggravate the infiltration of soil
23 moisture and the loss of ammonia nitrogen. The impact of raindrops desorb the nutrients that
24 absorb on the soil particle, resulting in a rise of the nutrient concentrations that enter the
25 runoffs. At the same time, raindrops disperse the soil particles and affect the soil infiltration
26 and the leaching of nitrate nitrogen (An, 2011).

1 **3.5.2 Leaching rate of nitrogen and pollution-yield rate under the**
 2 **alternating scenarios of drought and flood**

3 Ammonium nitrogen can be directly absorbed by plants and can be dissolved in water easily.
 4 It will be transformed into nitrate nitrogen in the soil of good ventilation, easily giving rise to
 5 nitrogen leaching and loss. In the alternating droughts and floods stage, nitrogen form in soil
 6 changes. The leaching and loss of nitrogen in soil not only generates nitrate pollution in
 7 underground water, but also results in the loss of nitrogen in the wake of surface runoffs,
 8 which causes the deterioration of surface water quality. The leaching rate of nitrogen under
 9 different alternating scenarios of drought and flood can be estimated by using indoor
 10 simulation data and Formula (2), see Table 5 and 6.

11 Table 5 Leaching rate of [ammonium nitrogen](#) under different alternating scenarios of drought
 12 and flood

Drought degree Rainfall intensity	Mild	Moderate	Severe	Extraordina ry
2mm/min	1.82%	2.16%	2.67%	3.22%
2.5mm/min	1.93%	2.31%	3.12%	3.60%
3.5mm/min	2.38%	3.19%	3.73%	4.15%

13 Table 6 Leaching rate of nitrate nitrogen under different alternating scenarios of drought and
 14 flood

Drought degree Rainfall intensity	Mild	Moderate	Severe	Extraordina ry
2mm/min	19.68%	23.54%	27.45%	31.84%
2.5mm/min	22.30%	26.86%	33.00%	36.25%
3.5mm/min	28.19%	31.18%	36.09%	42.13%

15 Due to the excessive use of fertilizers, a great amount of nitrogenous fertilizer remains in the
 16 soil (Zhu, 2008). Evaporation leads to a rise in nitrogen in the wake of moisture, and it piles
 17 up gradually in the surface soil (Zhang, 2010). With a high temperature condition, enzymatic
 18 activity enhances, which promotes the nitrification. An increase in nitrates intensifies nitrogen
 19 leaching. The pollution-yield rate under different alternating scenarios of drought and flood
 20 can be estimated by using Formula (2), see Table 7 and 8.

1 Table 7 Leaching rate of [ammonium nitrogen](#) under different alternating scenarios of drought
 2 and flood

Drought degree	Mild	Moderate	Severe	Extraordina ry
Rainfall intensity				
2mm/min	4.16%	4.97%	6.06%	6.92%
2.5mm/min	4.67%	5.66%	6.06%	6.63%
3.5mm/min	4.96%	6.28%	7.38%	9.01%

3

4 Table 8 Pollution-yield rate of nitrate nitrogen under different alternating scenarios of drought
 5 and flood

Drought degree	Mild	Moderate	Severe	Extraordina ry
Rainfall intensity				
2mm/min	52.07%	57.03%	62.46%	68.21%
2.5mm/min	53.72%	60.12%	65.88%	69.81%
3.5mm/min	58.65%	64.83%	70.71%	76.40%

6 As is shown in Tables 5-8, the leaching rate and pollution-yield rate of ammonium nitrogen
 7 and nitrate nitrogen are negatively correlated with soil moisture content, while positively
 8 correlated with rainfall intensity. Under the scenario of extraordinary drought-rainfall
 9 (3.5mm/min), the leaching rate and pollution-yield rate of ammonium nitrogen and nitrate
 10 nitrogen reach the highest point, which denotes that drought and extreme rainfall not only
 11 aggravate the nitrogen loss in soil, but also boost the nitrogen content in surface runoffs,
 12 resulting in increasing impacts of non-point source pollution on surface water quality.

13 Compared with ammonium nitrogen, nitrate nitrogen has a higher rate of leaching and
 14 pollution yield and is more significantly affected by droughts and rainfalls. With an increase
 15 in rainfall intensity, there will be an increase both in the leaching rate and pollution-yield rate
 16 of ammonium nitrogen and nitrate nitrogen in the soil of various drought degrees. It proves
 17 that, to some extent, rainfall intensity affects nitrogen leaching, and nitrate nitrogen loses
 18 mainly in the way of surface runoffs under the scenario of extraordinary drought-rainfall
 19 (3.5mm/min).

20

1 4 Assessment of the impact of basin scale

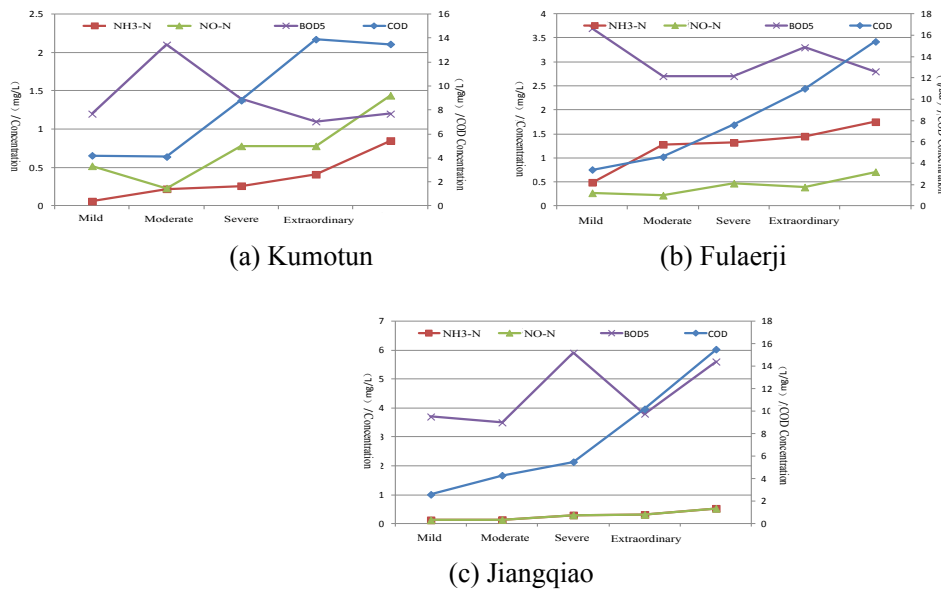
2 For the purpose of verifying the impact of droughts of different severity levels and the after-
 3 drought rainfall on the surface water quality of the basin, this section of the paper analyzes the
 4 water quality data of different periods from the embankments of Kumotun, Fulaerji and
 5 Jiangqiao in Nenjiang Basin. The monitoring data of water quality in this paper are taken
 6 from *Monitoring Results of Environmental Quality of Surface Water in Heilongjiang*
 7 *Province, Monitoring Results of Environmental Quality of Surface Water in Jilin Province*
 8 and *Monitoring Results of Environmental Quality of Surface Water in Neimenggu Province*
 9 from 2000 to 2006. The continuous days of effective rainfall free (Dry spell) is used as one of
 10 the indicators of drought during the crop growth period (Chen, 2010), see Table 8. The changes
 11 of different water quality indexes of various drought degrees during the drought period and of
 12 the first rainfall after the drought in Nenjiang Basin during the summers (June to August) of
 13 2000-2006 are analyzed. The features of water quality change under the different alternating
 14 scenarios of drought and flood are identified, see Figure 4.

15 As is shown in Figure 4, there presents an upward trend in the density of COD, [ammonium](#)
 16 [nitrogen](#) and nitrate nitrogen in Kumotun, Fulaerji and Jiangqiao when the drought degrees
 17 increase, while there is no significant change in BOD₅. The overall water quality becomes
 18 worse. The significance of growth trend is varied too. The growth trend of COD density is
 19 significant, and the growth rate is most conspicuous when the drought severity increases from
 20 the severe level to extraordinary one. Theoretically, higher temperature will enhance the self-
 21 purification of BOD₅. Meanwhile, due to the reduction of runoff during drought, they offset
 22 each other. The density variation of BOD₅ is not significant. During the drought, point source
 23 pollution dominates, and the density of COD is significantly higher than that of [ammonium](#)
 24 [nitrogen](#). Therefore, as the drought severity deepens, density of COD, [ammonium nitrogen](#)
 25 and nitrate nitrogen increases at the same time; it constitutes a more serious impact on COD.
 26 The impact of BOD₅ on drought is not significant. Water quality deteriorates.

27 Table 9 Number of continuous days of effective rainfall free during crop growth period

Drought		Mild	Moderate	Severe	Extraordinary
Days of rainfall free	Spring(Mar.-May);Autumn (Sep.-Nov.)	15~30	31~50	51~75	>75
	Summer (June-Aug)	10~20	21~35	36~50	>50

1 Effective rainfall free refers to daily precipitation amount in Spring and Autumn<3mm; daily precipitation amount in
 2 summer<5mm.



5
6
7 Figure 4 Changes of water quality under various drought degrees and of the first rainfall
 8 after the drought in Nenjiang Basin in 2000-2006

9 As can be seen from Figure 4, when it rains after a drought that lasts for a period of time,
 10 there is a more significant increase in the density of COD, ammonium nitrogen and nitrate
 11 nitrogen in Kumotun, Fulaerji and Jiangqiao than it is during the dry spell. There is the most
 12 significant increase in density of COD, ammonium nitrogen and nitrate nitrogen resulted from
 13 the rainfall after a drought, while the change of BOD5 of the three embankments is not
 14 significant. After the rainfall, water resources increase to some extent. The majority of
 15 pollutants that accumulate on the surface, mainly non-point sources pollution (the main
 16 reason of ammonium nitrogen change), enter the surface water in the wake of runoff because
 17 of rain wash and soil erosion. Due to the supplements of rainfalls, underground water levels
 18 rise. The underground water flows into the surface water along with river runoff, resulting in
 19 an increase of pollutants in the water. A rainfall after a drought leads to an increase in water
 20 resources as well as an increase in the number of pollutants in the water. The rapid growth of
 21 pollutants result in a water quality deterioration in the surface water in a short time, and the
 22 water ecological environment worsens.

23 In the light of the case analysis of Nenjiang river basin, it can be concluded that: the higher
 24 the drought degree, the worse the surface quality of a basin will be; the main source that
 25 affects the water quality during the drought is point source pollution; the first rainfall after a

1 drought is the key factor that gives rise to the change of water quality in the surface water of a
2 basin and exerts a greater impact on water quality; meanwhile, non-point pollution is the main
3 source. The case of Nenjiang river basin proves this theoretical analysis.

4

5 **5 Conclusions and Prospects**

6 Taking climate change and human activity as the background, this paper identifies the
7 mechanisms of pollutants' generation, transfer and transformation in the circulation process of
8 dualistic water cycle, as well as the main factors that affect the water quality of the river basin
9 during the drought. The main findings are as follows:

10 Firstly, climate change and human activity are at present the main causes that give rise to the
11 deterioration of water environment in the basin area during the dry period; however, the key
12 factors that determine the water quality are a decrease in the river discharge, a rise in the
13 temperature and runoff scouring toward non-point source pollutants during the rapid
14 alternating period of drought and flood.

15 Secondly, with the aggravation of drought, the density of ammonia nitrogen, COD and
16 nitrates in water will increase. A rise in temperature will enhance the self-purification
17 capacity of BOD5 in water, but there is no significant change in BOD5 density due to the
18 reduction of discharge during drought.

19 Finally, drought severity, rainfall duration and intensity are the three main factors that play a
20 role in the loss of non-point source pollution. When the rainfall duration is identical to the
21 rainfall intensity, there will be an increase in drought severity as well as an increasing loss of
22 non-point source pollution. When the drought degrees are at the same level, rainfall duration
23 and intensity will enhance the loss of non-point source pollution. Under the alternating
24 scenarios of droughts and floods, there will be a greater loss of ammonia and nitrate nitrogen
25 in soil. Under the combining scenario of extraordinary drought-rainfall 3.5mm/min, the loss
26 of non-point source pollution is the most serious and the pollution rate reaches at 76.4%.

27 With a setting of climate change and human activity, the impact of drought on water
28 environment is a complicated process. Therefore, it is quite urgent to develop some
29 simulation models of water environment systems, come up with some scientific assessment
30 methods used to assesses the impact of drought on water environment quantitatively, and do
31 research on the emergency management and comprehensive measures toward the extreme

- 1 hydrological events on the basis of the analysis and forecast of the impact of drought on water
- 2 environments.

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