SD simulation study on degraded farmland policy on farming-
pastoral area under the constrains of water resources--Taking
Tongliao City of Inner Mongolia as example

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Abstract. Water resources are the primary factor in restricting the sustainable development of
farming-pastoral regions. To support the sustainable development of water resources, whether
or not the land uses patterns of farming-pastoral areas is a reasonably important issue. This
paper takes Tongliao city as example for the purpose of sustainably developing the farming-
pastoral area in the north. Several scientific preductions and evaluations were conducted to
study the farming-pastoral landuse pattern, which is the key problem that effects sustainable
development of farming-pastoral areas. The paper then proposes that 1:7 landuse pattern is
suitable for the sustainable development of farming-pastotal area. Based on the analysis of the
research findings on sustainable development of farming-pastoral area, the paper established a
suitability evaluation indicators system of degraded farmland policies in Tongliao city, and
used an Analytical Hierarchy Process (AHP) method to determine the weight to run system
dynamic (SD) model. The simulation results were then obtained on social economic ecological
development in Tongliao city under different degraded farmland policies, and used the
comprehensive evaluation model to optimize the results. It is concluded that stabilizing the
policy of degraded farmland policy is the preferential policy in Tongliao, which provides
useful theoretical research for the sustainable development of farming-pastoral area.

1. Introduction
The northern farming-pastoral area is the typical ecological fragile area, which is the crucial ecological
safety barrier in China [1]. Since the 1980s, the developing model of irrigated agriculture being the
leading industry made the regional landuse pattern turn to an unsustainable state, resulting in a series
of problems, such as an imbalance in development of agriculture and husbandry, depletion of surface
water, decline of groundwater level, and serious desertification. On the one hand, the imbalanced
farming and pastoral landuse ratio led to the waste of too much water resources (average of 75%) in
low productive irrigating production sectors, restraining the development of secondary and tertiary
industry. On the other hand, the regional ecological environment was seriously damaged [2]. In this
case, it becomes promoting regional sustainable development that retionally determines the landuse
proportion of farming-pastoral and husbandry areas become the important scientific issue, as well as the water resources allocation in all sectors of social economy.

The sustainable development of farming-pastoral area is the current hot topic, and some scholars hold research on the relationship between the vulnerability of farming-pastoral area and its sustainable development. Hu Binghui et al [3] state that there is a close relationship between ecological vulnerability and social construction of sustainable development. Xu Erqi et al [4] think that over exploration on agriculture is the root of ecological degradation on farming-pastoral area. Wang Xiuhong et al [5] believe ecological restoration is the most effective way to enhance sustainability, and the primary factor effecting sustainable development of farming-pastoral area is resource capability. Zhang Juntao et al [6] think water resources and environmental conditions are the key factors effecting regional sustainable development. Long Yinhui et al [7] believe that strength of water resource capability is the important factor of ecosystem sustainable development in grassland area, and the suitable use of land resource is another key factor to control the sustainable development of farming-pastoral area. Qi Yuepu [8] and Jin Xin et al [9] research the rural sustainable development and the strength and potential of farmland use. Ma Jiwei et al [10] studied the complex adaptive configuration model of soil and water resources. Zheng Jiuyu et al [11] constructed the matching calculation model on agricultural water and land resources, and evaluated the matching degree on agricultural water and land resources in Hetao irrigation area.

Many research results show the importance of the sustainable development of farming-pastoral area. Furthermore, the harmonization development in farming-pastoral area relates to the ecological safety and economic development in local and large parts of the country. The comprehensive study discovered that farming-pastoral landuse pattern is rarely involved in present studies. Therefore, this paper uses Tongliao city as the typical farming-pastoral area to study sustainable developing pattern under different farming-pastoral areas, and uses system dynamics to simulate the effect of the policy, which is degraded farmland to grassland. The paper provides theoretical and practice research on enhancing the sustainable developing capability in Tongliao and larger farming-pastoral areas.

2. Research Region
The farming-pastoral regions in northern China mainly spread in the southern edge of Inner Mongolia plateau and the area along the Great Wall that has an annual rainfall of around 200~400 mm and degreeness of 1~2. It is the ecological barrier connecting the east and west region of China. Table 1 shows that the urbanization level, industrial structure, industry growth rate, water use efficiency, and the proportion of ecological water use in Tongliao are similar to those in the northern region of farming-pastoral area. Tongliao city can be used as a typical representative of the northern farming-pastoral region. It is worth mentioning that the proportion of the primary industry output in the

| Table 1. Comparison table of social and economic development between Tongliao and Northern Agro-pastoral transitional zone. |
|---|---|---|---|---|---|
| region | urbanization | Capita GDP | Industry structure | Proportion of agriculture water | Agriculture water-use efficiency | Total water-use efficiency | Proportion of ecological water |
| (%) | (10^4yuan/p ) | ——— | (%) | (yuan/m^3) | (yuan/m^3) | (yuan/m^3) |
| The northern farming-pastoral area | 38 | 5.7 | 14:58:28 | 85 | 10.8 | 63.4 | 36 |
| Tongliao City | 39 | 2.54 | 13:59:28 | 76 | 9.8 | 67.5 | 32 |
industrial structure of Tongliao and Northern China farming pastoral region is greater than 10%. According to Chenery’s theory of standard industrial structure, which means that the primary industry occupy a more important position, the farming and animal husbandry is the main part of the northern farming-pastoral areas. Therefore, it is very important to study the structure of the proportion of agriculture and animal husbandry in the primary industry in the northern farming-pastoral areas.

Tongliao city is located in the eastern part of Inner Mongolia 43°22'~43°58'N 121°42'~123°02'E. The average rainfall is 350~400 mm and the evaporation is about five times the rainfall. In recent years, the Liaohe River, Xinkai River, and Jiaolai River in Tongliao dried up throughout the year due to the arid climate and human development; more than 70 small water reservoirs died, and local underground water level declined, resulting in a lack of water.

Water shortage, the imbalance of water use structure, low water use efficiency, and deterioration of water environment are found to be the important factors restricting the sustainable development of Tongliao. The reason lies in the unbalanced development of agriculture and animal husbandry in Tongliao. The long-term excessive development of agriculture led to the high ratio of farmland. In 2014 the ratio of farmland and grazing grassland is 1:1.4, which is much higher than the water resources carrying capability in farming-pastoral areas, resulting in agricultural irrigation water reaching 85% of the total use of water in Tongliao city, and the output being only 8%. With no more than 15% of usable water resources left, it is hard to allocate into other production departments and urban rural sectors. The way of this inefficient and imbalanced water resources allocation is dangerous for the social economic sustainable development in Tongliao city. Comprehensive analysis shows that the water resources exploration is close to the limit, but the social economic developing status is still on a lower level. Regional water resources will exhaust fast if the maintenance of present farming-pastoral development status is continued, leading irreversible ecological disaster. Therefore, it is crucial to implement the policy of degraded farmland to grassland and only improve the situation of use water resources. It is also necessary to study the suitable ratio of farmland and pastoral land.

3. Evaluation on farming and pastoral landuse pattern
The primary industry in farming-pastoral areas plays an important role on the development of society and economy. This tuition is quite typical in Tongliao city. The primary industrial sectors in Tongliao city mainly consist of agriculture and animal husbandry, and the forestry and fisheries only account for 4%. Because agriculture has higher efficiency than husbandry, a large-scale land reclamation began in Tongliao city since the 1980s, resulting in a drastic shrinkage in husbandry and prosperous agriculture. However, contrary to rain-rise husbandry, agriculture needs many water resources, which is the short board in farming-pastoral areas. Through the comprehensive study and interpretation of remote sensing data and long-term observation of underground water data, in the 20 years since 1995, the agriculture land increased 35% and the husbandry land decreased 28% in Tongliao city. At present the surface water resources nearly dried up and the water resources are all from under the ground; the underground water level declines 0.1m each year. It declined from 3.5 m to 5.5 m in the Horqin area, which formed an underground funnel that was 2- meters deep. With the decline of the underground water level, a series of ecological problems followed as the lakes and wetlands disappeared, rivers cutoff, lands deserted, and biodiversity diminished. The development of water and soil resources in this uncontrolled farming and grazing system poses a great threat to the sustainable development of Tongliao's economy and society.

Based on the comprehensive study on the northern farming-pastoral areas and investigation of Tongliao city, the paper constructed different evaluation tables of agriculture and husbandry developing patterns (table 2). Through interpretation of remote sensing data, the investigation shows that the ratio of agriculture and husbandry lands in Tongliao city is 1:1.4. According to the 60% irrigation rate and average water amount, agriculture irrigation water is about 42.81×10⁸ m³, accounting for 85% of total water consumption at 50.36×10⁸ m³. According to “the most stringent water resources administration of water resources department in Inner Mongolia”, the average annual available water resources is only 31.54×10⁸ m³, and use of the high water will lead to the overdraft of
59.67% underground water; long-term persistence will lead to ecological disaster. If maintaining the development of promoting agriculture and degraded husbandry, there may be a 1:1 ratio of agriculture and husbandry lands. Although the increased farmlands are slope or barren lands, the popularity of irrigation rate will be reduced to 50%, its total annual water demands will still reach 52.88×10^8 m^3, and the overdraft rate will reach 67.66%. This is the dangerous state of comprehensive development of economy society ecology. To seriously prevent the ecological disasters, it should be strictly controlled on the aspect of the continued expansion of farmland. In the sense of possible ecological disasters, the suitable and reliable ratio of agriculture and husbandry lands is 1:3, which reduced the scale of agriculture development and increased husbandry landusing. Although the degraded farmlands are mainly the low-yielding fields whose irrigating technology is hard to cover, total irrigation rate increased to 60%, the irrigation technology would improve, and the water consumption would greatly reduce to about 28.47×10^8 m^3.

Using the situation to comprehensively consider the domestic and foreign farming-pastoral areas’ agriculture water, the proportion of agriculture irrigation water will reduce to 80%, and the total assumption of water will be 35.58×10^8 m^3. At this time, at a groundwater overdraft rate of 12.82%, it still in the long-term overdrafted situation and is not safe. Considering it is still in an insecure state, keep degraded farmland scale, and reduce the ratio of agriculture and husbandry lands to 1:5, and the overdrafted rate of underground water is -13.14%; the underground water would get a better supplementary. Long-term maintainance would make the economic, social, and ecological development a much safer situation. It is the sustainable situation that the proportion of landuse for agriculture and husbandry is 1:7, and the overdrafted rate is -25.84%. It is ideal, but hard to realize that the proportion of landuse for agriculture and husbandry is 1:9 and the overdrafted rate is -33.18.

### Table 2. State evaluation table of development pattern of different agriculture and husbandry in Tongliao.

| Ratio of agriculture and husbandry | Farmland area 1×10^4 km^2 | Agriculture irrigation rate | Irrigation water demands 1×10^8 m^3 | Total water demands 1×10^8 m^3 | Annual water resources available 1×10^8 m^3/a | Groundwater overdraft rate % | State evaluation |
|-----------------------------------|---------------------------|----------------------------|---------------------------------|---------------------------------|----------------------------------|-------------------------------|------------------|
| 1:1                               | 2.14                      | 50                        | 44.95                           | 52.88                           | 31.54                            | 67.66                         | Super dangerous   |
| 1:1.4                             | 1.78                      | 60                        | 42.81                           | 50.36                           | 31.54                            | 59.67                         | Present state     |
| 1:3                               | 1.07                      | 70                        | 28.47                           | 35.58                           | 31.54                            | 12.82                         | Unsafe state      |
| 1:5                               | 0.71                      | 80                        | 20.55                           | 27.40                           | 31.54                            | -13.14                        | Safe state        |
| 1:7                               | 0.54                      | 90                        | 16.37                           | 23.39                           | 31.54                            | -25.84                        | Sustainable state |
| 1:9                               | 0.43                      | 100                       | 13.7                            | 21.07                           | 31.54                            | -33.18                        | Ideal state       |

### 4. System dynamics simulation

#### 4.1. System dynamics method
Contrasting with other methods, the system dynamics method has time-varing, nonlinear and multiple feedback characteristics, such as analytic hierarchy process [12] information entropy [13] and principle component analysis [14]. It has its own advantage [15] when dealing with the problem of complex and dynamic social economic ecological sustainable development. This paper takes water resource as an important prerequisite to constrain Tongliao’s sustainable development. Based on the present farming-pastoral landuse pattern, the simulation model of system dynamics was established to carry on the simulation study of “degraded farmland to grassland” strategy. The evaluating process of
farming-pastoral landuse pattern was searched in order to provide useful theoretical exploration of the sustainable development of farming-pastoral areas in northern China.

4.2. System dynamics simulation

This paper uses Vensim as a simulation platform to establish a system dynamics model of the sustainable development in Tongliao city with regional, dynamic, and limited characteristics, which include social development subsystem, economic development subsystem, water resources support subsystem, ecological environmental subsystem, and so on. Figure 1 describes the structure of the system dynamics model in detail.

It took Tongliao city around 30 years to change from being advantaged in husbandry production to agricultural production. During this period, uncontrolled development of agriculture industry made an accumulated destruction on Tongliao’s ecological environment. This situation could not be reversed in one day; long-term strategies are needed to reach a sustainable situation in Tongliao city. The fast or slow implementation of degraded farmland has different degrees of impact on Tongliao’s economy development due to its fragile ecology, and the normal prerequisite is to take “emergency degraded farmland policy”, “stable degraded farmland policy”, and “relieve degraded farmland policy”. In this paper, the definition of “emergency degraded farmland policy” refers to reaching a 1:7 ratio of agriculture and husbandry lands by 2030, and “stable degraded farmland policy” and “relieve degraded farmland policy” refers to reaching a 1:7 ratio by 2040 and 2050. This model has the ability to consider the ecological protection in operation processes, as well as economic development by allocating the water saved by degrading farmland to the secondary and tertiary industry sectors to ensure regional ecological protection and smooth development of the economy. In order to provide useful theoretical reference for the development of farming-pastoral policies in Tongliao city, this paper uses system dynamics to simulate the social economic ecological developing situations under three types of policies, to enrich the sustainable development theory of northern farming-pastoral areas.

4.3. Simulation results and scheme optimization

4.3.1. Simulation resutes. By running the system dynamics model from 2013 to 2050, we obtained the different simulation results separately under fast and slow policies in Tongliao city. Table 3 shows the typical index simulation results, such as rate of urbanization, total GDP, industrial structure, capita GDP, water demands, groundwater overdraft rate, comprehensive water efficiency, intensity of conversion to grassland, and so on during key years.
Table 3. Dynamic simulation results of different policies of degraded farmland of Tongliao city.

| degraded farmland policy | indicator        | 2020         | 2030         | 2040         | 2050         |
|--------------------------|-----------------|--------------|--------------|--------------|--------------|
| Emergency                | Urbanization %  | 54.73        | 74.80        | 77.85        | 80.77        |
| Stable                   |                 | 50.35        | 64.91        | 77.85        | 80.77        |
| Relieve                  |                 | 48.33        | 60.36        | 71.23        | 80.77        |
| Emergency                | Industrial structure | 18:54:28    | 16:52:32     | 10:51:39     | 7:50:43      |
| Stable                   |                 | 18:54:28     | 20:51:29     | 13:52:35     | 7:52:41      |
| Relieve                  |                 | 18:54:28     | 20:51:29     | 20:50:30     | 10:52:38     |
| Emergency                | Total water demands $1 \times 10^8$ m$^3$ | 40.6         | 29.0         | 31.2         | 31.5         |
| Stable                   |                 | 44.0         | 36.0         | 28.2         | 30.8         |
| Relieve                  |                 | 45.5         | 39.7         | 30.8         | 27.6         |
| Emergency                | Wateruse efficiency $\text{yuan/m}^3$ | 54.27        | 125.21       | 257.02       | 457.1        |
| Stable                   |                 | 49.29        | 81.88        | 204.49       | 437.8        |
| Relieve                  |                 | 47.23        | 71.86        | 126.42       | 359.7        |
| Emergency                | GDP $1 \times 10^8$ yuan | 2202.88     | 3627.94      | 8017.23      | 14392.5      |
| Stable                   |                 | 2167.86      | 2950.64      | 5762.85      | 13496.1      |
| Relieve                  |                 | 2150.59      | 2853.17      | 3894.65      | 9923.43      |
| Emergency                | groundwater overdraft rate % | 28.29        | -7.84        | -0.15        | 1.43         |
| Stable                   |                 | 39.00        | 14.61        | -9.79        | -0.69        |
| Relieve                  |                 | 43.92        | 26.28        | -1.38        | -11.11       |
| Emergency                | Intensity of degraded farmland % | 5.78         | 13.69        | 13.69        | 13.69        |
| Stable                   |                 | 3.16         | 4.63         | 8.62         | 8.62         |
| Relieve                  |                 | 2.18         | 2.79         | 3.86         | 6.29         |

4.3.2. Evaluation method. Based on the obtainable possibility principle of the output results of the system dynamic model and the relationship of reason and result impact, the paper established the suitable evaluation index system of degraded farmland policy in Tongliao city. The system biases on the water resource’s support ability and farming-pastoral developing pattern, therefore, the primary indicators are urbanization rate, total GDP, industrial structure, capita GDP, water requirement, groundwater overdraft rate, comprehensive water efficiency, intensity of conversion to grassland, and so on, which are all listed in table 4. According to the impact mechanism of degraded farmland policy and some principles like the comprehensive and conclusive characteristics of index system, the system and hierarchy, dynamic and static, and paper divided the suitable evaluation indicators into the level of evaluation target, level of evaluation subsystem, and level of evaluation indicators by assigning the weight of each index using AHP. This specific method is referenced in [16].

Table 4. Suitable evaluation system of degraded farmland policy in Tongliao city.

| Evaluation target | Weight | Evaluation subsystem | Weight | Evaluation indicator | unit | Weight | direction |
|-------------------|--------|----------------------|--------|----------------------|------|--------|-----------|
| Suitability of degraded farmland policy | 1      | Social development subsystem | 0.0435 | urbanization | % | 0.0435 | +         |
|                   |        | Economic development subsystem | 0.2472 | GDP | 108 yuan | 0.0817 | +         |
|                   |        |                       |        | Industry | -- | 0.0724 | +         |
|                   |        |                       |        | Capita GDP | 104 yuan/person | 0.0931 | +         |
4.3.3. Scheme optimization. By the method in reference [16], this paper took comprehensive evaluation on system dynamics simulation results. As shown in table 5, the dynamic evaluation results were obtained from 2020-50 in Tongliao city.

**Table 5.** Comprehensive evaluation of 3 degraded farmland policies of Tongliao city 2020–2050.

| Degraded farmland policy | 2020     | 2025     | 2030     | 2035     | 2040     | 2045     | 2050     |
|--------------------------|----------|----------|----------|----------|----------|----------|----------|
| Emergency                | 0.47797  | 0.47797  | 0.48087  | 0.48350  | 0.37150  | 0.37185  | 0.37198  |
| Stable                   | 0.52825  | 0.54547  | 0.51472  | 0.54653  | 0.59408  | 0.63249  | 0.66055  |
| Relieve                  | 0.52203  | 0.52203  | 0.52203  | 0.50246  | 0.51462  | 0.62850  | 0.62589  |

The dynamic evaluation results show advantages and disadvantages under three policies of degraded farmland during 2015–2050: “emergency degraded farmland policy” is weaker than “stable degraded farmland policy”, which is weaker than “relieve degraded farmland policy”. The simulation result of emergency degraded farmland policy appeared best, but evaluated lowest, because Tongliao is located in northeast inland area of China and lags in economic development. It still has a middle stage of social economic development when using the Chenery standard industrial structure and industrialization stage theory, which means the industrial foundation is relatively weak, causing a large number of landless peasants and unemployed if the “strong and emergency degraded farmland policy” is used turning this period. The husbandry that has limit capacity could not involve large amounts of agricultural labor, and the urban development could not provide sufficient employment to absorb unemployed farmers, therefore causing a wide range of social contradictions. The “relieve degraded farmland policy” slowly reduced the ratio of agriculture and left enough time and space for Tongliao’s social economic development. It could also better absorb labors that came from the degraded farmland policy and better relieve the social contradictions. However, the simulation shows that the “relieve degraded farmland policy” has a long developing period, which leads to poor societal and economic performances in various indicators, resulting in a slightly weak comprehensive evaluation. The “stable degraded farmland policy” could absorb surplus agriculture labors better and also has a better societal and economic development performance, making it the ideal degraded farmland policy in future of Tongliao city.

5. Conclusion and discussion

- The present farming-pastoral developing pattern could not support the future sustainable development. According to the comprehensive evaluation, the farming-pastoral landuse pattern is between a safe and dangerous situation. If developing agriculture industry and expanding agriculture scales is continued, it will cause Tongliao city to have a dangerous
ecological safety status and will cause ecological disaster. Therefore, improving the landuse pattern of agriculture and husbandry has become Tongliao’s urgent task.

- The farming-pastoral pattern is the key factor impacting the sustainable development. The farming-pastoral pattern has great influence on Tongliao, which has a lack of water resource. The best way to realize Tongliao city’s sustainable development is to implement the degraded farmland to a grassland policy, reducing the ratio of agriculture land and forming the 1:7 ratio of agriculture and husbandry in order to reverse the situation that agriculture production consumes large amount of groundwater resources.

- Reasonable carrying out the degraded farmland policy is the key of sustainable development. We established a system dynamic model, imitated three different types of policies: “emergency degraded farmland policy”, “stable degraded farmland policy”, and “relieve degraded farmland policy”, and established a degraded farmland suitable evaluation indicator system. We then conducted a comprehensive evaluation based on the simulation results. The results show that “emergency degraded farmland policy” may obtain good results, but its intensity is great and easy to cause social contradiction, making it inappropriate to adopt. The “relieve degraded farmland policy” could sufficiently relieve social contradiction, but its effects are too slow to obtain the recognition, so it is the suboptimal selection. The “stable degraded farmland policy” could better resolve social problems and quickly develop social economy, so is the best choice.

- The paper enriched the theory and practice of sustainable development in the northern farming-pastoral areas, which Tongliao city is the representative of. By conducting simulation research on different degraded farmland policies, this paper obtained different proactive effects based on different degraded policies of sustainable development, provided good practice guidance for the implementation of the degraded farmland policy, and enriched the sustainable developing theory for farming-pastoral areas.

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