Impacts of environmental external driving forces on land-use changes of farm ponds in Taiwan

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Abstract. In Taiwan, the ponds which are mostly distributed on tablelands in the north areas are the special landscapes established for the water diversion and agricultural irrigation in the past. They provide beneficial functions to local environments and ecology under extreme climate. However, with the relocations of urban development centers, the urban expansions focusing on land developments leads the land-uses changes of ponds. Land uses are modes constructed by the interactions of manual activities and natural environmental factors, and the land-use changes are caused by the multiple interlacements of environmental external driving forces. Through the investigations of the external driving forces and the influence ways, the early analysis and to predictions of land-use changes will provide the references for environmental managements and plans. The contributions are more essential to Taoyuan areas with many ponds and rapid development especially. Based on the research achievements of coast environmental land-use changes, the research establishes the environmental external driving factor systems. Then it applies the DPSIR model to explore the land-use modes driving the changes of ponds, inducts the categories of land-use changes, and investigates the causality between them. Exploring how the ponds disappear and finding the factors will contribute to not only the environmental protection and ecological system maintenance, but also the adaption for climate change. The research results will provide the reference for land resource plans and developments by simulating the land-use changes of ponds.

1. Introduction

Early Taiwan was dominated by agriculture, and because Taoyuan was influenced by climate, topography, soil characteristics and erosion of rivers and lakes, farm ponds were built for water storage to irrigate farmland, with over 8,000 at the peak, hence touted as the land of a thousand ponds [1] [2]. However, regional landscapes vary with the changes of politics, people, human rights and social life. The landscapes of the Taoyuan area are also distributed in different forms on the surface space in different periods. For example, in the early rule by the Kuomintang, agriculture was the main driver of economic growth, which gradually shifted to industry. With the change of social patterns, agriculture was no longer the most economically efficient way of land use, causing its original function to disappear and be abandoned gradually and resulting in the change of land use for farm ponds in Taoyuan to industrial, commercial and residential use [3] [4].

Based on the landscape changes of Taoyuan’s farm ponds from 1978 to 2014, this study establishes an environmental external driving factor system, and uses the driving force-pressure-state-impact-response (DPSIR) model to explore the change in land use patterns for the farm ponds in the Taoyuan
area, and discusses the causal relationship between the two. Finally, the results of land use development and change in the farm pond are analyzed with a geographic information system. This study explores the causes of the disappearance of farm ponds and identifies the influencing factors, which will contribute to environmental conservation and ecosystem maintenance, as well as to the adaptation to climate change.

2. Function of Taiwan’s farm ponds
Water conservancy often played an important role in the early settlement. The interaction between survival and environment was based on the demand for irrigation water resources, so the ancestors built dykes or excavated ponds on the surface. The formation of the ponds mainly includes three levels: climatic conditions, topographic and soil characteristics, and river capture [5].

Taiwan’s farm ponds operate for agricultural production, ecological conservation, storage and purification of water, cultural landscapes, leisure and recreation, flood prevention and detention, and other specific purposes. The farm pond is not only connected with production and life but also has a significant effect on the conservation of biological environment [3]. However, the farm pond is often regarded as a hindrance to urban development. Therefore, this study hopes to understand the competitive and cooperative relationship between land development and resource conservation, and to identify the key driving factors in pond change by analyzing its land use development and change, so as to provide a reference for future planning and research.

According to historical records, the pond culture in Taoyuan can be traced back to the 17th century. It was on record that excavation of the ponds began in 1711 and went through four stages: the Qing dynasty (1711-1895), the Japanese rule period (1896-1945), the early days following World War II (1946-1964), and the ROC rule (1965 to date). Before 1901, the ancestors reclaimed land in Taoyuan and built ponds for agriculture by conforming to nature, during which most of them were irrigated privately, with different shapes and sizes. From 1901 to 1945, the authorities during Japanese rule promulgated the “Rules for the Management of Public Canals,” where large canals with public interest involved were held in public ownership. The Shimen Reservoir Construction Project started in 1946 and was completed in 1964, and a sharp decline in the farm ponds began in 1978, which means that Taiwan society had transformed itself from agriculture to industry and commerce [2] [5].

Traditionally, the function of Taoyuan farm ponds were mainly dominated by agriculture purpose to provide irrigation and aquaculture functions. However, due to the decline of agriculture in northern Taiwan, irrigation functions have been reduced. Recent years, due to the rapid development of leisure activities many ponds have gradually transformed into ecological and recreational functions. In addition, with issue of natural disaster, ponds started to provide the disaster prevention and detention functions [5].

3. Establishment of analytical models
The framework of this study is mainly based on DPSIR land use change indicators. Driving force, pressure, state, impact and response are used to construct the impact model of land use change in farm ponds. The DPSIS mode is a decision-making model that illustrates causal reactions and can be used as a model for explaining the concepts of real-world problem operations [6] [7].

3.1. Establishment of model architecture
Land use change is formed by the interaction of many factors such as natural conditions and human activities, and the theory of land use change needs to conceptualize the relations between the driving forces that affect land use change [8].

Therefore, this study, by summarizing relevant theories and literature, sorts out the main factors affecting land use change, analyzes these factors and establishes impact categories and the impact model of land use change in farm ponds as the basis for follow-up research, as shown in Figure 1.
3.1.1. External driving factors. The main external driving factors affecting land use change can be classified into five types:

(1) Natural environment

The most direct factor affecting land use is the natural environment. Different natural environments have limitations on and potentials for various land uses. These conditions determine whether the area belongs to a restricted development area or a developable area. They also have considerable restrictions on the type and development intensity of land use supply and the change of land use [9].

(2) Socioeconomic environment

The preconditions and forces of the external socioeconomic environment are not controlled by the user or the owner, but have influence on the decision of land use. Economic factors are the fundamental basis for land use behavior and decision-making, and its basic assumption is that land use decision-making originates from individual utility maximization; social factors often restrict the demand for land use in regions, and determine urban land use models through various operational processes [9] [10].

(3) Neighborhood traits

Geographers use spatial interaction to analyze land use patterns. The results show that land use is not an independent development of individual locations, and each development will affect neighborhood conditions and nearby locations. The phenomenon of spatial interaction can be explained by one factor. On the one hand, it causes the concentration of urban functions (centripetal force: economies of scale, intensive labor market), on the other hand, it also causes the spatial spread of urban functions (centrifugal force: congestion, rent rise) [10].

(4) Site conditions

The resources that the owner or user can control on the characteristics of land attributes are enough to influence their decision-making and management, such as land shape, initial land use pattern, adjacent land use pattern, and adjacent road width, which are the main variables that can respond to these factors [11] [12].

(5) Plans and policies

Plans and policies can be divided into two categories: land use plans and spatial policies. The former is based on regional population, industrial growth and distribution, regional spatial structure objectives, and future development. The latter is the impact of policies at the national or regional level on land use, such as the zoning of conservation areas, transport or public construction, and specific industrial development policies [13].

3.1.2. Land use categories following farm pond change. The change of pond land is mainly influenced by external driving factors. The use types for the change of pond land can be proposed by method of induction. The land use types are mainly built-up land, transportation land, agricultural land and hydrological land, as shown in Table 1. The land use categories are defined as follows:
(1) Built-up land
   Urban planning area is the base area with a license for the use of buildings; non-urban areas are all kinds of construction bases.
(2) Transportation land
   The area of roads that have been paved in the urban planning area; non-urban areas use non-urban land for transportation.
(3) Agricultural land
   Land on the surface that is still used for growing crops
(4) Hydrological land
   Land where surface water or groundwater is used for flood control, drainage, storage and water supply.

3.2. Survey on the current situation of pond land use change and database establishment

In this study, geographic information system (GIS) is used to construct the spatial information and distribution of farm ponds in Taoyuan, in order to present the basic map of farm pond land in different periods, and collect data through Government Statistical Abstract to establish the model of pond change factors with pond land area.

3.2.1. Sources and limitations. In this study, aerial photographs will be used as the basic data in the pond map. However, in the process of data collection, the complete calendar data were not obtained.

Therefore, according to the years of aerial photographs, 1978, 1984, 1994, 2004, 2009, 2012, 2013 and 2014 are used as the data years of this study, in order to analyze and discuss the situation of pond land change, and to serve as an annual benchmark for the calculation of other variables affecting the pond change factors.

3.2.2. Farm pond area definition. In this study, we will use a new feature method to draw farm ponds, and construct its attribute data to calculate the area of the feature data. Super GIS software will be used to map the distribution of farm ponds in Taoyuan.

The input GIS coverage is based on the most common TWD97 coordinate system. The distribution patterns of the ponds are drawn from the aerial photographs of the eight years mentioned above in order to understand the changes of the ponds over the years. In the process of building, the map data are converted and plotted into the GIS program for drawing ponds, calculating and analyzing their area, and then the electronic image file is converted into a map file with coordinate systems by image registration, and precise coordinates are set to interpret and depict the map of the pond land.

3.2.3. Establishment of land use category database following farm pond change. In order to understand the impact of land use patterns on pond change, the main land types following the farm pond change are summarized through literature review.

The land types are built-up land, transportation land, agricultural land and hydrological land, with the subsequent analysis model established based on relevant statistical data.

3.3. Establishment of regression program

In this study, correlation analysis and regression analysis of pond area are carried out by using the land use types after farm pond change.

The land use types are independent variables and pond area is dependent variables, so as to understand the main land use types and their changes affecting the change of the farm ponds (Table 1.).
Table 1. The framework of land use types following farm pond change.

| Indicators             | Definition                                                                 | Regression variable $X_j$ |
|------------------------|---------------------------------------------------------------------------|---------------------------|
| Built-up land (B)      | The area of farm pond converted into a built-up area                       | $X_1$                     |
| Transportation land (T)| The area of farm pond converted into a transportation land use             | $X_2$                     |
| Agricultural land (A)  | The area of farm pond converted into a agricultural land use               | $X_3$                     |
| Hydrological land (H)  | The area of farm pond converted into a hydrological land use               | $X_4$                     |

Dependent variable Y: Pond Area

4. Empirical analysis

4.1. Land use change in farm ponds

In order to understand the change of land use in Taoyuan’s farm ponds, this study uses geographic information system to explore the distribution of the ponds from 1978 to 2014 (Table 2.).

Through map data, we can clearly understand that the situation of ponds in Taoyuan over a period of 8 years shows a decreasing trend (Figure 2- Figure 9). And the northeast and southwest regions saw the sharpest reduction, which was supposed to be influenced by the urban development of New Taipei City, and then drove the development of eastern Taoyuan, resulting in the gradual transformation or disappearance of the ponds.

Table 2 shows that the area of Taoyuan’s farm ponds dropped from 118.28 hectares in 1978 to 40.69 hectares in 2014, with a change rate as high as -65.60%. It is estimated that the establishment of traditional industrial areas like Zhongli and Guishan in the 1960s had led to rapid industrial and commercial development, and the opening of the Taoyuan International Airport in 1979 had resulted in increasingly dynamic regional construction and land development. Coupled with the national construction plan implemented in the 1980s to develop new towns, transportation and other systems, the land use in the Taoyuan area changed dramatically from 1980 to 2000.

Table 2. 1978-2014 farm ponds areas change in Taoyuan City.

| Year     | Total area of ponds (hectare) | Rate of change |
|----------|-------------------------------|----------------|
| 1978     | 118.28                        | --             |
| 1984     | 93.16                         | -21.24%        |
| 1994     | 65.94                         | -29.22%        |
| 2004     | 57.67                         | -12.54%        |
| 2009     | 43.86                         | -23.95%        |
| 2012     | 41.76                         | -4.79%         |
| 2013     | 40.95                         | -1.94%         |
| 2014     | 40.69                         | -0.64%         |
| 1978-2014| -77.59                        | -65.60%        |
Figure 2. Land-use in the ponds of Taoyuan City in 1978.

Figure 3. Land-use in the ponds of Taoyuan City in 1984.

Figure 4. Land-use in the ponds of Taoyuan City in 1994.

Figure 5. Land-use in the ponds of Taoyuan City in 2004.
Figure 6. Land-use in the ponds of Taoyuan City in 2009.

Figure 7. Land-use in the ponds of Taoyuan City in 2012.

Figure 8. Land-use in the ponds of Taoyuan City in 2013.

Figure 9. Land-use in the ponds of Taoyuan City in 2014.
4.2. Analysis on change of land use affecting farm ponds

This study uses different independent variables and farm ponds for regression analysis. When the four independent variables of built-up land, transportation land, agricultural land and hydrological land are included in the multiple regression model simultaneously, it shows significance, with the explanatory power of \(F(4,1) = 87.621\), \(p = 0.002\). As discussed in Table 3, the estimation results of post hoc test coefficients of individual independent variables show that agricultural land has a collinearity problem, and its tolerance is small and VIF is greater than 10, which will interfere with the results of the model. However, the built-up land, transportation land, and hydrological land are negatively correlated with the area of the farm pond, indicating that the above three kinds of land use will threaten the existence of the farm pond. The relationship between agricultural land and the farm pond is positive, which means that the farm pond will decrease with the loss of agricultural land.

According to the results of regression analysis, it is clear that the decrease of farm ponds in Taoyuan is mainly affected by the development of built-up land, transportation land and hydrological land. Although the existence of agricultural land will not reduce the area of the farm pond, the decline of agricultural land will make the irrigation function of the farm pond disappear and the area of the pond decrease. The growth and decline of all kinds of land use will affect the existence of the pond. In the process of urban development, the increasing demand for built-up land and transportation land and the decreasing demand for agricultural land all pose a major threat to the existence of the farm ponds. Although hydrological land is the related facilities of the farm pond, with the decrease of agricultural irrigation function and the improvement of flood control and water control function, the decrease of the farm pond area can be partially attributed to the increase of hydrological land. It can be seen from various regression models that there are reasons for the disappearance of the area of the farm pond.

Table 3. Regression coefficients.

| Unstandardized Coefficients | Standardized Coefficients | t    | Sig. | Collinearity Statistics |
|-----------------------------|---------------------------|------|------|-------------------------|
| (Constant)                  |                           |      |      |                         |
| B                            | 65.227                    | 28.046 |      | 2.326 | 0.103                  |
| Std. Error                  |                           |      |      |                         |
| Beta                        | -0.020                    | 0.012 | -0.216 | -1.747 | 0.179 | 0.186 | 5.385 |
| t                            | -0.028                    | 0.076 | -0.061 | -0.370 | 0.736 | 0.103 | 9.750 |
| Sig.                        | 0.037                     | 0.011 | 0.626 | 3.325 | 0.045* | 0.080 | 12.516 |
| (Constant)                  |                           |      |      |                         |
| B                            | -5.509                    | 5.423 | -0.124 | -1.016 | 0.385 | 0.189 | 5.298 |

Dependent variable Y: Pond Area

* Significant at \(\alpha=0.05\)

5. Conclusions

Taoyuan is known as the land of a thousand ponds, but due to the influence of administrative geographical location and urban planning development, the ponds are gradually transforming itself or disappearing.

In this study, the cause of the decrease of pond land use in Taoyuan is investigated, and it is found that the area of Taoyuan’s farm ponds and agricultural land showed a significant tendency of decrease between 1978 and 2014, while the area of built-up land, transportation land and hydrological land presented a positive growth. This indicates that the built-up land, transportation land and hydrological land are the main land use patterns in the process of urban development. Agricultural land no longer has the highest utility of land, so its area has been reduced. The disappearance of agricultural land is also the main factor affecting the change of farm ponds.

The change of Taoyuan’s farm ponds is mainly influenced by the urban growth. In order to prevent urban over-expansion, relevant planning regulations should be put forward according to land use. In
terms of built-up land, the Taoyuan City Government should investigate the supply and demand of land development. In recent years, due to the rapid development of building sites in Taiwan, the supply exceeds the demand, resulting in unsalability of real estate. In order to prevent land competition between building sites and farm ponds, the utility of existing built-up land should be improved, the damage and impact on the farm ponds and environment should be reduced, the restriction of volume control laws and regulations should be strengthened, and the development of local intensive cities should be promoted to avoid excessive expansion of built-up areas. In terms of transportation land and hydrological land, although the area has no increasing trend in recent years, relevant regulations should be formulated for these two kinds of land to avoid unnecessary development and protect the existing resources of the farm pond.

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