Sustainable Development Analysis of Agriculture Using System Dynamics Approach

Mahdi Bastan[a,b,*], Saeid Delshad Sisi[b], Zahra Nikoonezhad[a], Ali Mohammad Ahmadvand[a]

[a] Department of Industrial Engineering, Eyvanekey University, Eyvanekey, 35918-99888, Iran

[b] Department of Industrial Engineering & Management Systems, Amirkabir University of Technology, Tehran 15875-4413, Iran

ABSTRACT

Sustainable Development is the management and conservation of the basic natural resources through which organizational and technological changes are lead to meet present and future needs of humans. In developing and analyzing the solutions based on sustainable development principles, we require to pursue an integrated and holistic approach. Not only system dynamics has the essential tools for systemic analysis, but also it is an appropriate approach for perceiving problems and offering solutions. The goal of this study is to present an integrated and systemic model to analyze the existent dynamics in sustainable development of Iran's farming industry. In order to achieve the mathematical equations and values of model's variables, a simulation is carried out using the data gathered from Damavand city, Tehran, Iran. The parameters of the model are selected and calculated considering the specifications of this case study. After modeling the system, Vensim simulation software has been employed, followed by identifying the leverage points of the model; then, a set of scenarios have been generated and tested through simulation in order for us to achieve a much improved understanding of the system's dynamic behavior. The results show that two factors are among the most important leverage points: "profit gained from agriculture" and "required water". We could also observe that the main issue in Damavand is the lack of water for which saving policies would be a major step towards agriculture's sustainable development in this area.

Keywords: *Sustainable Development, System Dynamics, Change of Use, Agriculture level*

I. INTRODUCTION

Sustainable agriculture is one of the most important branches of sustainable development, and is known to be a promising approach for agriculture's economic stability considering the lives of people in developing countries. Complex systems' sustainable development, especially in agriculture as a sector related to environment, must be regarded as a constant development paradigm for the human being. This means that there should be a situation in which the nature could rehabilitate itself after being affected by humans' activities; therefore, enough resources would be saved for the next generations.

United Nation's Food and Agriculture Organization (FAO), by emphasizing the role of farming industry and rural life sustainability in the world, asserted that in most countries, especially the low-budget, employment and income is highly depended on agriculture; hence, farming industry and rural life sustainable development has a high priority in FAO's strategic plans [3]. Nowadays, the ever increasing growth of population has raised a greater concern for food which itself has horribly influenced the soil and basic resources. Using fertilizers and pesticides not only has contaminated the soil and subterranean water, but also has caused the genetic erosion and extinguishment of many plants and animals.

On the one hand, sustainable development, basic resources' conservation, and introduction of technical advances, necessitates us to employ modern farming techniques and to consider environmental issues as well as the economic turnover [4].

[*] Corresponding Author. E-mail addresses: mbastan@eyc.ac.ir

On the other hand, analyzing the sustainability of farming industry requires a holistic study of the factors and functions influencing all sectors with a systematic approach. For example, eco-agricultural view of farming industry seeks an equilibrium between environment and economic resources insuring the sustainability of both. In this context, beyond the humans' role in agricultural business activities and all existing interactions, we need to consider natural factors, namely soil and water. These factors would have direct and indirect effects, and with attention to the lack of resources, they cause serious dynamics in the system.

United Nations Sustainable Development committee elaborates the internal measures of each of social, economic and environmental divisions.

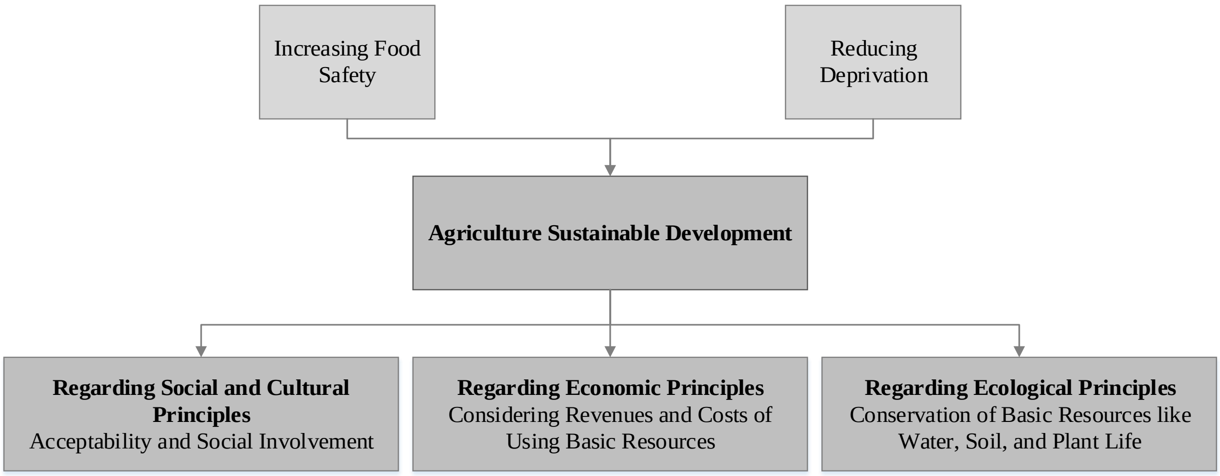

Figure 1- FAO's suggesting system for Agriculture's sustainable development in Developing countries

As it can be seen in figure 1, achieving sustainable development in a systemic and holistic way would be the result of actions, reactions and coordinated balance of ecological, economic, and social and cultural factors.

Right now in the area of ecology, we are facing inappropriate management of water and soil resources; in economy sector, as a consequence of implementing wrong policies, we are observing worsening farming conditions; and in the area of culture, considering the population and people's dynamic behavioral changes in tourism and residing, we are confronting unbalance [5]. Hence, achieving a coordinated and stable balance to control impacts and an effectual management of resources requires an integrated and comprehensive study of agriculture's sustainable development based on systemic thought.

Above all of the reasons that hinders agriculture's development is the land use change which occurs when farmlands turn into lands incapable of farming, e.g. into a residential area. World communication advancements in several aspects and expansion of cities have made a situation in which the human has crossed the line in principled employment of earth's resources, and heightened the increasing trend of land use change. External factors e.g. changes in life standards and technology, market forces, and cities expansion pressure have been quite influential in ruining farmlands [6]. In this situation, physical expansion has often occurred without taking into consideration the natural and ecological parameters, and this has led to ruin of farmlands for construction purposes, encroach on environmental values, increase at ground slope, and land use conflicts [7]. Rural tourism is an old phenomenon, and has appeared as a recreational-social activity in middle 18th century in UK and Europe [18]. In Iran during recent decades, simultaneously with world alterations and the raise in tourism, secondary residing houses in rural areas has become quite popular among Iranians for recreational purposes [5].

Based on FAO's statement, sustainable development is the management and conservation of natural resources and leading technology changes and administrative structure to a path which guarantees the continuous provision of humans' needs, and present and future generations' satisfaction. Sustainable development in agriculture, foresting, etc. is accompanied with the preservation of soil, water, and genetic sources of plants and animals; it does not result in any harm to environment; it gets use of appropriate technology; and finally, it is economically promising and socially acceptable.

Abugamea [10] emphasized the amazing role of agriculture in Palestine's GDP, exports, business, labor employment, etc. He also managed to analyze the dynamics of farming production and the factors influencing it. Agriculture-environment consistency approach supports the sustainability of both agriculture and environment. Fu Jia et al. [11] used Agriculture Effect Policy System Dynamics (AEP-SD) method for an integrated analysis of negative effects of organic farming slow development from 2009 to 2050 and discussed the unstable energy structure and ways for decreasing its effects to present improvement policies. Thomas et al. [12] presented TOPMARD for modeling agricultural and rural development policies for better understanding farming, environmental, economic, and social conditions of rural areas. This model that was hierarchically developed by a team of people from eleven countries, included a variety of dynamic feedback mechanisms similar to environmental systems. The experiments on their model showed that short-term, mid-term, and log-term pauses in performance makes complicated dynamic patterns. Additionally, they managed to illustrate the quality of the interactions between economy and environment, the life quality, and sometimes the effects of negative feedbacks like the relation of income and migration or positive feedbacks like processes among local divisions. In another investigation in Slovenia by Kljajić et al. [2] system dynamics was used to analyze organic agriculture development. They also presented a number of improvement policies e.g. subsidizing farming industry. In Southeast Anatoly (GAP) Kerem Saysel et al. [13] reviewed the potential environmental issues e.g. water resources, soil, land erosion, and farming contaminations. They used a simulation model based on system dynamics (GAP-SIM) as an experimental model for analyzing the problem and presenting improvement policies e.g. cyclic farming systems and changing from cotton to plants with low level of water requirement like corns. Mehrabi et al. [14] pointed out some ways and tools to achieve agriculture's sustainable development in Iran e.g. organic farming, retraining weeds, biological control, and stable and continuous farming.

As mentioned before, one of the obstacles on the way of agriculture's sustainable development is land use change. The issue of land use change and urban infrastructure is related to social, economic, and environmental factors. In order to meet sustainable development, we need to find meaningful relations among different system elements; therefore, in an investigation by Farokhi [15] by means of patterning land use with DPSIR qualitative model and multi-temporal satellite images, land use change and its causing factors were analyzed. It was seen that the growth of population and the increase in land price have been effective on the increase of land use change. Kalardasht in Mazandaran [16], Zanjan [17], Gorgan [6], and Sanandaj in Kordestan [20] are all among the examples of this land use change in Iran. Furthermore in Tabriz, the Enhanced Thematic Mapper (ETM) and Thematic Mapper (TM) satellite multi-temporal images were used to model the physical expansion of this city from 1989 to 2001. Results showed 38.49% decrease of green area replaced by residential area [18]. The data bases used in modelling Tabriz's urban expansion included environmental, economic, social, and land use change information. In another paper presented by Sudhira [19] the concept of *Urban Sprawl* and its impacts are noted. It is reported that this phenomenon is the consequence of urbanism and the high increase in immigration to cities. Even for Tehran, several papers like [21] and [22] have investigated the extreme expansion of the urban area which has destroyed close villages. Factors e.g. urbanism, villages' industrialization, residing expansion, lack of systemic policies to support agriculture, and a mechanism to implement them, are all among the reasons that have caused this problem [23]. In contrast to Iran, factors e.g. agriculture infrastructure growth, modern farming development, higher turnovers, and productivity has caused great improvements in China's agriculture [24]. To sum up, it is proved that land use change behave against agriculture's sustainable development. Unfortunately, our case study, the Damavand city has the same issue; so here in this research, we regard land use change as one of the influencing factors on our analysis of agriculture's sustainable development. Many researches have been done on issues of sustainability, optimization and environmental modeling [30], [31], [32], [33], [34] and [39], [40]. Also using system dynamics approach for same problem modeling is common [41], [42], [43].

II. METHODOLOGY

Our research methodology is based on general steps of System Dynamics (SD) approach. This methodology was first created by J. W. Forrester at MIT in 1950. After a while, the application of this method extended to be used in other sectors of industry [35]. System dynamics can pattern different aspects of a problem, and it is an effective method of analyzing a system by simulation. [25]. It can also elucidate the unspecified or unexpected outcomes of a decision and help us with understanding complex systems [36]. System dynamics may be used for testing different scenarios with a systemic view of the problem [37]. So, it allows the decision maker to simulate and test his proposed policies and to see long-term outcomes of implementing each policy before making his final decision [26].

In order to solve a problem by means of system dynamics we need to pursue five steps below:

1. Identifying and defining the problem
2. Mapping cause and effect diagrams
3. Developing the mathematical model (stock and flow diagram)
4. Model simulation and validation
5. Scenarios generation and evaluation, then selecting and implementing the most appropriate solution

Forrester believed that system dynamics has joined the human mind capability with modern computers' power [38]. In the first steps of developing the model, in order to specify the appropriate variables and possible feedback iterations, we need creativity of a human mind [28]. Computers are employed to elucidate the unexpected outcomes emerged from complexity and dynamic behavior of the system. Because predicting the feedbacks and nonlinear impacts of decision variables in complex systems would be too difficult for humans [29]. People often consider the relations among variables as linear in order to predict the outcomes which can clearly lead to wrong inferences [44].

System dynamics is often employed to analyze complex social and economic systems; as these systems dynamically change due to many unknown causes. Sterman [27] describes the steps of system dynamics modelling according to figure 2.

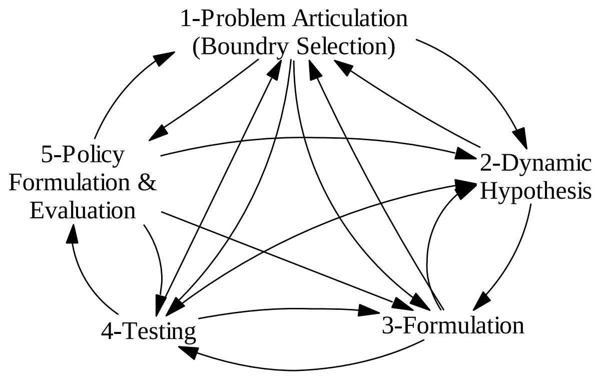

Figure 2- Iterative feedback process of modelling a problem based on system dynamics methodology [27]

As it can be seen from figure 2, this modelling is not a linear sequence of steps, but it is a feedback process. This modelling process is iterative, so it improves our understanding of the problem in each iteration by providing more and more feedbacks [27].

III. Dynamics Modelling

3.1. Problem Statement

Damavand city and this divisions in east of Tehran is chosen as a case study to investigate the problem of decrease in growth of agriculture and being far from sustainable development. This city has one of the greatest climates all around Iran. North of Damavand is mountainous and its south is a flat area with a very appropriate soil for farming. Statistically, the district of Damavand, with more than 305 tons of products, has a 7% share of all production in Tehran province. Unfortunately, based on figure 3, we are faced with a decline in farming in this areas.

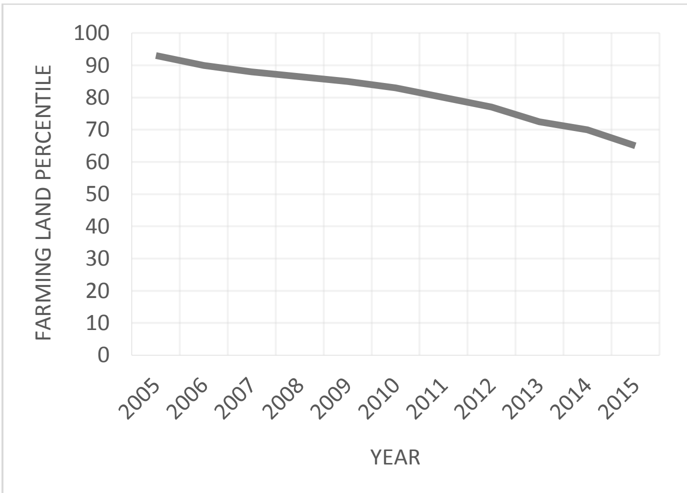

Figure 3- Farming trend in Damavand (in percentile)

There are several factors influencing this problem. Water levels are decreasing everyday as a result of decline in rainfall. Employing old traditional methods of irrigation, digging many unauthorized wells in private properties, and planting flowers requires much water. Figure 4 shows the rainfall trend during recent years.

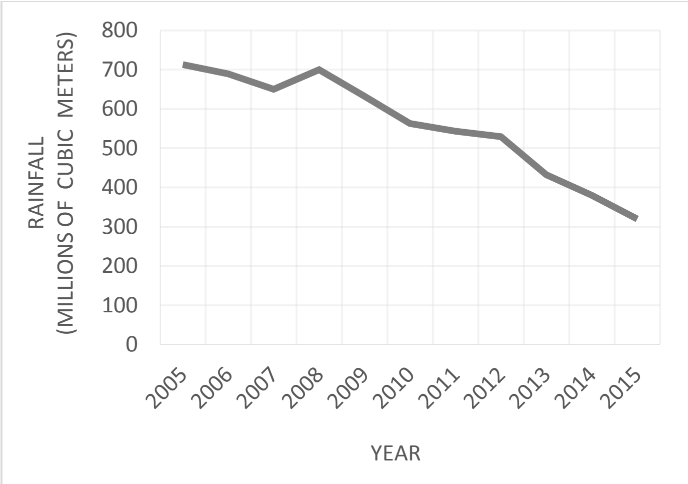

Figure 4- Damavand Rainfall Trend (in millions of cubic meters)

Farmlands' use change has been as harmful as a cancer tumor to the body of Damavand agriculture. In recent years, there has also been a growth in travelling to Damavand and residing there for the summer. Furthermore, in consequence of limited satisfying living environment and pollution in Tehran, demand for land in Damavand has increased which has caused an increase in land price. Obviously, expensive lands are more likely to be used for residing and construction; therefore, we have observed the expansion of residential areas in Damavand (figure 5).

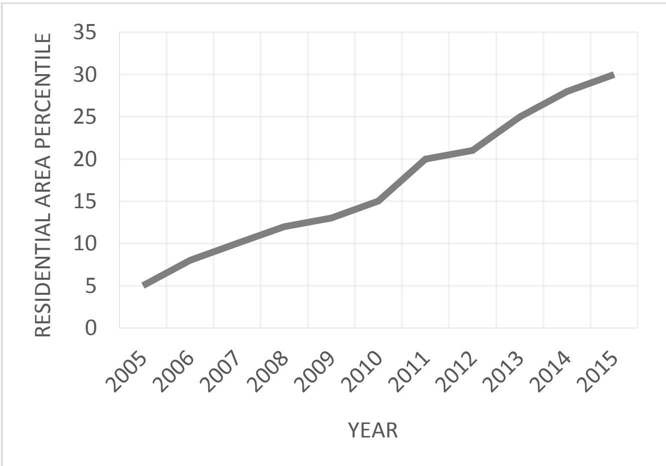

Figure 5- Construction trend and the share of residential area in Damavand (in Percentile)

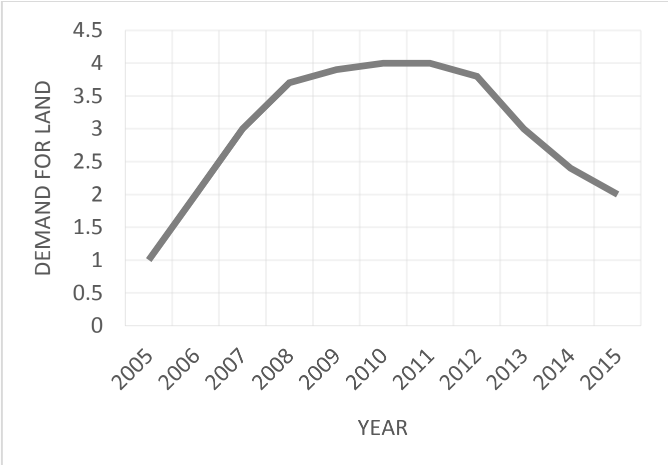

Figure 6- Demand for Land in Damavand

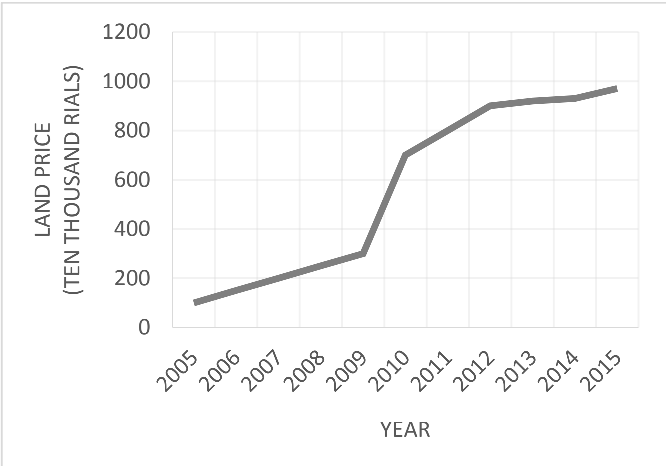

Figure 7- Damavand land Price Trend (in Ten Thousand Rials)

As it can be inferred from Figure 6 and 7, after 2012 followed by government new policies against farmlands' use change to constructions, the demand for land has decreased and the increasing trend of land price has stopped; however, we can still spot these land use changes in Damavand. Because rural people enthusiastically seek the great benefits of taking their farmlands out of economic cycle by selling or changing their lands for legal or illegal construction.

Another important factor is the low income of farming in Iran which has discouraged young people from farming. High costs of seeding, buying manure and seeds, transportation, workers wage, and current economic conditions have decreased farming profit. Therefore, necessary food products have reduced, and another dynamic factor has been created which is land use change from planting crops and grains to flowers. As a result of using special pesticides for flowers, the quality of soil has gone even worse.

Here was mentioned all the hypotheses beyond agriculture's weakening condition in Damavand district. Responsible parties have devoted most of their effort to fight against land use change, and have lost a holistic view of the problem. So in long term, they may not be able to make any improvement. The real question is "what is the main root cause of the problem?"

So, this investigation tries to use a holistic and systemic approach, considering all the factors and looped feedback relations to achieve a higher knowledge of the real problem and its solution.

3.2. Dynamic Hypothesis

As mentioned before, several factors cause the decline in Damavand's agriculture. One of them was the profit gained from selling the products. Farmers are used to compare their acquired profit with the expected profit. When it is less than the expected, they will have limited options. For one, they could rent their land to plant flowers; or, they might leave their land for a while; they may become disappointed from farming and sell their lands; and some will go to join middlemen.

The other factor was the lack of water which has made the farmers to leave some part of their land and work the rest of it. One of the economic relations of the model is among price, demand, and offering of land. As we know price depends on the fraction of offering to demand. Offering the lands for construction creates another dynamic factor behaving against agriculture growth.

3.3. System's Rich Picture

At the most holistic level of system analysis, we can spot a rich picture of the system with four subsystems: water, agriculture, land (including lands planted with flowers and lands for construction), and economy (including the mathematical relation among price, demand, and offering and the impact of using middlemen). The relations among these subsystems is shown on figure 8.

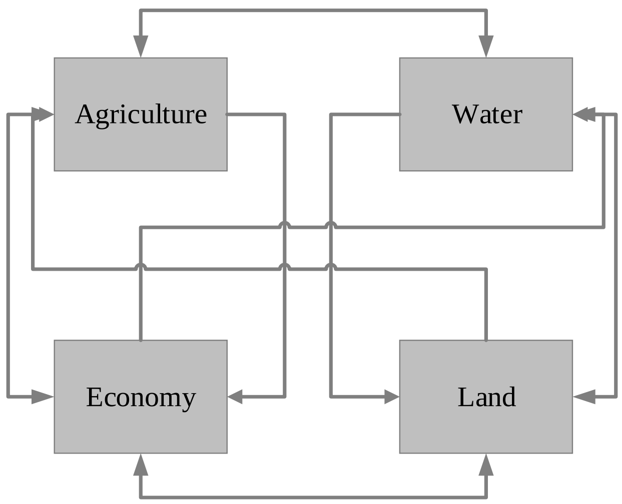

Figure 8- Subsystems of the problem structure

3.4. Cause & Effect Diagram

Considering the abovementioned dynamic hypothesis and also the subsystems of the problem, the productive structure of the problem can be drawn as a cause and effect diagram (figure 9).

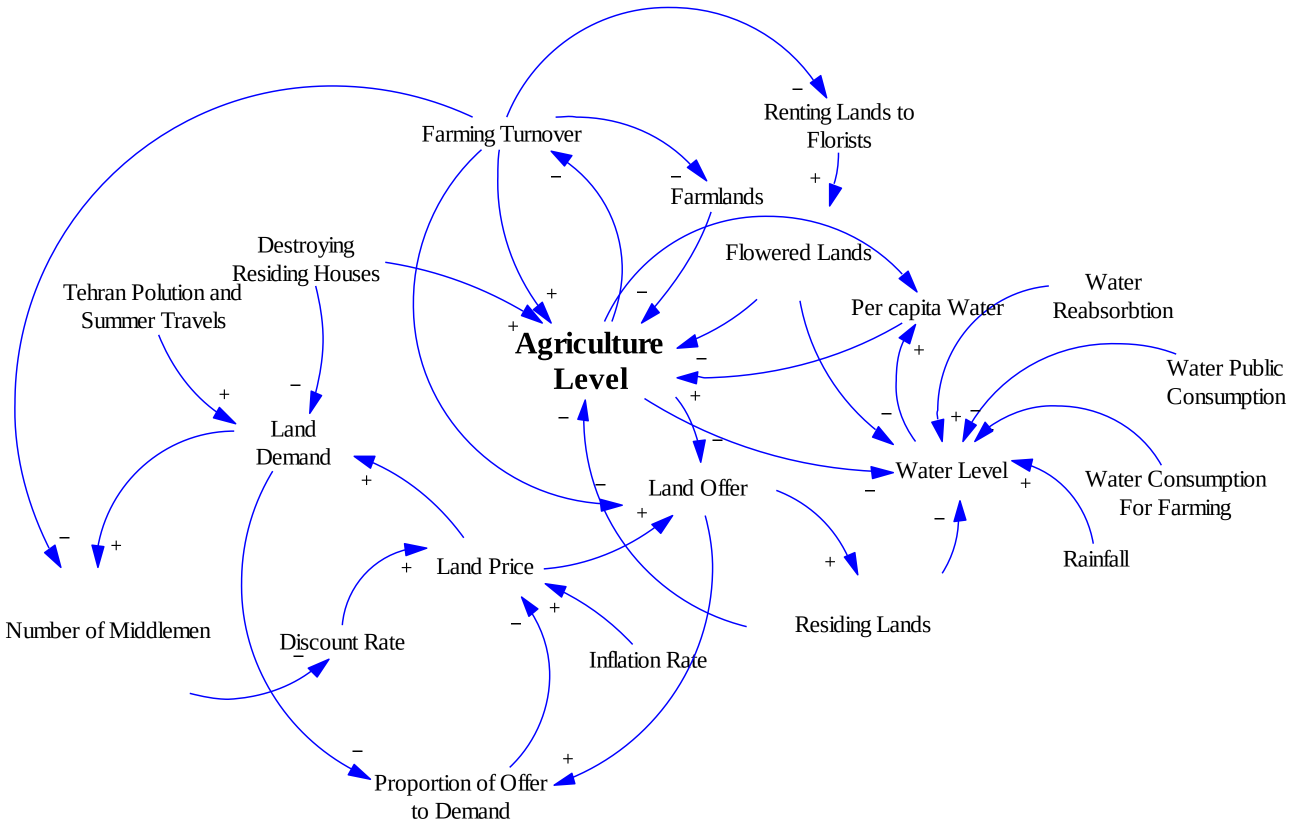

Figure 9- Cause and effect diagram of the problem

The structure of this problem consists of twelve feedback loops in which variables' dynamic behavior depend on their functions.

3.5. Stock and Flow Diagram

After drawing the main loops of the model, we used the stock and flow diagram to involve the model's mathematical equations. The stock and flow diagram is used to illustrate the model variables regarding the accumulation process and flow of information and materials in the system. Figure 10 demonstrates the stock and flow diagram of our problem. As it can be seen, several state variables are defined; e.g. water level, farming level, land use change for planting flowers, land use change to villa, land price, land offering and demand (in Rials), and number of middlemen. Beyond these, there are some other variables defined in order to evaluate or estimate the quantity of state variables; e.g. rainfall, profit gained by farming, number of unauthorized wells, and the number of destroyed illegal constructions.

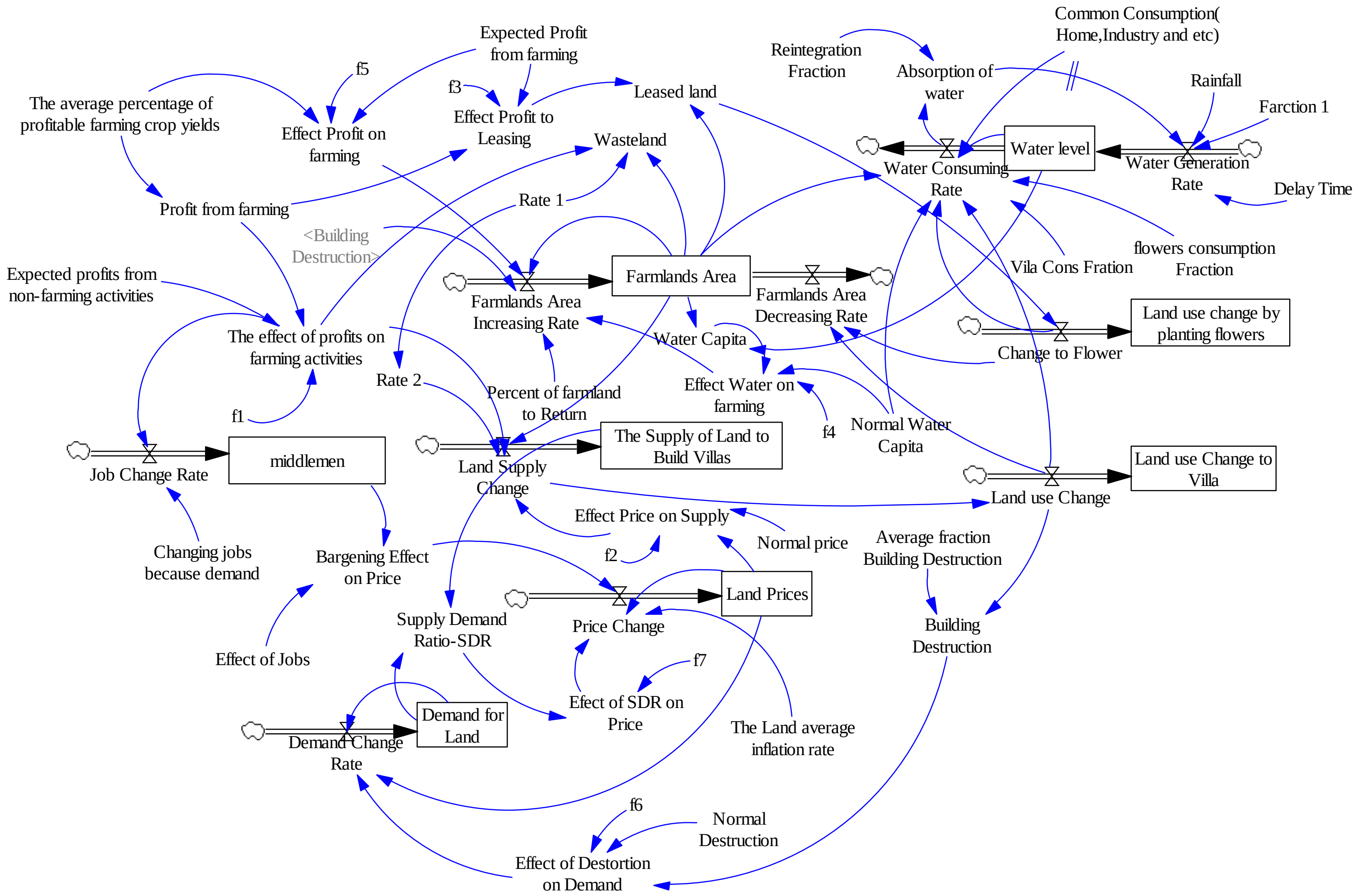

Figure 10- stock and flow diagram

After drawing the stock and flow diagram, mathematical equations related to each of these relations must be involved in the model regarding the data and information accumulated from Damavand district. Then, the model must be validated. In case the validation was confirmed, the model would be simulated with different scenarios.

3.6. Model Testing, Leverage Points Identification, and Scenario Generation

Different structural and behavioral tests were carried out to validate the model which are expressed below.

- *Extreme Condition Test:* the consistency and significance of variable's behavior was tested by setting the parameters to their extreme values.
- *Boundary Adequacy for Structure Test:* the adequacy level of the model boundaries was confirmed by asking for the ideas of five experts.
- *Structural Behavior Test:* the compatibility level of behavior generated by the model was determined by the reference variables' behavior.
- *Model Equations Logic Test:* if the model's equations was written based on logical relations, then it could be considered as a necessary but not sufficient condition for model's accuracy.

- *Dimensions Consistency Test:* the dimensions of all variables in all equations was reviewed and it was determined that the dimensions of two sides of equations were in balance.

After validation, different scenarios based on different policies were generated. To do this first we needed to identify the leverage points of problem. Regarding the results of simulation and dynamic hypotheses, the leverage points of presented model consist of:

- Profit gained from farming
- Water required for farming

Now based on these leverage points, three scenarios below can be analyzed for farming level, water level, and construction level:

1) First scenario: increasing the profit gained from farming to its expected value

By subsidizing taxes and other costs and opening sale centers in Damavand to directly sell the farming products to end users and cutting out middlemen, expected profit could be achieved. Because middlemen pay a lower price to farmers for buying products.

2) Second scenario: employing modern irrigation techniques instead of old traditional ways

Unfortunately, about 95% of subterranean water is now used for lands irrigation, and half of the farmers of the district use old traditional methods. By training farmers for modern irrigation techniques, significant changes could be made.

3) Third scenario: blocking unauthorized wells in private properties

In many villas, people have dug illegal wells for recreational purposes. By blocking these wells and fining these people, much water can be saved.

3.6. Simulation of Scenarios and Policies

After model validation and assuring accuracy and precision, model behavior was simulated and results of applying different policies is evaluated.

1) Results of first scenario simulation

By applying the first scenario and increasing the profit gained by farming to its expected value, figure 11 was achieved. As it can be seen that simulated farming area level do not look promising; since it falls at first then becomes stable.

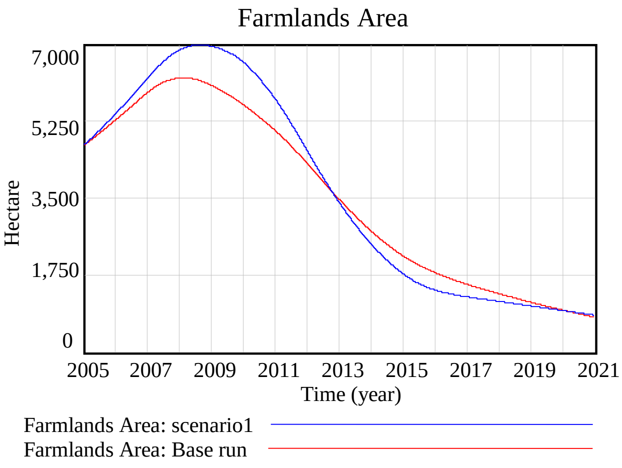

Figure 11- Simulated effects of increasing the profit of farming to its expected value on farming level

Figure 12 shows that as a result of increase in farming Area level, more water will be required and water level will reduce, too.

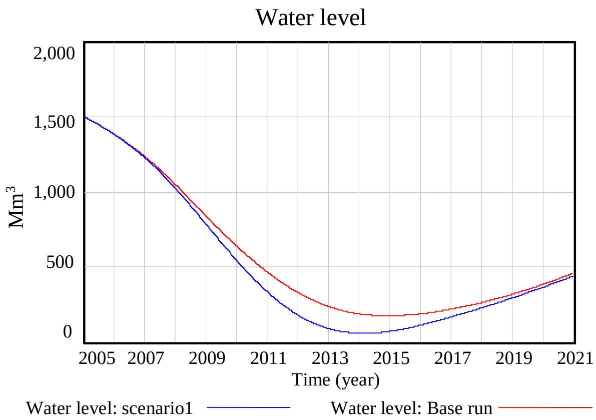

Figure 12- Simulated effects of increasing the profit of farming to its expected value on water level

It can be inferred from figure 13 that construction level will also go down. The increase in farming profit is not going to be a right policy, as it will decrease the water level without improving farming. Lack of water is apparently really serious and may cause even harsher problems in the future.

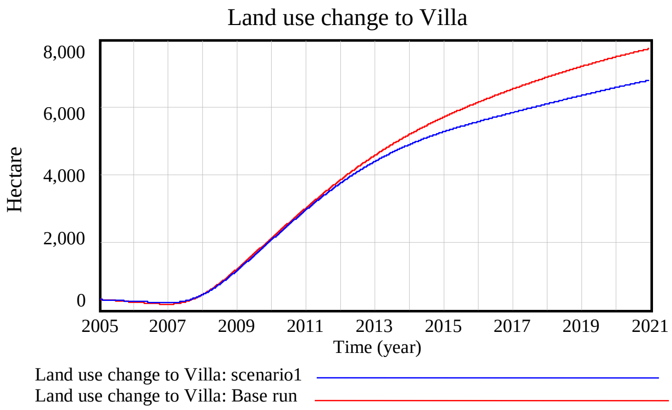

Figure 13- Simulated effects of increasing the profit of farming to its expected value on construction level

So we need to pursue modern techniques of irrigation as well as subsidizing taxes and opening sale centers in this scenario.

After simulating the corrected scenario, we observed a significant growth in farming as well as water level (figures 14 and 15). So, applying both of these policies together will most probably have satisfying results.

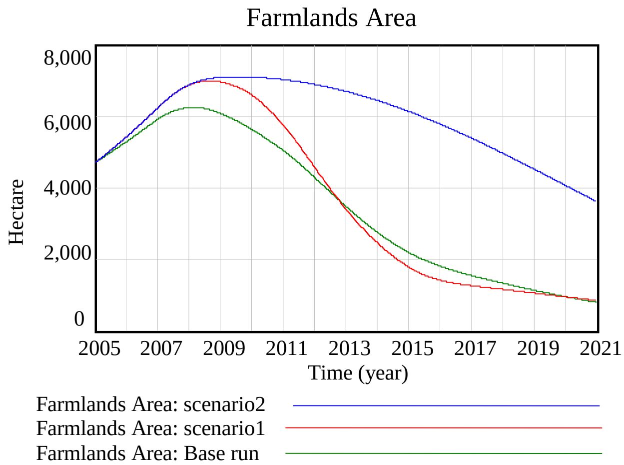

Figure 14- Simulated effects of increasing profit and employing modern irrigation techniques on farming level

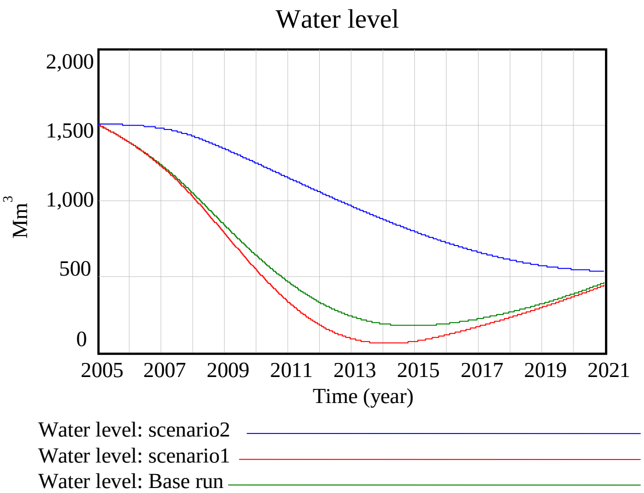

Figure 15- Simulated effects of increasing profit and employing modern irrigation techniques on water level

2) Results of second scenario simulation

In the second scenario, employing modern irrigation techniques instead of old traditional ways was followed as an infrastructural policy for managing the present issue of water shortage. After simulating this scenario and looking at figure 16, we can see a growth in farming level. In addition, water level rises as a result of consuming less water for farming (figure 17).

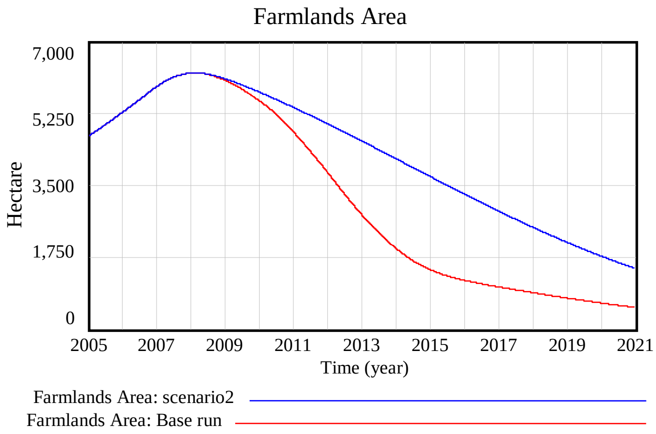

Figure 16- Simulated effects of employing modern irrigation techniques on farming level

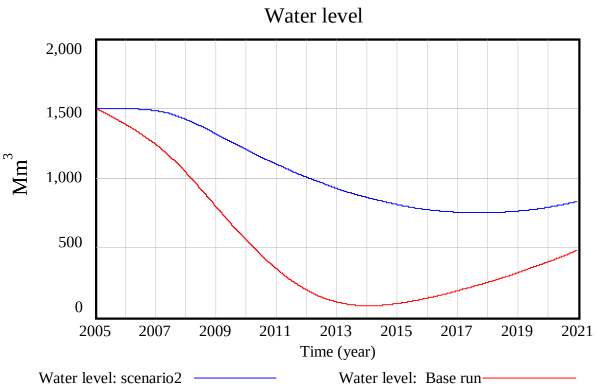

Figure 17- Simulated effects of employing modern irrigation techniques on water level

Figure 18 shows the effect of this policy on construction level and the issue of land use change. We see that after applying water saving policies, illegal construction level will reduce; because improvements in farming and availability of much water would less encourage farmers to build villas on their lands. In general, it can be claimed that applying the second policy will result in positive impacts on farming, water, and construction level.

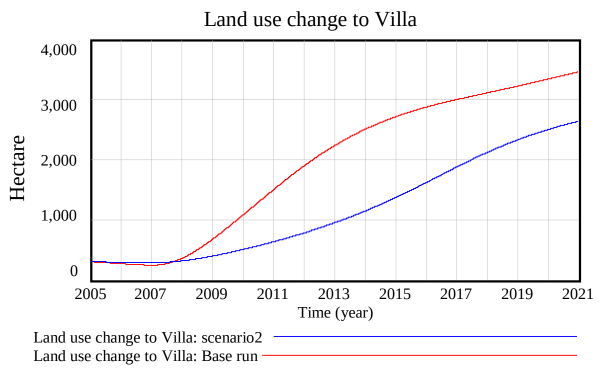

Figure 18- Simulated effects of employing modern irrigation techniques on construction level

3) Results of third scenario simulation

In the third scenario, we followed the policy of fighting against illegal water consumption by digging unauthorized wells. Figure 19 demonstrates its positive influence on farming level.

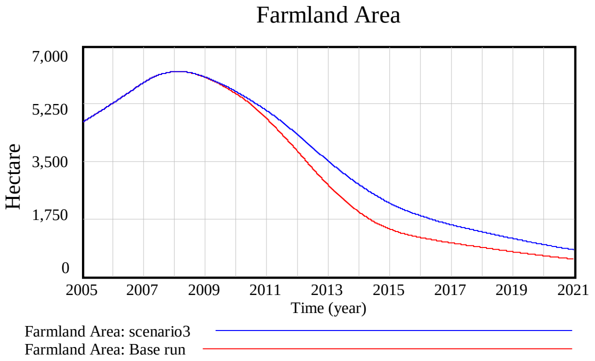

Figure 19- Simulated effects of blocking the unauthorized wells on farming level

We can also see that in consequence of less illegal water consumption from unauthorized wells, the water level will arise (figure 20).

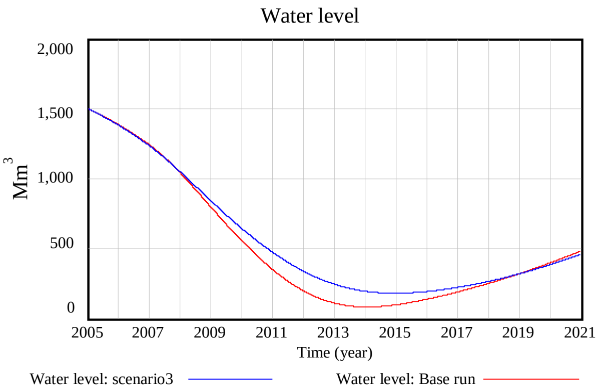

Figure 20- Simulated effects of blocking the unauthorized wells on water level

Additionally, applying third policy can decrease construction level to some extent. Figure 21 shows how land use change to villa will reduce.

To sum up, we can say blocking the unauthorized wells will have promising results. As farming and water levels will arise and illegal construction level will go down.

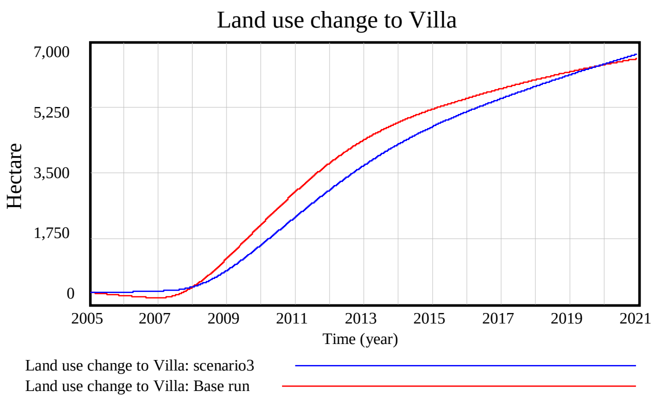

Figure 21- Simulated effects of blocking the unauthorized wells on construction level

With regard to three abovementioned scenarios, the most important issue that farmers are confronted with is lack of water. Because in the first scenario while we increase the farming profit, we cannot hope for sustainable development of farming industry in the area. Therefore, the first priority above all policies is to consider ways for saving more water for the future.

IV. CONCLUSION

In this research, dynamics related to farming level and land use change in Damavand were analyzed. Due to its closeness to Iran's capital city and appropriate weather, many Tehran dwellers travel and reside there during the summer for recreation as their second house. They may destroy farming lands to construct villas. This has led to water shortage due to digging of unauthorized wells and low rainfall, sale of farming lands due to little farming profits and raise in land price, and finally decrease in farming products. Therefore, there are several dynamics regarding the farming level (or farming area), construction level (or land use change to villas), and water level. By simulating the system's behavior under several circumstances, system's leverage points was found out, including farming profit and water availability. Three certain scenarios was tested on these leverage points to improve the system via simulation; e.g. increasing the profit gained from farming, employing modern irrigation techniques, and blocking unauthorized wells.

Simulation of first scenario resulted in little improvement in farming level due to the lack of water. So, this scenario was modified by adding water saving policies by using modern irrigation techniques. For the second scenario, use of modern irrigation methods was solely simulated. In this case, we observed improvements in all the three levels. In the third scenario, we simulated blocking of illegal wells which also resulted in acceptable improvements. As a final word, water resources management seem to be the most important factor in every plan to achieve sustainable development of agriculture in Damavand district.

V. LIMITATIONS AND FUTURE RESEARCH

This research was restricted by some limitations which affected its conclusion and recommendations. Lack of economic information about quantitative impacts of model parameters has made us use approximated values in the model. These approximations may help us understand the structural behavior of the system, but in order to predict the system's behavior more precisely, existent mathematical relations need to be calculated.

This investigation was carried out for Damavand district. The same approach can clearly be generalized to other cities and the whole country which would elucidate more comprehensive and holistic aspects of agriculture's sustainable development in national and international scales. In modelling problem's dynamics, the factor of pesticides used in nurturing flowers and their effect on soil was not investigated and left for future studies. This investigation, however, has considered flowers as luxury but not necessary products for our country; so, we assume land use change from planting necessary food products to flowers as a negative factor acting against Damavand's farming industry sustainable development. Under different circumstances, one might take a different approach for nurturing flowers.

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