Water Resources Dynamics: Chabahar Free-zone Case Study

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Abstract

The proper design of the urban infrastructure is crucial to develop civilization in a developing area. While there are dozens of managerial suggestions to go along with the static aspects of components in urban infrastructure design, hardly any piece of advice may be found to ensure dynamic outcomes of the whole design in advance. In this paper, a novel system dynamics model is introduced and applied in this context as a contribution to fill the research gap. The modular nature of the model development helps to alleviate the challenge of simultaneous design of components and system, with the potential capability of both static and dynamic verification. It allows the decision aider to observe the results of policies with the growth of the model over time and be informed of the consequences of policies before deployment. The model is developed for water infrastructure design. It involves various inter-related subsystems such as industry consumption, geographical location, and labor asset. According to the scope of the model, Chabahar free-zone is selected as a case study to validate the temporal aspects of the model design. A comparison is also made between two policies for water supply. The consequences of adopting each policy on other aspects of the free-zone development are discussed. The model truly depicts that the main challenge in developing the water infrastructure, considering the geographical condition of Chabahar, is choosing an efficient and beneficial way to supply water for industrial and urban consumption.

Keywords
System dynamics; modeling methodology; water infrastructure; free-zone design

1. Introduction

Today one of the vital issues facing most developing countries is the excessive consumption of water resources. Due to expanding industrial and agricultural activities and applications, the limitation of water resources is getting more important in these regions than others. As free zones are among the premier channels of industrial thrive, their role is much more critical in the water consumption rate. Specifically, when it comes to the development and extension of new trades in free zones, it is of more importance to be able to detect the behavior of consumption based on the anticipated volume of industrial and civil activities in that region.

Iran, as one of the rapidly growing developing countries in the world, is also challenging the shortage of water resources significantly. Chabahar, as an Iran future trade hub, is important due to its geopolitical location. It is the closest access to free waters in Central Asia (Afghanistan, Turkmenistan, Uzbekistan, Tajikistan, Kyrgyzstan, and Kazakhstan) and lots of governmental and private investment has been deposited in its formation throughout the last decade. Since the growth and development of a region depend on investing in industrial and agricultural sectors, investors have a great need for water in addition to economic wealth. According to existing reports (Islamic Republic of Iran Meteorological Organization (IRIMO) website, URL: https://data.irimo.ir. ; Bagheri, 2007; Bagheri, 2007), freshwater resources in Chabahar have been declining for the past five years. Thus, close attention should be paid into optimal water consumption and the requirement of projects for water resources.

In general, water infrastructure is a set of interconnected structural factors such as desalination plants, groundwater resources, municipal sewage systems, etc. that are created to manage water supply and demand. Failure to pay attention to any of the above factors can affect various sectors, such as industry or agriculture in the long or short term (Bagheri, 2007). Although most of the previous studies consider water supply with explicit relationships among the important parameters, the temporal and spatial dynamic significance of the water infrastructure is not considered appropriate. Policies are also set based on the assumption that the amount of water available in the region was the least fluctuating and commensurate with the demand. The impact of policies adopted in other important sectors such as industry, agriculture, population and labor market are also ignored

(Holmes, 2014). Hence, in the present research, it is tried to improve the water infrastructure design of the region by applying dynamic modeling and simulation analysis with a more comprehensive look at the Chabahar water system and adopting a policy to achieve optimal results in each of the major components of the system, including water resources. The remaining of the paper is adjusted as follows: literature review; methodology; validation, verification, and results; analysis of the results and scenarios; conclusion.

2. Literature review

In a world of accelerating complexity and change, thoughtful leaders increasingly recognize that the tools we have been using have not only failed to solve the persistent problems we face, but may, in fact, be causing them. All too often, well-intentioned efforts to solve pressing problems create unanticipated side effects. Our decisions provoke reactions we did not foresee. The result is policy resistance, the tendency for interventions to be defeated by the response of the system to the intervention itself (Sterman, 2000). In responding to the challenge of social system complexity, the concepts, tools, and world-view of the engineers and scientists have much to contribute. Scientific methods and the concepts of nonlinear dynamics are just as applicable to human systems as they are to physical, biological, and technical issues (Ramalingam, 2008). System Dynamics (SD) is firmly rooted in these traditions. Growing out of control theory and servomechanisms design and pioneered at MIT in the 1950s by Jay Forrester, SD is, partly, a method for developing and testing formal mathematical models and computer simulations of complex nonlinear dynamical systems; as such it has much in common with other modeling methods (Sterman, 2000).

SD modeling utilizes symbolic notation that combines diagrams, graphs, and equations to represent how the behavior of interconnectedly variables change over time. Many of the concepts used in SD originate from the work that has been done in the mid-twentieth century on information theory and general system theory (Simonovic, 2009). With the SD methodology, first, the systemic problem under study should be clearly identified by formulating a dynamic hypothesis that explains the dynamic root of the problem. A computerized simulation model of the system is developed in order to examine and test the model to ensure the reproducibility of the historical behavior in the real world. Ensuring the model validation and verification, various policies may be designed and tested on the simulation model to examine the improvement of the system behavior and finally, the preferred policies are suggested to be implemented (Sterman, 2000).

Because the factors affecting water resources need to be studied simultaneously and complex relationships exist among them, the use of the flat model development may not be effective and the modeler may have difficulty in establishing relationships or being forced to ignore many relationships between different factors. So, a hierarchical model development may be utilized to analyze the factors in a step by step manner, so that their impact would be well visible to the analyst by increasing the number of parameters and relationships throughout the modeling process. Because this type of modeling leads to a new understanding of the behavior and structure of the system that will allow the development of more complete models at deeper levels. In fact, the hierarchical dynamic modeling outperforms the flat one for studying and managing complex and feedback systems (Holmes, 2014).

A review of past researches (see *Table 1*) shows that water infrastructure and its simultaneous impact on the industry, agriculture, population, and the workforce of the region have not been studied in a systemic manner yet. Due to the specific geographical and economic characteristics of Chabahar and especially the privileges for the investors, the improvement of Chabahar water infrastructure can play a key role in Chabahar city prosperity and recovery.

Table 1. Review of the studies in urban water management with system dynamics methodology

Study area	Work field	Reference
Tehran city, Iran	Identifying indicators of sustainable development in urban water systems	(Bagheri, 2007)
Tabriz City, Iran	Urban water modeling	(Zarghami, 2012)
Qom City, Iran	Extracting sustainable urban water policies with dynamic systems approach	(Entezam, 2019)
New Zealand	The use of system dynamics simulation in water resources management	(Winz, 2009)
South Africa, small town	Using dynamic modeling to find water supply and demand difficulties	(Holmes, 2014)
The United States	Dynamic analysis systems bottled water industry	(Moloney, 2013)

3. Methodology

According to existing reports, freshwater resources in the Chabahar free-zone have been declining for the last 5 years. As Chabahar is located in an arid area, the growth and development of the region depend on freshwater

resources. Therefore, in this paper, we intend to present a model with a system dynamics approach for the development of Chabahar free-zone infrastructure specifically in the field of water resources (Islamic Republic of Iran Meteorological Organization (IRIMO) website, URL: https://data.irimo.ir.).
An important component of the infrastructure development system is the attraction of capital and the allocation of capital to industry, agriculture and desalination facilities. Since the development of the Chabahar free-zone has been outsourced to the private sector, this study assumes that the initial capital will be provided by the government, but the attraction of more funds for infrastructure development is the responsibility of the private sector. The way of providing water in the region for solving the problem of dehydration is also one of the most important parts of the system. Solutions to this problem include the construction of desalination sites, water imports and the use of water resources of other provinces. Here, what constitutes the system boundary is the endogenous approach, so we limit the boundary of the system to factors such as private sector solutions for infrastructure development and limit the role of the government to the implementation of facilitating policies.

The case which is being studied in this paper includes some major parts such as industry, agriculture, and population. Considering these major parts together makes the system complex and difficult to be analyzed. Therefore, a novel SD approach is employed for modeling this case. This way, all of the details in the model can be accurately detected. As it is shown in Figure 1, the model is broken down into three levels and each level is explained in the following paragraphs.

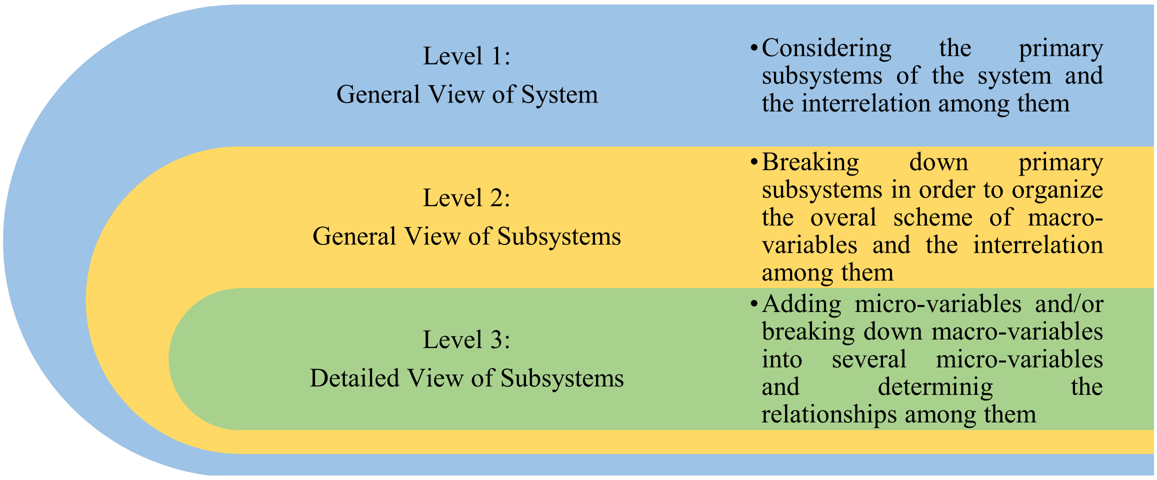

Figure 1. Breakdown structure

3.1. Level 1: general view of system

At the first level, it is tried to present a general insight into the model. Therefore, just the primary variables of the model and the interrelations between these variables are considered at this level. As we are studying water infrastructure in Chabahar free-zone the primary variable of the model should be the amount of water which is available for urban, industrial and agricultural consumption, i.e. available water. Also, the major variables affecting the primary variable are water supply infrastructure, urban consumption, industrial consumption, and agricultural consumption. To distinguish the relationship between the major variables of the model, some objects and variables are included such as industry, population, and investment. The key variable is an investment that relates the variables affecting water consumption to the variables affecting water production. The interaction between the aforementioned variables is shown in Figure 2.

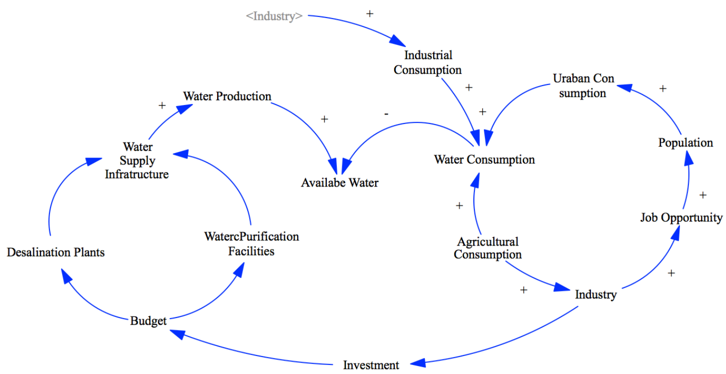

Figure 2 . General view of system

3.2. Level 2: general view of subsystems

After making a general understanding of the system, we should break down every variable in order to determine the causal loops of the model. In this part, we will explain all of the loops gradually and step by step. First, the main loop will be explained and after that other loops will be added to former loops. Finally, the model will be completed. The casual loop of the model consists of three major loops and three minor loops.

3.2.1. Major Loops

There are three major loops which are originated from three main variables of the model. Budget, Agriculture and urban consumption are these main variables. In the following paragraphs, the major loops will be explained.

- **Budget loop**

The mechanism of providing the budget for water infrastructure is shown in Figure 3. Investing budget devoted to water infrastructure in establishing new facilities such as water purification facilities and desalination facilities or improving current systems leads to more capacity for freshwater production. Current desalination facilities that are implemented by Noor Vijeh company in 2010 have a daily capacity of 175000 m^3. An increase in water production capacity and some other reason which will be discussed in the following paragraphs will cause development in the industry. By the development of industry, investors will be interested in investing their money in the region and it will bring more budget for water infrastructure development (FRONE, 2011).

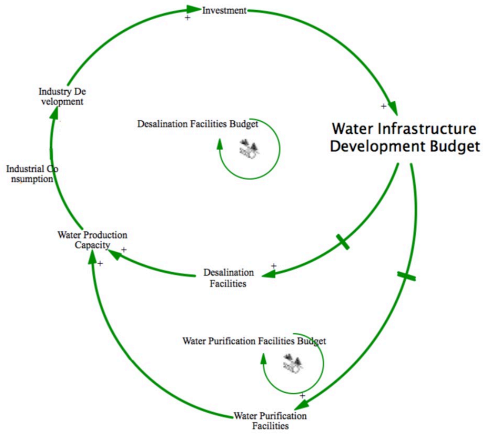

Figure 3. Budget loop

- **Agriculture loop**

Improvement in desalination and purification facilities will provide more freshwater for the region. Since adequate water is one of the most important factors for agricultural development, having enough water will make native people and also other investors interested in developing agriculture in the area. As well as sufficient water, agricultural development requires some equipment such as fertilizer, so agricultural development will increase the demand for such equipment. As a result, investors will invest their money in establishing the companies to satisfy the agricultural equipment demand. This leads to industry development. The explained mechanism is shown in Figure 4.

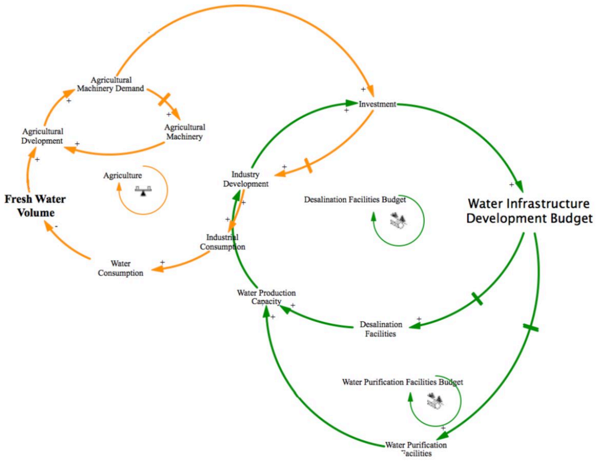

Figure 4. Agriculture loop

- **Urban consumption loop**

Having enough freshwater is a key point that affects the tendency of migration from or to a place. Therefore, adequate freshwater in the region will increase the tendency of foreign people to migrate to Chabahar and also decrease the number of people who have been migrating from Chabahar due to lack of freshwater[1]. Consequently, if enough water is provided for the region, the population will increase. Population growth leads to urban water consumption. As Figure 5 shows, this mechanism makes a goal-seeking loop which results in a decrease in the volume of freshwater.

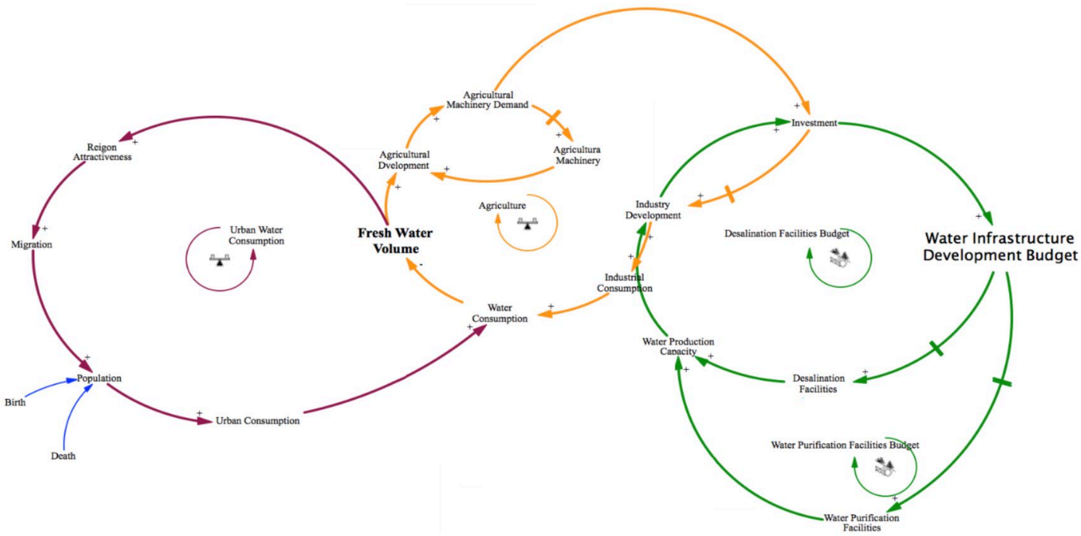

Figure 5. Urban consumption loop

3.2.2. Minor loops

Three minor loops (Cardoso, 2012) are considered to complete the model and determine interrelation between major loops. In the following paragraphs, these loops will be explained.

- **Population loop**

This minor loop indicates the impact of agriculture and industry on urban water consumption. As Figure 6 illustrates, the improvement of industry and agriculture will increase job opportunities in the area and this increase leads to less unemployment rate. The unemployment rate is considered as one of the factors affecting region attractiveness. As a result, the decrease in the unemployment rate increases the region attractiveness.

[1] Mehr news agency (April 7, 2018). The head of the Chabahar city council said," Chabahar has the highest population growth in the world due to the 20-year droughts in Sistan and Baluchistan and the increasing rural migration.".

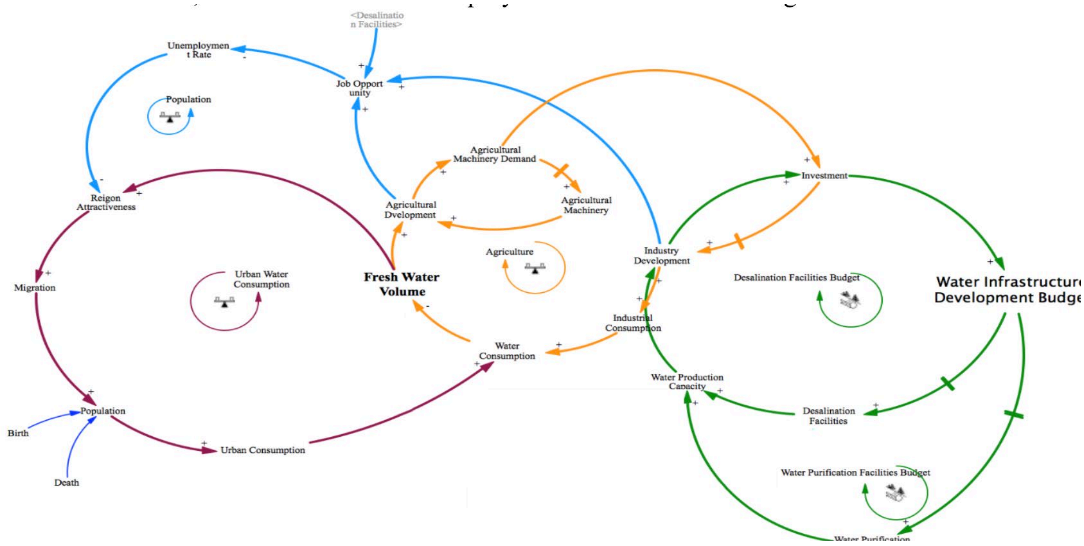

Figure 6. Population loop

- **Desalination facilities**

Improving current desalination facilities increases the volume of freshwater and activates the agriculture development which leads to more investment and brings more budget for water infrastructure development. This mechanism is shown in Figure 7.

Figure 7. Desalination facilities

- **Volume of water in the sewage**

Population growth and more urban water consumption increase the volume of water in the sewage. As a result, the potential for water purification will be increased. Since purification is one of the effective ways to produce more freshwater, as explained before more urban consumption can provide more freshwater through purification. As you can see in Figure 8, This mechanism will influence industry and agriculture along with other sectors which were discussed.

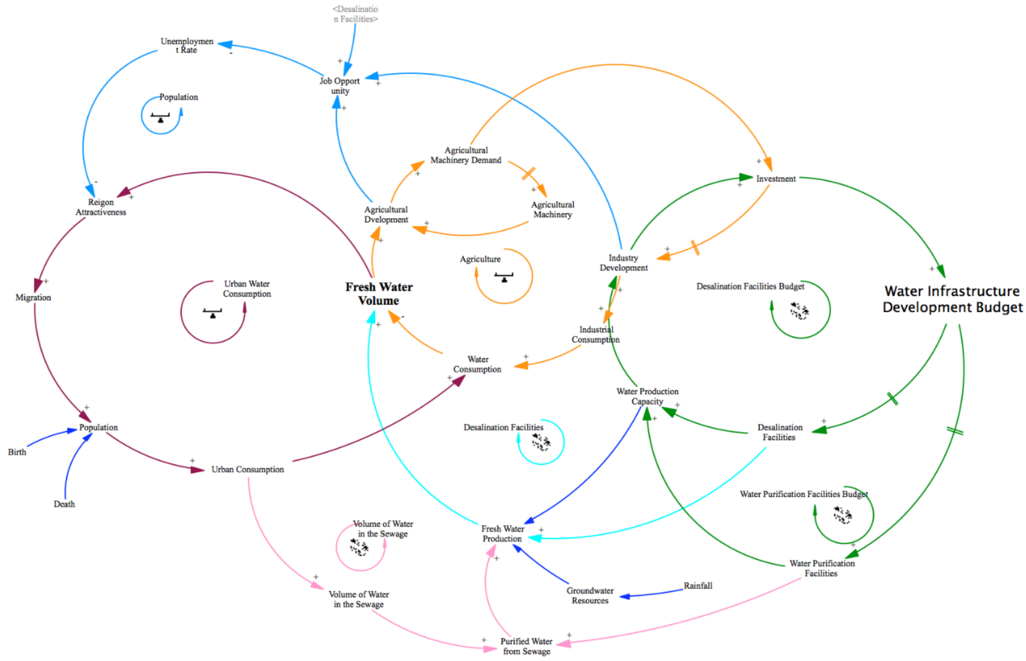

Figure 8. Volume of water in the sewage

3.3. Level 3: Detailed View of Subsystems

The last level of the hierarchy is building a system dynamics model based on casual loops of the second level. In this section, every module of the SD model will be explained. A module consists of a stock variable and the related variables to that stock variable.

- **Population**

The population is assumed to change because of two factors. The first factor is “Net Increase in Population Coefficient” which is considered 0.037 according to the collected data from the population of the region (Sistan and Balouchestan Statistics Annals.).The second factor is migration. To simulate the effect of migration two factors are considered for the attractiveness of the region. According to the geographical location of Chabahar and its weather, sufficient water supply can directly affect migration. Another significant cause that may motivate people to migrate is the job opportunity which will be made by the ndustrial improvement of the region. Therefore, water and employment rate are two factors which are considered for determining the attractiveness of the region. The abovementioned factors are qualitative. To formulate them, they are quantified by using a lookup function. We considered Tehran as a standard city and formed the function in comparison to the condition of Tehran. The lookup functions are shown in Figure 9.

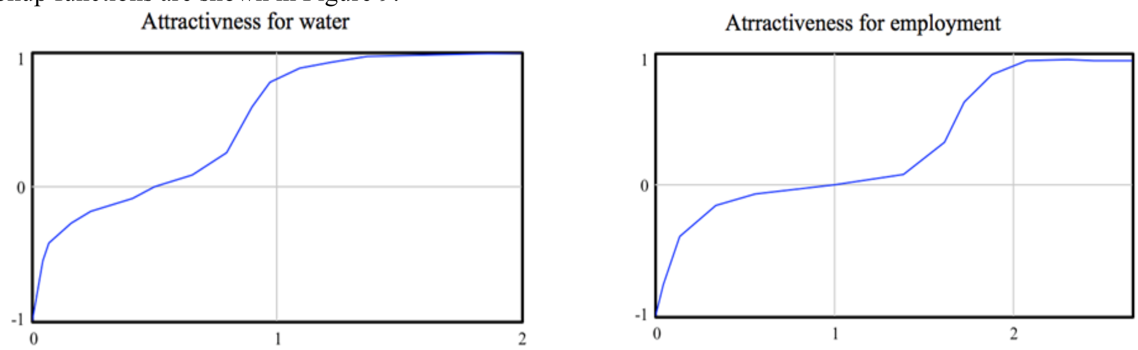

Figure 9 . The look up functions for attractiveness induced by water and employment

- **Volume of water in the sewage**

This stock means the part of the water in the sewage which will be purified with a delay. As it is shown in Figure 9, the stock variable has one input rate variable. The resource of water in the sewage is urban water consumption. Also, the purification facilities have a limited capacity. As a result, in each period regarding the purification capacity and the amount of urban consumption the level of stock changes. Three different outputs are considered for this stock. First, a part of the water will be purified to make freshwater. Secondly, some of the water in the sewage will be cleaned for being used in industrial companies. Cleaning means purifying it in a different way than the one which is considered for freshwater and with less precision. The third one is similar to the second one in the way of cleaning but it is the amount of water which is assigned to agricultural consumption.

- **Volume of water in the desalination**

As Chabahar is located in an arid area, it has been facing water shortage for years. In recent years, due to the development of science and technology in the field of desalination, some programs are being planned and developed for the supply of water in this area. One of these programs is implementing desalination plants which have a daily capacity of 17500 m^3. These facilities were established by Noor Vijeh company in 2010. The amount of water purified by desalination facilities depends on their capacity. The increase in capacity determined by the allocated budget for desalination development and the cost of increasing capacity. Therefore, with these two variables, we can calculate the amount of desalinated water, and the output of these waters will be diverted to the freshwater tanks with a delay of 1 month to be used as freshwater.

- **Freshwater volume**

Groundwater, desalinated water and a part of the water in the sewage which is purified for urban consumption are considered as three major resources for the supply of freshwater. Groundwater level depends on the rainfall which is predicted by using historical data and an exponential regression model. The other two resources which are purified and desalinated water were discussed before. The output of the stock would be urban consumption which is determined by population and per capita consumption.

- **Area under cultivation**

Since wheat cultivation is being done in Chabahar and the potential for its development exists in the region, wheat is considered as the major agricultural product of the region. It is assumed that the factors which contribute to the increase in wheat cultivation area are the amount of water, fertilizer, and workers required per hectare. The area under cultivation that is added each year (in hectares) is the minimum of the following ratios:

- Number of unemployed people divided by the number of workers needed per hectare
- Amount of water available for agricultural consumption divided by the amount of water needed per hectare
- The amount of fertilizer available in the market is divided by the amount of fertilizer needed per hectare

- **Industrial companies**

Since the industry is a complex concept in order to be modeled it should be specifically determined so that we can consider it in our model. As agriculture is one of the major parts of our model we should consider the part of the industry which has more interaction with that sector. Therefore, we assume that the companies which produce fertilizer are the dominant party in this system which is acceptable according to the collected data. In order to formulate the number of new factories in each year, it is assumed that three key factors of the worker, fixed costs of factory construction and demand are involved. Thus the number of new factories per year is the minimum amount of following ratios:

- Number of unemployed people divided by the number of workers needed for each factory
- The amount of budget allocated to the construction of new factories divided by the fixed cost of each construction
- Unsatisfied demand divided by the production capacity of each factory

All of the equations and data which are used in order to build the stock-flow diagram, the stock-flow diagram itself, and the executive model are fully available and access can be made through contacting the authors.

4. Validation and verification of results

According to the approach which has been discussed so far, the water infrastructure in Chabahar is modeled. The model is simulated using Vensim PLE version 8.0 on a MacBook Pro PC by the processor speed of 2.7 GHz. In the following sections, the results will be explained. In this section, we will show the behavior of the stock variables of the model and compare it with the reference modes.

4.1. Population

The result of the simulation for the stock variable is shown in Figure 10 As you can see in the Figure 11 trend of the stock variable is the same as collected data from the Chabahar population in a ten-year period (Sistan and Balouchestan Statistics Annals.).

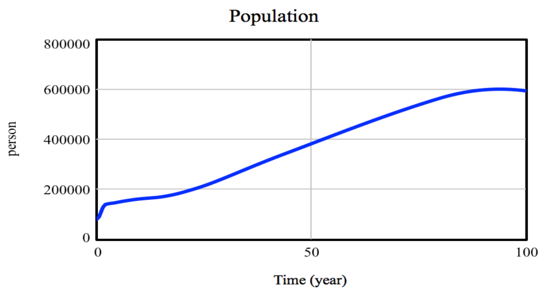

Figure 10. The behavior of population in the model

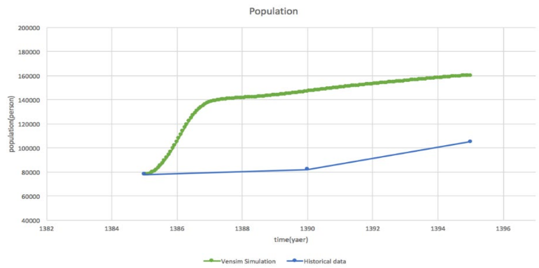

Figure 11. Validation of population

4.2. Freshwater volume

According to the simulated model, the behavior which is shown in Figure 12 has been obtained. In Figure 13, the result of the simulation and the real data is compared and as you can see the result clearly fits the real data plot (Islamic Republic of Iran Meteorological Organization (IRIMO) website, URL: https://data.irimo.ir.).

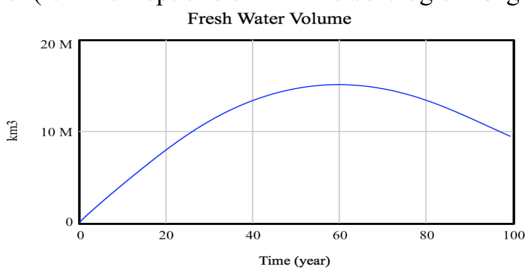

Figure 12. The behavior of freshwater volume in the model

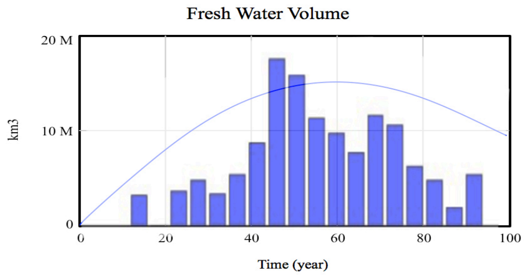

Figure 13. Validation of freshwater volume

4.3. Industrial companies

In our model, we considered the companies which produce fertilizer as industrial companies. As it is shown in Figure 14, until about 20th period no companies will be established and according to the news reported from Chabahar, it is quite true. In this model, we consider 2006 as the begging year for simulation and according to the news, there is a plan for establishing the fertilizer producer companies in Chabahar during future years. In fact, we expect that until 2025 some of these companies will be established. In this case, real data will completely verify our simulation.

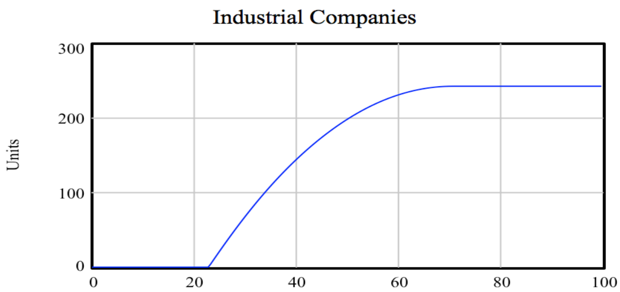

Figure 14 . Industrial companies' behavior in the model

5. Scenario planning

After the validation of model two policies have been examined on the model separately in order to improve the function of the system. In the following paragraphs, these two policies will be explained. the simulation results of adopting them will be discussed.

5.1. Importing Water

According to the results of the simulation, the volume of water produced by the desalination facilities is negligible compared to the total freshwater in the region, while the budget allocated to the construction and expansion of the facility is substantially higher than other investment costs. As a result, we looked for an alternative way of supplying freshwater with the allocated budget to desalination facilities. Since Chabahar is a free-zone importing freshwater can be more cost-effective than producing it through desalination. A switch variable is considered for assigning the desalination budget to import water.

As we see in the model, we have a steady investment volume, which can be spent in two parts of the desalination plant or the water importation, since the cost of building and maintaining fresh water equipment is higher than the importation cost in the first few years, it is preferable to desalination plants.

It is quite expected that the population has a positive correlation with the amount of water available to the region. As shown in the model, one of the factors affecting the population will be the amount of water available to each person, which will be increased by the imported water. The increase is visible in Figure 15.

As it is shown in Figure 16 after adopting this policy the behavior of the Freshwater volume will be more stable than the original behavior if the model in which desalination plants were used to provide freshwater.

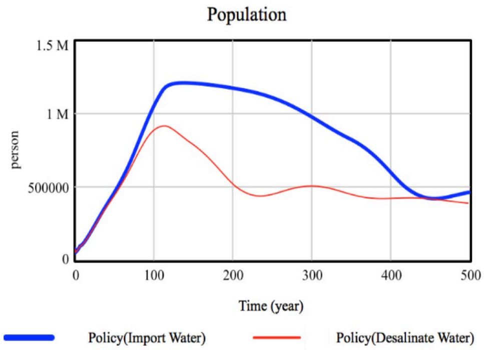

Figure 15. Population after adopting import water policy

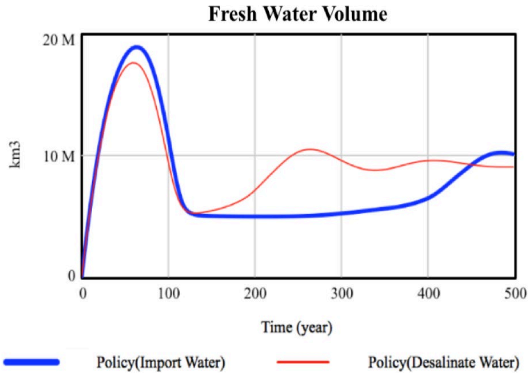

Figure 16. Freshwater volume after adopting import water policy

As it is shown in Figure 17,Due to the delay in the import of water into the region, it is predicted that the number of industrial units (compared with the main model) will not change for a while. But as the volume of water imports grows, the number of desalination plants decreases (thus reducing the region's industrial production capacity).

To interpret agricultural growth in water importation, we should be noticed that in this scenario population is growing faster so the volume of water in the sewage will increase and since the agricultural volume changes according to the volume of water in the sewage (not the volume of potable water), therefore it's reasonable that the area under cultivation would be larger in water importation. The comparison can be seen in Figure 18.

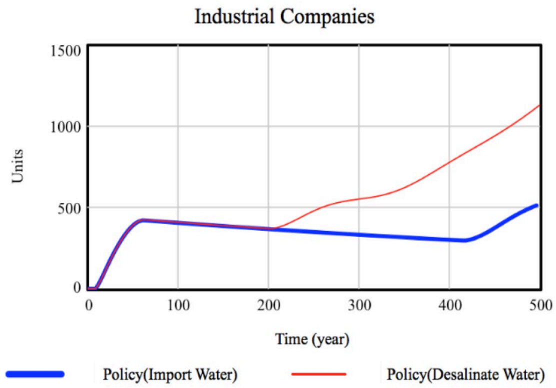

Figure 17. Industrial companies after adopting import water policy

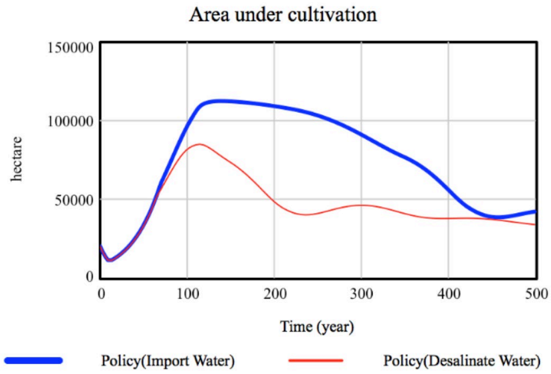

Figure 18. Area under cultivation after adopting import water policy

5.2. Variable budget coefficient

Another policy which can increase the productivity of the system is considering variable coefficient for assigning budget to different fields. In the current model there are three constant coefficients which determine the amount of allocated budget to industry, desalination facilities and agriculture. We designed a policy in which the whole budget will be aggregated in a stock variable and be distributed to three aforementioned fields. To do this, we considered a coefficient for every field which indicates the importance of investment on that field in a scale of 0 to 1 in every period. The summation of these coefficients will be 1 in every period. In the following paragraphs, it will be discussed that how the coefficients have been formulated.

- **The coefficient for industry:** Industry development and more investment on that will be important when there is a potential for development in the industry, in other words when the potential demand is higher than the current demand. Accordingly, the importance of the industry is equal to the ratio of unsatisfied demand to the current demand.

- **The coefficient for agriculture:** In this policy, investment in agriculture will increase when there is a high potential for agriculture. Agricultural potential refers to areas where no crop is cultivated, in other words, the difference of total hectares for cultivation from the cultivated lands. So, the weight and importance of agriculture is equal to the ratio of agricultural potential to agricultural land.
- **The coefficient for desalination facilities:** The criterion for deciding whether to invest in desalination facilities is urban consumption. Whenever urban consumption deviates significantly from normal consumption, the mode of investment must change. If consumption is higher than normal, investment should be reduced and if consumption is lower than normal, investment in desalination should be increased. In this case the weight and the importance will be equal to the ratio of the difference in water consumption per person from normal to individual consumption.

In this policy, we have population control at a constant level without drastic changes. As Figure 19 shows, in the original model, the population had been increasing exponentially, which would certainly be difficult to afford but in this scenario, we will achieve the desired level with population control and drinking water supply.

Another positive point in this policy is that we prevent overshoot behavior in water volume, as we observed in model behavior, the water volume had an undesirable behavior for water supply infrastructure, and It will cost a lot. As you can see in Figure 20, after adopting this policy the freshwater volume will reach to a stable state.

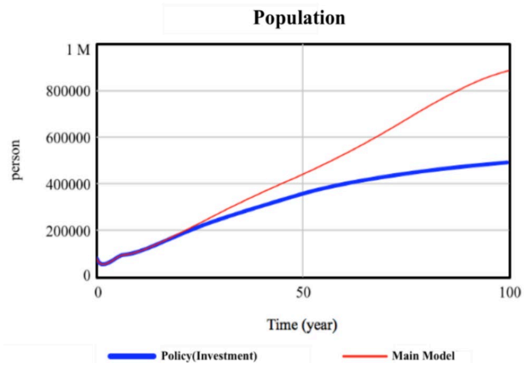

Figure 19. Population after adopting variable budget coefficient policy

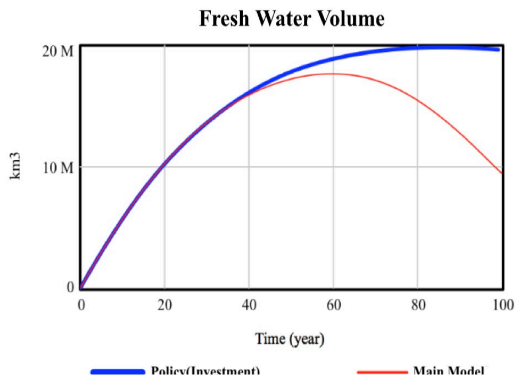

Figure 20. Freshwater volume after adopting variable budget coefficient policy

The most important advantage of adopting this policy is determining the budget coefficient for investment in different fields (FRONE, 2011). In this population, according to the productivity of investment (the growth in the field in comparison to the investment in that field), a dynamic budget allocation will be done. As it is shown in Figure 21, these dynamic coefficients will reach a stable state. Therefore, by adopting this policy we can determine a budget allocation in which the system will have more productivity with the same amount of budget.

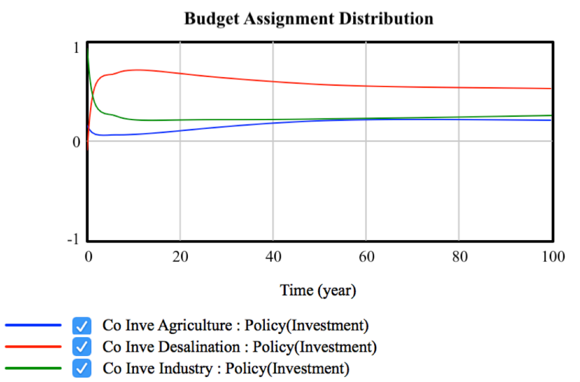

Figure 21. Dynamic budget allocation coefficients

6. Conclusion

One of the most important factors for the development of free zones which are located in undeveloped areas is providing freshwater. Water infrastructure and its impact on other major parts of the free-zone development like industry, agriculture, and population have not been studied with a holistic approach yet. In this research, a three-layer SD modeling methodology is utilized to fill the gap, which is an improvement in comparison to the flat SD modeling approach. In order to build the model, three major and three minor loops are considered. After building the model, validation and verification of the model are done using the simulation results. Two scenarios are designed to improve the performance of the model. The first scenario which is named "importing water" leads to a more cost-effective way to provide the required water. The second one is the "variable budget coefficient" which makes the system more sustainable and determines a budget allocation strategy. We hope that in future research these two scenarios will be developed further and other important factors like water price and stochastic demands will be considered.

Reference

Bagheri, A. & Hjorth, A framework for process indicators to monitor for sustainable development: practice to an urban water system. *Environment, Development and Sustainability*, 9, pp. 143-161, 2007.

Ben Ramalingam, Harry Jones, Toussainte Reba, John Young. Exploring the science of complexity Ideas and implications for development and humanitarian efforts, Second Edition, *Overseas Development Institute*, Westminster Bridge Road, London, 2008.

Cardoso, M. A. ,Urban water infrastructure asset management–a structured approach in four water utilities. *Water Science and Technology* 66.12, pp. 2702-2711, 2012.

Clifford Holmes, J. K., Slinger, J. H., Musango, J. K., Brent, A. C. & Palmer, C. G. ,Using system dynamics to explore the water supply and demand dilemmas of a small south african municipality. 32nd *International Conference of the System Dynamics Society*, Delft, The Netherlands, Authors version, System Dynamics Society, Netherlands, pp. 20-24, 2014.

Entezam, H. Farmani. 2019. Extracting Sustainable Urban Water Policies with Dynamic System Approach. *Journal of Water and Wastewater.*

FRONE, Simona, and Dumitru Florin FRONE. Prospects of Investment in Water Infrastructure: standing for Sustainable Development. *Quality-Access to Success,* 2011.

Islamic Republic of Iran Meteorological Organization (IRIMO) website, URL: https://data.irimo.ir.

Moloney, Brendan, Matthew Doolan, and Barry Newell. A System Dynamics analysis of the Bottled Water Industry in the United States.

Simonovic, Managing flood risk, reliability and vulnerability, *Journal of Flood Risk Management* 2.4 : pp. 230-231.

Sistan and Balouchestan Statistics Annals, 2009.

Sterman, J., *Business dynamics: systems thinking and modeling for a complex world*, McGraw-Hill, 2000.

Winz, Ines, Gary Brierley, and Sam Trowsdale. The use of system dynamics simulation in water resources management. *Water resources management* 23.7, pp. 1301-1323, 2009

Zarghami, M. & Akbariyeh, S.,System dynamics modeling for complex urban water systems: Application to the city of Tabriz, Iran. *Resources, Conservation and Recycling*, 60, 99-106, 2012.

Biographies

Abolfazl Taghavi is majoring in industrial engineering at Sharif University of Technology. His research interest is simulation and analysis of complex systems with system dynamics and agent-based modeling approaches. He is going to continue his research on agent-based modeling and he is currently working on optimization in agent-based models.

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