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The Construction and Application of Sustainable Development Model for Bangladesh Based on System Dynamics

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ABSTRACT

Sustainable development is to reconcile human needs and the Earth's healthy balance. For eradicating poverty, changing unsustainable, promoting sustainable patterns of consumption and production, protecting and managing the natural resource, combining principles and methods of system dynamics modeling, we build a sustainable development model by analyzing the factors which influence the sustainable development. According to social economic development, the dynamics of environmental change, change of energy and matter between the subsystems and information interaction, the sustainable development model is divided into four subsystems, such as environment, resources, economy and social. In the model, the factor of sustainable development can distinguish more sustainable countries and policies from less sustainable ones. Then, we analyze the data of Bangladesh and predict the factor of sustainable development. By revising the parameters, we create a 20 year sustainable development plan for Bangladesh to move towards a more sustainable future to evaluate the effect our 20-year sustainable plan has on Bangladesh's sustainability measure. By implementing our plan in our evaluation, we predict the change that will occur over the 20 years in the future. Through on the analysis of our model, we give some reasonable policy suggestions for sustainable development of Bangladesh.

Indexing terms/Keywords

System Dynamic; simulation; sustainable development model; linear regression

Academic Discipline And Sub-Disciplines

Applications of mathematics in social sciences

SUBJECT CLASSIFICATION

MSC: 97M70 03C98

TYPE (METHOD/APPROACH)

System Dynamics method

INTRODUCTION

One of the largest challenges of our time is how to manage increasing population and consumption with the earth's finite resources. In order to reconcile this difficult balance, the concept of substantial development was introduced in the 1980's. Sustainable development is defined by the 1987 Brundtland Report as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Understanding that the earth is a system that connects both time and space is critical to sustainable development. Decreasing personal poverty and vulnerability encouraging economic development, and maintaining ecosystem health are the pillars of sustainable development.[1-5]

Sustainable Development is probably the key new paradigm on which to base policies for the future. However, so far the concept remains vague at best in many aspects, and in particular as regards the interaction environmental, economic and social politics. There is a trade off between growth and employment on the one and environmental concerns on the other hand, however sustainable compromises are possible. The concept of sustainability is defined as "to meet the needs of the present generation without compromising the ability of future generations to meet their own needs.[3] The system border is one of the variable factors of the system, which is used to determine the scope of the study object. Since then, there has generally been recognition of four aspects of sustainable development in the extensive discussion and use of the concept.

The model can clearly define when and how a country is sustainable or unattainable. Research on the Economy-Energy-Environment system is becoming more and more important in the field of sustainable development nowadays. It can be used to inform us on those countries that need the most support and intervention. The model should clearly define when and how a country is sustainable or unattainable. We propose the sustainable development model which has resonance at a commonsense level. They meet the criterion set forth earlier for a powerful, easily grasped concept which can have wide applicability. Surely if we could come closer to achieving this goal, the world would be a better place – and equally surely we frequently fall short in all the respects. It may be easy to identify unsustainability than sustainability and the identification of unsustainability can motivate us to take necessary policy action.

The rest of this paper is organized as follows. In the following section, we construct an Economy-Energy-Environment-Society system dynamics(SD) model for the sustainability of a country. In the model, we set the energy structure and the environmental investment as the adjusting parameters. By the model, we provide a measure to distinguish more sustainable countries and policies from less defensible ones. According to socio-economic progress, the dynamics model changes of energy and matter between the subsystems and information interaction, the four subsystems of society,

environment, resource, economy were connected. In Section 3, we select Bangladesh, which is a country from the United Nations list of the 48 Least Developed Countries (LDC) list. Through a combination of the variable are adjusted or several variables control experiment, and put it into the model to analysis and prediction. Evaluate the effect 20-year sustainability plan has on the country's sustainability measure created in Section 2. Based on the selected country, we consider additional environmental factors such as climate change, development aid, foreign investment, natural disasters, and government instability with the conclusions given in Section 4.

CONSTRUCTION OF SUSTAINABLE DEVELOPMENT MODEL BASED ON SYSTEM DYNAMICS

This model provides a measure to distinguish more sustainable countries and policies from less sustainable ones. Some factors may include human health, food security, access to clean water, local environmental quality, energy access, livelihoods, community vulnerability, and equitable sustainable development. The model need clearly define when and how a country is sustainable or unattainable. This model not only can compare to the sustainable development of comprehensive analysis, can also verify the correctness of the sustainable development.[4-5] The causal feedback of Economy-Energy-Environment system can be seen in Fig 1.

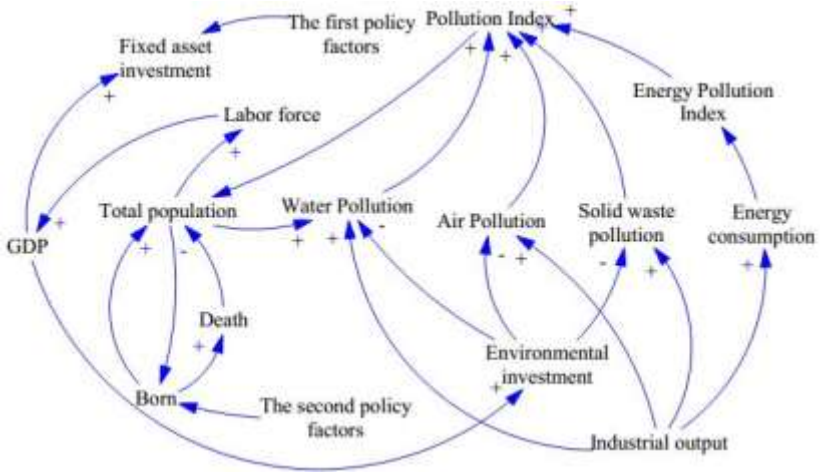


Fig 1: The Economy-Energy-Environment system of causal feedback

The formula is

$$SD = \frac{ZY + XF - HJ + YW}{JJ}, \qquad (2.1)$$

where *SD* is Sustainable development factor, it can provide a measure to distinguish more sustainable countries and policies from less sustainable ones. *ZY* is per capita occupancy of resources. *XF* is the average consumption expenditure. *HJ* is pollution load per unit area. *YW* is per capita water resources. *JJ* is per capita GDP.

Social subsystem

Population and the quality are the most important factor for sustainable development. In the subsystem, the number of population is determined by the amount of population. The amount of population is determined by birth and death. The amount of labor is determined by the amount of labor to move to vacate the decision. Labor immigration rate and quit rate and population birth and death rates are obtained by fitting the data by the calendar year in which the population of the birth and death rates in line with the normal distribution. Fig 2 is the flow of population subsystem.

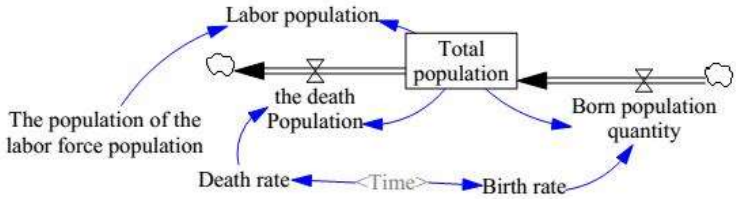


Fig 2: The flow of population subsystem

Economic subsystem

Economic subsystem is the material basis of sustainable development. The pursuit of economic development is part of the dynamic of the development of human society.[4] But if only the number of economic growth, during the abuse of natural resources in the early stage of the economy, it may increase exponentially. As the result of non-renewable resources dried

up quickly, renewable energy regeneration is suppressed, making the supply of the resource to meet the needs of economic development. It leads to late backward economic development and environmental pollution is determined. The contradiction between economy and environment is more and more highlighted. Therefore, the sustainable growth of the economy is proposed. The efficiency is rather important than pursuing growth speed. In Fig 3, the state variable GDP is determined by growth in GDP. And instrumental variable such as the GDP growth rate is based on historical data for fitting. The flow of the economic subsystem is Fig 3.

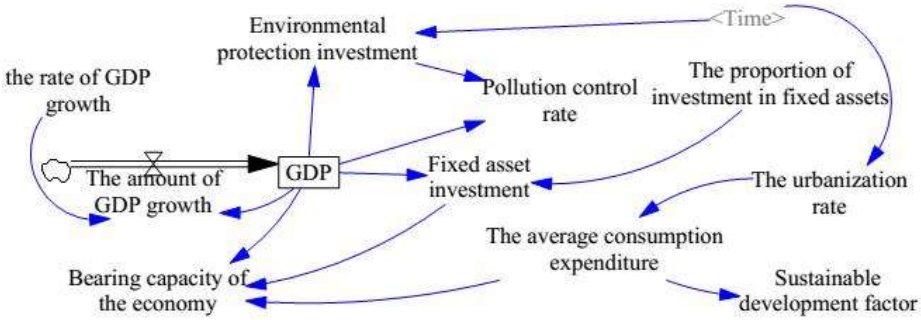


Fig 3: The flow chart of Economy Subsystem

Subsystem of resources

Resource is the basic condition of social development, sustained and effective utilization of resources is the premise of sustainable development. Resource is made up of land, water, mineral natural resources and their exploitation and utilization system.[6-7] Meanwhile, the human social and economic constantly develop, which their own continually provide material and energy circulation. However, the total resources are limited. The unreasonable use of resources will lead to insufficient resources and ecological environment is destroyed. It has a negative effect on the sustainable development of social economy. Capacity of water resources, mineral and available land, is each determined by water annual increment, mineral resources in growth and land construction, capital construction elements. Set capital construction and cover the land as constant, mineral growth, the growth rate of water resources and land development assess combine the data of former years. The flow of resource subsystem is Fig 4.

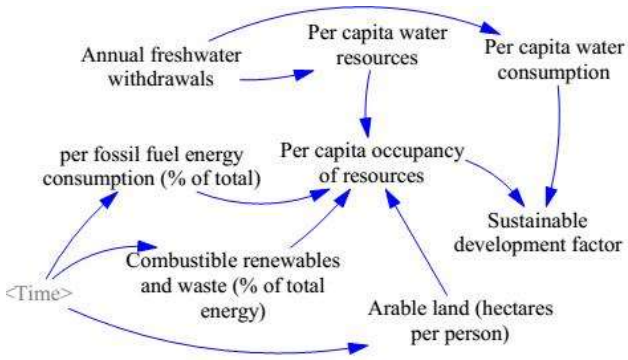


Fig 4: The flow chart of Resource Subsystem

Environment subsystem

Environment subsystem is the material basis of sustainable development. The pursuit of economic development is part of the dynamic of the development of human society.[8] But if only the number of economic growth, during the abuse of natural resources in the early stage of the economy could increase exponentially. But as a result of non-renewable resources dried up quickly and renewable energy regeneration is suppressed, making the supply of the resource to meet the needs of economic development. It leads to delayed environmental pollution is serious, the contradiction between economy and environment is more and more highlighted. Therefore, realize the sustainable growth of the country, the environment is rather important than pursuing growth speed. The flow of environment subsystem is Fig 5.

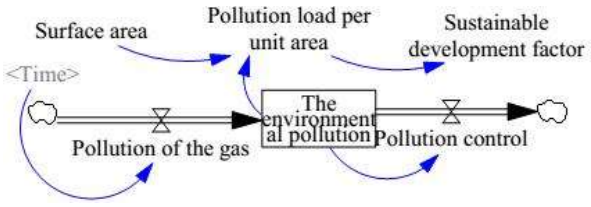


Fig 5: The flow chart of the environment subsystem

Result Analysis

The qualitative evaluation of standardization is

$$C = \frac{EBI}{EWI}, \qquad (2.2)$$

where *C* is Continuous index, it can define how a country is sustainable or unsustainable. *EBI* is economic benefit index, and *EWI* is ecosystem welfare index. Each indicator will be divided into excellent, good, medium, low, poor five levels, each grade were 1, 0.8, 0.6, 0.4, 0.2. Ratio closer to 1, it means that the better sustainability.

Table 1: The class of Sustainable Development

[0, 0.2]	[0.2,0.4]	[0.4,0.6]	[0.6,0.8]	[0.8,1]
unsustainable	Basic unsustainable	Medium sustainable	Basic sustainable	sustainable

Judging a country whether achieve sustainable is a dynamic process, it is by the economy, the environment, resources, social and other elements to the decision, and only when the ratio of the economic system through welfare benefits and ecosystem close to 1 (0.8-1 indicators between), will achieve a sustainable state. To achieve a sustainable level, it means to achieve a healthy balance between economic development and ecological systems.

THE SIMULATION OF SUSTAINABLE DEVELOPMENT MODEL FOR BANGLADESH

By analyzing the factors which influence sustainable development, combined with dynamic simulation software Vensim, and the system model, and construct a complete prediction experiment system dynamics model of sustainable development. Taking Bangladesh as an example, to study the regional sustainable development, according to the number, population in this area in the birth rate, mortality rate, the amount of labor and immigration and emigration area distribution of each land type, variation of GDP, urban and rural Engel coefficient data, determine the basic parameters required for the model, simulation was carried out with the analysis of the regional system based on the sustainable development of Bangladesh, through on the analysis of the model, put forward some reasonable policy suggestions for sustainable development of this area.

The basic information of Bangladesh

The People's Republic of Bangladesh is a nation in South Asia. It is bordered by India on three sides. Myanmar to the southwest and the Bay of Bengal forms the southern coastline. Together with the Indian state of West Bengal, it comprises the ethno-linguistic region of Bengal. The population of Bangladesh ranks 8th in the world, but its area is ranked 93rd, which is approximately 144,000 sq km. It is 3rd among Muslim-majority nations, though it has a slightly smaller Muslim population than the Muslim minority in India. It is also one of the most densely populated countries in the world.

The imitative operation and analysis of model

According to the principle of determining the control variable, we set the time boundary for the year 2009 to 2030 with the simulation system of natural process and regard 2009 as the basical period data simulation. We use the model to analysis and prediction after the variable adjusting and controlling experiment of several variables.

Population

By looking up World Bank Date, we obtain data of Population from year 2010 to 2013. See Table 2.

Table 2: The factors related to population

	2010	2011	2012	2013
Total population	151125475	152862431	154695368	156594962
Death rate, crude(%)	0.6	0.6	0.6	-
Fertility rate, total	2.3	2.2	2.2	-
Population growth	1.1	1.1	1.2	1.2
Urban population	30	31	32	33
Life expectancy at birth, female	70	71	71	-
Life expectancy at birth, male	68	69	70	-

By analyzing the population data of Table 2, based on the trend, we use the logistic model to forecast Bangladesh's population in the future 20 years.

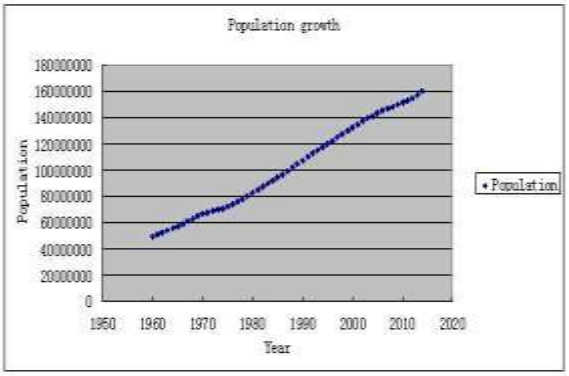


Fig 6: Flowchart of population growth in Bangladesh

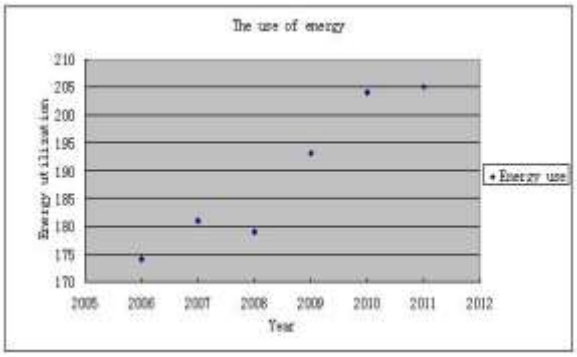


Fig 7: Flowchart of resource growth in Bangladesh

We can see that $R^2 = 0.989$ is close to 1 from Fig. 6, which shows the linear regression (3.1) is good. Then we use the regress equation (3.1) to predict Bangladesh's population between 2014 and 2030.

$$y_1 = 6*10^{-12} e^{0.0223x_1}, \qquad (3.1)$$

where y_1 indicates the number of the population, x_1 indicates the year.

Resource

By looking up World Bank Date, we obtain data of Resource from year 2010 to 2013. See Table 3.

Table 3: The factors related to resource

	2010	2011	2012	2013
Energy use	204	205	-	-
Forest area	144220	14394	14368	-
Agricultural land	70	70.1	70.1	-
Annual freshwater withdrawals	-	-	3.59	3.59
Arable land	59.5	58.6	59	-
Access to electricity	55.2	-	-	-
Fossil fuel energy consumption	71.4	71.5	-	-
Combustible renewables and waste Water productivity	28.4	28.2	-	-
Water productivity	-	-	3	3

By analyzing the above resource data, based on the trend, we get the regress equation (3.2), and we use the regress equation (3.2) to forecast the resource of Bangladesh in the future 20 years.

We can see that $R^2 = 0.914$ is close to 1 from Fig 7, which shows the linear regression is good. Then we use the regress equation to predict the energy between 2014 and 2030.

$$y_2 = 6.8x_2 - 13468, \qquad (3.2)$$

where y_2 indicates the ues of energy, x_2 indicates the year.

Environment

By looking up World Bank Date, we obtain data of Environment from year 2010 to 2013. See Table 4.

Table 4: The factors related to environment

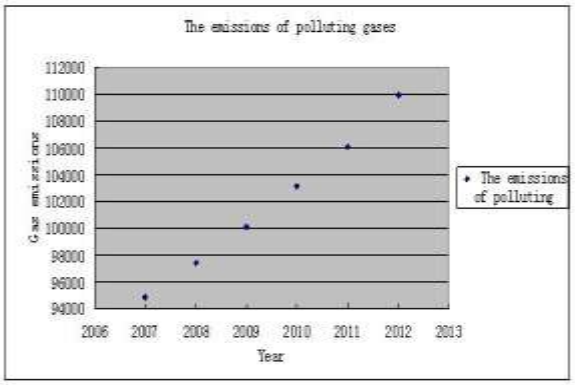
	2010	2011	2012	2013
CO_2 emissions	0.4	0.4	0.4	0.5
Agricultural methane emissions	68.3	68.2	68	68
Other greenhouse gas emissions, HFC, PFC and SF6	0	0	0	0

Methane emissions	103080	106079	109950	-

By analyzing the above environment data, we get the regress equation (3.3). We can see that $R^2 = 0.9948$ is close to 1 from Fig 8, which shows the linear regression (3.3) is good. Then we use the regress equation (3.3) to predict the emissions of polluting gases between 2010 and 2030 in Bangladesh. The predicating equation is

$$y_3 = 2982.6x_3 - 6000000 \qquad (3.3)$$

where y_3 indicates the emissions of polluting gases, x_3 indicates the year.



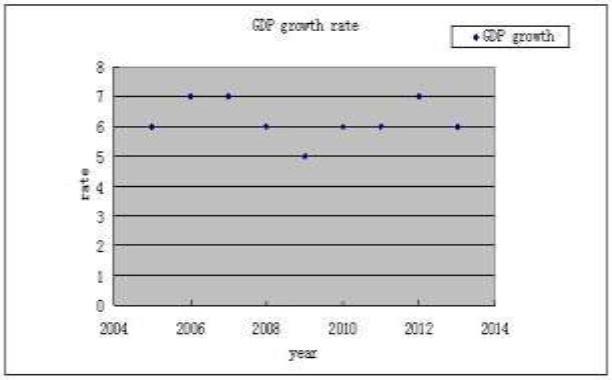


Fig 8: Flowchart of environment growth in Bangladesh **Fig 9: Flowchart of GDP growth in Bangladesh**

Economic

By looking up World Bank Date, we obtain data of Economic from year 2010 to 2013. See Table 5.

Table 5: The factors related to economic

	2010	2011	2012	2013
Agriculture, value added	17.8	17.7	17.1	16.3
GDP per capita	762.8	841.5	862.1	957.8
GDP per person employed	3841	4004	4146	-
Foreign direct investment	861736237	1184776059	1474542605	1501647072
Cash surplus/deficit	-0.8	-0.8	-	-
Current account balance	168042394	380885639	3216119668	2366161992
Net official development assistance	1414950000	1490020000	2152090000	-

By analyzing the above economic data, we get the regress equation (3.4) about GDP growth rate and the year. We can see that $R^2 = 0.873$ is close to 1 from Fig 9, which shows the nonlinear regression is good. Then we use the regress equation (3.4) to predict the GDP growth rate between 2010 and 2030 in Bangladesh. The regress equation for GDP growth rate is

$$y_4 = 0.0281x_4^2 - 113.09x_4 + 113642 \qquad (3.4)$$

where y_4 indicates the growth rate of GDP, x_4 indicates the year.

The model simulation

By the sustainable development model, we get the sustainable development factor of Bangladesh. From Fig 10, we can find that the sustainable development factor of Bangladesh is continually increasing. By analyzing the social, economic, resource and environmental factors provided in 20 years, we can conclude that Bangladesh will have a sustainable future.

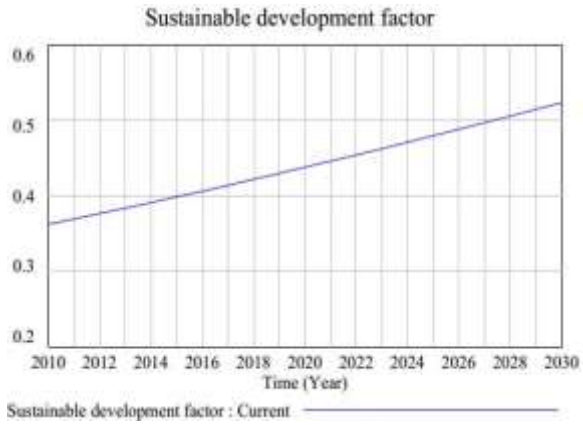


Fig 10: Sustainable development factor

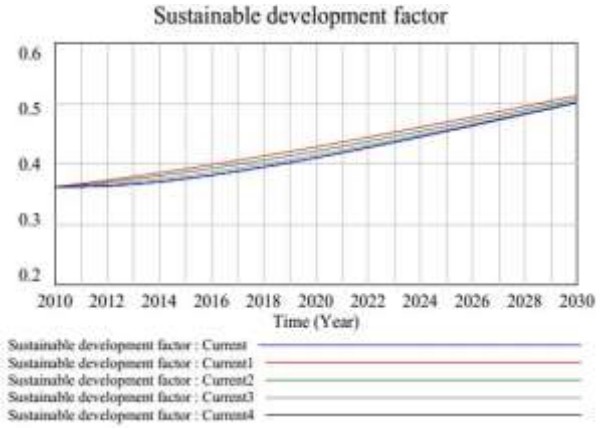


Fig 11: The impact of foreign investment

If such a combined strategy is applied, it is possible to improve the currently sustainable high levels to significantly below four percent of the labor force, while at the same time reducing resource consumption, safeguarding or increasing the standard of living and not running into significant public debt.

With climate change, global warming, sea level rise, the land area is reduced, the sustainable reduction factor is changed, but the effect is not obvious. Through increased foreign investment and development assistance, the sustainable factor increases with the GDP increasing. See Fig 11 in detail. The Natural disasters result in the total population decreasing, the amount of GDP increasing, and the amount of pollution increasing. So that, the sustainable development factor changes. See Fig 12 in detail.

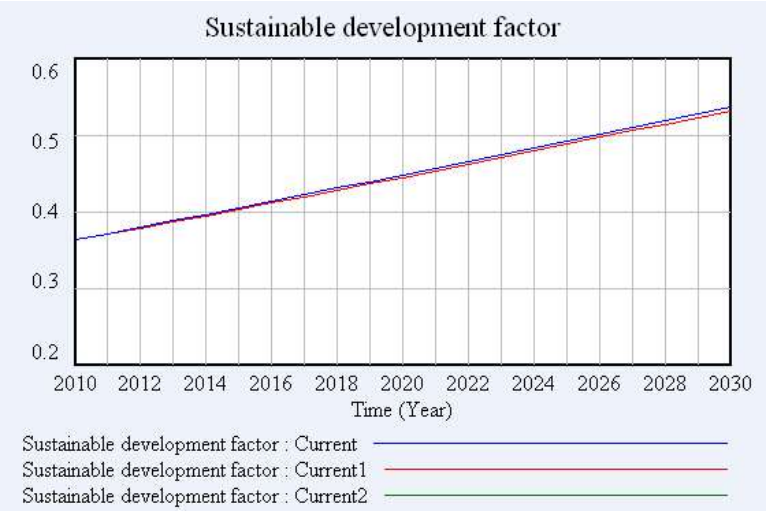


Fig 12: The impact of natural disaster

With the various types of changes, we can see that the total area have a tendency change in Bangladesh between 2010 and 2030. It also reflects an obvious tendency in the future 20 years. By the development of Bangladesh economy, the citizen's living standard will be continuously improved.

Suggestions

World Commission on Environment and Development in the extensive discussion and use of the concept, there has been a growing recognition of three essential aspects of sustainable development.

Economic: An economically sustainable system must be able to produce goods and services on a continuing basis, to maintain manageable levels of government and external debt, and to avoid extreme sectoral imbalances which damage agricultural or industrial production.

Environment: An environmentally sustainable system must maintain a stable resource base, avoiding over-exploitation of renewable resource systems or environmental sink functions, and depleting nonrenewable resources only to the extent that investment is made in adequate substitutes. This includes maintenance of biodiversity, atmospheric stability, and other ecosystem functions not ordinarily classed as economic resources.

Social: A socially sustainable system must achieve fairness in distribution and opportunity, adequate provision of social services including health and education, gender equity, and political accountability and participation.

CONCLUSIONS

Sustainability is a multi-dimensional concept that takes into account different elements of territorial development, such as economic growth, well-being of population, environmental quality, etc. Since the early '90s many countries and international organizations have been working on sustainable development assessment by means of specific indicators. With specific reference to urban areas, the indicator approach is useful to give information about the sustainability condition of the system under examination and it can be used in order to make provisions about future sustainable trends. Urban residential areas, facing restriction by social-economic level, environmental pressure, population pressure and traffic pressure, etc, also attract growing attentions nowadays as an important component of sustainability study. It can be possible to conclude that the integration of System Dynamics model and GIS technology is a feasible and effective strategy to study sustainable development. The methodology allows the decision makers to predict the single unstable factor or follow up the entire sustainability situation in the process of residential development with a quantitative criterion.

System Dynamics is a realistic tool for sustainability assessment, utilized to better understand the sustainable development in a considered period and forecast the future trends. Firstly, we check the model's fundamental network property from the perspective of fit, critical nodes, and missing relationships. As case studies, we applied our model to specific nations on a time span of 2010-2013, namely Bangladesh in the hope to demonstrate that our model is able to generate prediction and warnings of state changes, and provide information for decision-makers. The sustainable development model which is based on system dynamics, has shown a completeness of functionality and impressive flexibility in these tests. We can see that the prediction test of t he sustainable development model coincides fairly well with the fact. Compared to other simulation approaches, System Dynamics model is more beneficial to explain the developing trends of dynamic behaviors in the long-term (simulation duration) owing to its feedback structure and capability to function under different parameter settings and initial inputs. Thus the SD model could assist decision makers with the simulation results to develop sustainability policies.

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Author' biography

Liguo Huang was born in Shandong Province, China. He obtained his Bachelor degree in Information and Computer Science from Shandong University of Science and Technology in 2003. He earned his Master degree in Operational Research and Cybernetics from Shandong University of Science and Technology in 2006. Then, he worked in Binzhou University. His research interests are the application of mathematics in social sciences.