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Rice Self-Sufficiency Model to Enhance the Food Security Status in Nepal

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ABSTRACT

The study focuses on the slow growth of rice production in Nepal and the country's heavy reliance on rice imports to meet its food demand. The government has been spending a significant portion of its budget on imports, and it aims to reduce this dependence by increasing domestic production and achieving food security goals. To understand the dynamics of this issue, system dynamics modelling steps were employed. The key variables considered in the model testing were domestic production, imports, per capita consumption, productivity per hectare, and average area expansion rate. The study utilized time series data from 1991 to 2020 and projected the analysis up to 2050 using Stella Architect, a computer-based software program. The findings reveal that both the population and imports have exhibited exponential growth over the years. The model also indicates goal-seeking behaviour, with the government setting targets for yield increment based on available harvest areas. However, the policies implemented thus far have mostly been quick-fix approaches focusing input subsidized programs. According to the model, an increase of 70-100% in rice production will be required by 2050 to meet the growing population's demand. The study presents three policy options for achieving rice self-sufficiency: 1) a 2% annual increase in average area expansion, 2) raising productivity from 3700 kg ha^{-1} to 5000 kg ha^{-1} and 3) increasing productivity to 3900 kg ha^{-1} while reducing per capita rice consumption from 200 kg to 130 kg. The study suggests that adopting the recommended policy implications can help increase rice production in Nepal. Decision-makers should adopt a dynamic approach to the rice production system to address the issue of slow growth and achieve national self-sufficiency and food security goals.

Keywords: rice production, food security, self sufficiency

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INTRODUCTION

Rice is one of the major staple crops for food security in Nepal. Rice contributes 50% of grain and 30% of calorie requirements (Bhandari et al 2015). Nepalese have cereal-based dietary food habits and rice contributes basics of cereal requirements. It is a fundamental source of carbohydrates (Subedi et al 2017), according to National Living Standard Survey NLSS (2011), the consumption of milled rice was 122 kg $person^{-1}year^{-1}$ out of 191 kg of total cereals consumed per year. It also provides livelihoods for 65% of the population engaged in agriculture. Annual rice harvest has a direct impact on food security and the national economy. In the fiscal year, 2019/20 total cultivated area and production was 1,458,915 ha 5,550,878 mt. ton. while during the year 2011/2012 1,531,493 ha and 5,072,249 mt ton respectively (MoALD 2020). Rice production in Nepal is predominantly affected by the prevailing monsoon of the growing year, availability of chemical fertilizer, seed use, diseases and pests, and government policies. During the 1970s and before, Nepal used to export rice to India, however, rice production is slowed over the years and Nepal is relied on imports since 1981 to fulfil the demand. Moreover, *Dhan-Chamal Niryaat Company* (Rice Export Company) was dissolved in 1981 because of a lack of rice to export overseas. Therefore, Nepal becomes a net importer of rice after 1981. There could be many reasons for skyrocketing imports such as, low domestic production, population growth, change in food habits, and easy accessibility.

Meeting the domestic demand and to substitute the import the government of Nepal implemented several programs such as the "Special Agriculture Production Program" was implemented in 2012 to support seed and fertilizer subsidy to farmers, "Mega Rice Production Program" started in 2015, targeting expansion of the area of spring rice and NRs 5000 per ha was provided to the growers. Similarly, the "Fine and Aromatic Rice Production Program" was implemented in 2014/2015 to substitute the import however the output of all the programs and investment remains unsatisfactory, and import has risen further. Those government-initiated quick-fix approaches gave a positive result in the short term however something is lacking to achieve the targeted goal. Based on programs and policies mainly four interventions that had taken by the government; improve seed support, fertilizer subsidy, support price, and import facilitation. In addition, migration, change in food habits, population, and trade policy could be the other variables that make the system iterative (Gauchan et al 2022, Joshi and Maharjan 2007). This report aims to understand the dynamics of the slow growth of rice production, reliance on imports, rice self-sufficiency and the food security dynamics in Nepal.

Five steps represent the system modelling process (Sterman 2000) are involved to study the dynamics. In addition to Sterman (2000), dynamic modelling method illustrated by Maani and Cavana (2007) is also followed. In the first part of the report, problem articulation and dynamic hypothesis is discussed followed by a simulation model, model testing, and scenario analysis and policy design in the second part.

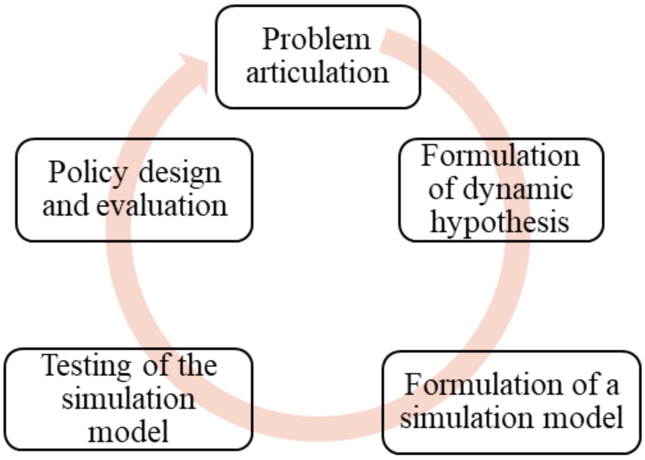

Figure 1: Five steps of the system modelling process

1. Problem articulation

The real problem in this study is why all efforts invested in the increased production of rice are not able to fulfil the demand in Nepal. A set of interacting variables are responsible for the problem. This problem is identified based on the statistical records available for production and import, and previous program and policies to promote rice production. The import of rice from overseas has been increased in recent years to meet the demand. In 2019 rice import value was NRs 30,236,664,342 which is 2% of the total allocated government Budget of that fiscal year (TEPC 2020).

Demand for rice is created by overdependence on the rice-based diet. Rice consumption in Nepal is 122 kg capita^{-1} year^{-1} and its availability is about 94 kg capita^{-1}year^{-1} (Bhandari et al 2015). Prasad, Pullabhotla, and Ganesh-Kumar (2019) calculated optimistic supply for 2030 will be 4,085,000 tons and demand will be 5,764,000 tons. Moreover, Giri et al (2018) reported that based on FAO data in 2013, a 14% increment in yield can substitute all the rice imports in Nepal. Fulfilling the demand from domestic production is a complex phenomenon and it needs to explore interacting variables and their relationship. Key variables such as; production pattern, import, population growth fertilizer subsidy, variety release, improve seed and government policies were considered as dynamic factors affecting the system.

1.1 System behaviour

Goal seeking is the most important behavior of this system. The goal is to increased production and makes a country self-reliant on rice. Accordingly, the government is also emphasised rice production promotion. There is a yield gap between the actual production and potential production. Out of the total area cultivated for rice, only 54% (ASA 2019) is irrigated, rainfed rice farming delayed the production and increased the potential yield gap. The government of Nepal facilitates the import of rice from overseas to reduce the gap, however, import is only a short-term solution and also increases the targeted gap.

The gap between the goal and action can be resolve by corrective action. The government-subsidized programs are the corrective action. In 2018/19 productivity of rice was 3.76 t ha^{-1} and is expected to achieve 4.5 t ha^{-1} by 2023/24 (NPC 2020). However, the exploitable yield gap is 2.57 t ha^{-1} (40%), and the total yield gap of 4.85 t ha^{-1} (55%) (Devkota et al 2021) which shows there is a scope of yield increment.

2.4 Archetypes

2.4.1 Fix that fails

In this case, insufficient availability of rice at the domestic level is a problem and policymakers thought the import of rice from overseas is well-intended action. However, the price of import rice is cheaper or the same as the domestic product so farmers are less interested to grow or even left their land fallow. Unintended consequence disrupts the domestic production and further intensifies the food insecurity.

2.4.2 Limits to growth

Cultivable land suited for rice production is limited in Nepal and has been decreased in recent years due to new settlements in those fertile lands. The availability of rice is increased at a slow rate which enables food sufficiency and production. However, the limitation of land for rice leads to the decreased overall production.

2.4.3 Eroding goals

Having lower production and increasing rate of populatin there is a gap between the current domestic production and desire production to fulfils the rice demand. The goal is to increase the production and managers set the program according such as cash incentive to the farmers, seed and fertiliser subsidy. However, holistic thinking is lacked in the rice system, for example, irrigation is one of the major components in the system, population management could be another options. Managers went through the easy quick fix approches that reduced the desire goal and inceased the gap further. Mangers could take alternative corrective action such as such as increase in irrigated area and conversion of winter fallow land into rice farming. However, corrective action is costly, time taking and demands manager's passion.

2.5 Time horizon

In this study, time-horizon represents the imports of rice started in Nepal, its symptoms emerged and the expected period of simulation. This study is based on the available data from 1980 to 2019 because imports of rice in Nepal was started form 1981 and several government-initiated programs were implemented thereafter. Nepal has set a target to reduce hunger, make the country self-reliant on food, and provide nutritious food access to all by the end of 2030 (NPC 2021). On the other hand, food demand is expected to increase in the future. A study shows 70-100% more food should produce to feed the population by 2050 (McKenzie and Williams 2015). If a developing country like Nepal does not produce enough food, it would have to rely on food imports, which will require a significant expenditure. Therefore, for the simulation purpose time horizon is taken from 1980 to 2050 to see what would be a likely scenario.

2. Dynamic hypothesis

The causal loop diagram (CLD) tool is used to define a dynamic hypothesis, shows the relation and interaction of variables within the rice production system in Nepal.

3.1 Sub-system

The slow growth of rice production is categorised into 4 fundamental sub-systems; domestic production, food security, self-insufficiency, and import. There are government-initiated subsidized schemes and research and development programs to promote rice production in Nepal, however, their contribution is lower than expected because per unit productivity has not increased as expected. Food security is challenging because the population has increased exponentially and demad is growing. Due to the increasing population, pressure has been build-up on rice-growing areas because of new settlements and pressure to grow other crops. Therefore, there could more chance of food insecurity in the future if the fundamental solution is not taken on time. Some of the other key variable the promotes rice production such as availability irrigation, annual rainfall is not included in the study because of unavailability of time series data.

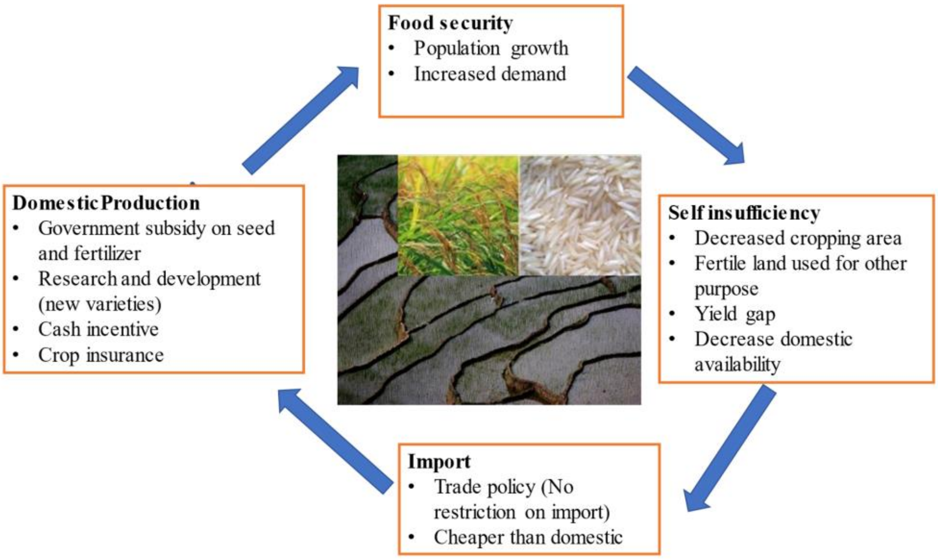

Figure 2: Subsystem diagram for the rice production system

3.2 Causal loop diagram

A causal loop diagram is developed to represent the interaction of variables and their relationship, details are given as follows:

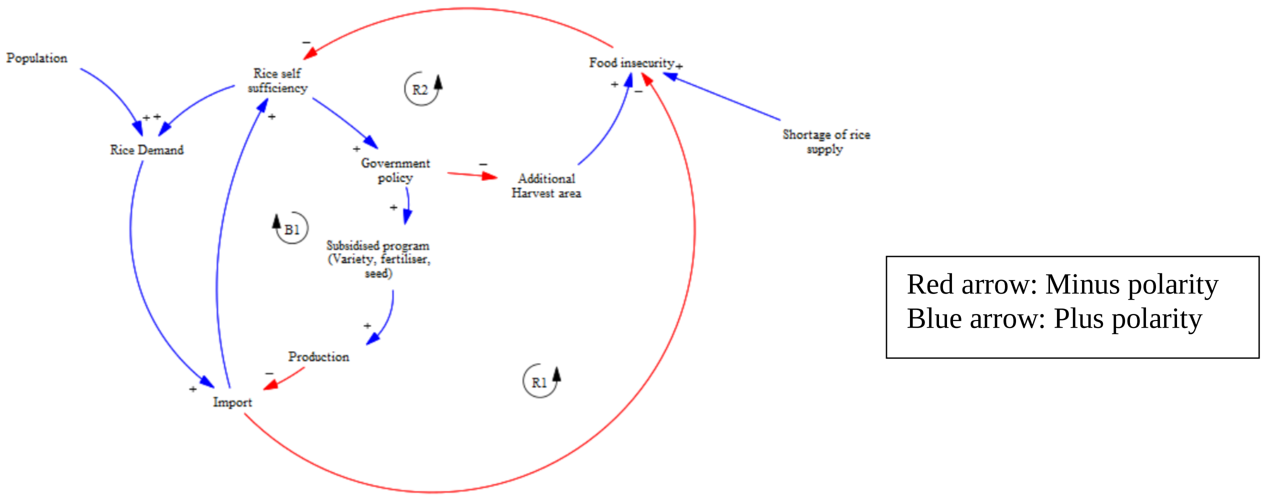

Figure 3: Causal loop diagram for the rice self-sufficiency and food security

1. **Reinforcing loop R1:** Rice demand – import - food insecurity – rice self-sufficiency

Statistical data shows the population is exponentially growing in Nepal which creates the demand for major staple food: rice. The domestic supply of rice unable to fulfill the demand so the country, therefore, relies on the import of rice mainly from India. Import is a quick fix approach to resolve food insecurity in the short-term, however, in the long run, import dependency promotes further imports and leads to decrease self-sufficiency.

2. **Reinforcing loop R2:** Rice self-sufficiency – government policy – additional harvest area- food insecurity

When the domestic production growth of rice lower, rice self-sufficiency is being reduced. Though the government realized the decreasing domestic sufficiency, it has no restriction policy to use productive rice land for other purposes such as establishing new settlements or use for other purposes. This leads to a decrease in additional rice harvest areas and promotes food insecurity.

3. **Balancing loop B1:** Rice self-sufficiency – government policy – subsidized program – production – import

Realizing the decrease in rice self-sufficiency, the government of Nepal implemented policies such as Agriculture Development Strategy (2015-2035), National seed vision (2013-2025), and National fertilizer policy 2002. Those policies envisioned to increase domestic production by providing subsidies to the farmer on varietal development, fertilizer, and improve seed. Subsidized programs help to increase a small volume of production and minimize the import to some extent and promote rice self-sufficiency, forming balancing loo B1.

4. Stock and flow model

The stock and flow model is based on the methodology adopted by Sterman (2000). In this study Secondary data from the Ministry of agriculture and livestock development (MoALD) Nepal, and the Central Bureau of Statistics (CBS) are used (appendix1). Based on the aforementioned causal loop diagram stock and flow diagram is drawn on *Stella Architect* (version 2.1.4).

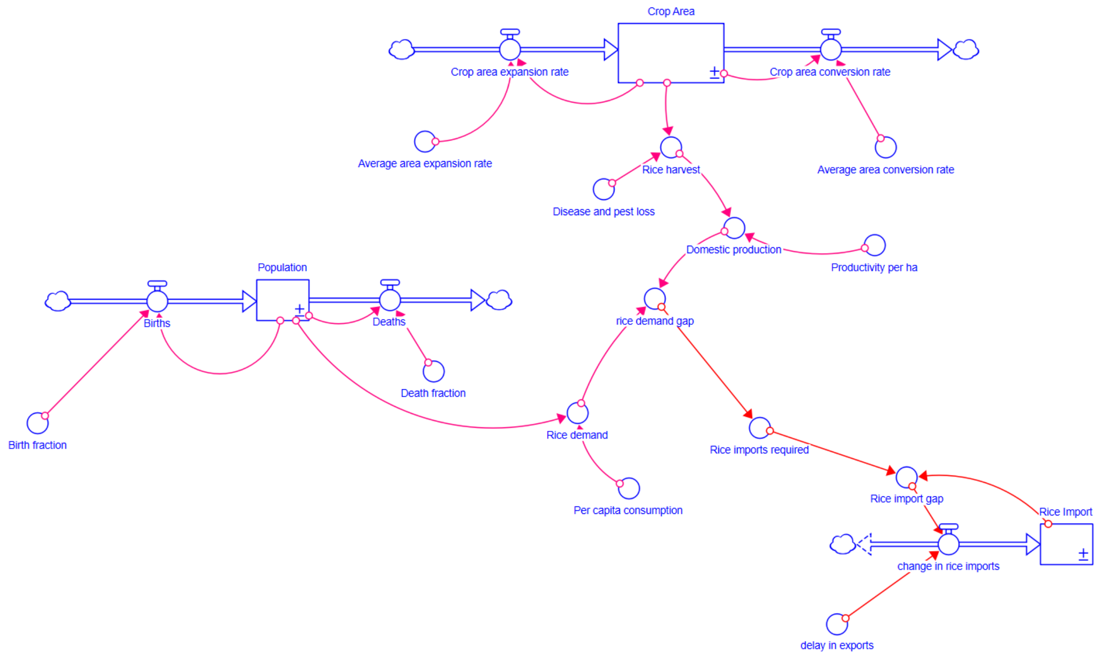

Figure 4: Stock and flow model

4.1 Definition of stocks, inflows, outflows, and variables

Rectangles in the model represent the stocks, the pipe having an arrow pointing towards stock represents inflow, the pipe pointing out from stock represents the outflow, and circles with valves represent inflow and outflow. Population, rice import, and crop area are the stocks. Rice demand, production, and import are the dominant sub-system of the model.

Table 1: Description of variables

Name	Description	Unit
Birth fraction	Number individuals born per year per 1000 people	People people^{-1}year^{-1}
Death fraction	Number individuals died per year per 1000 people	People people^{-1}year^{-1}
Births	Total individuals born in a year (Birth fraction*population)	People year^{-1}
Deaths	Total individuals died in a year(Death fraction*population)	People year^{-1}
Population	Total population in a year	People
Rice demand	Total rice requirement in a year (Per capita	Kg year^{-1}

Name	Description	Unit
	consumption*Population)	
Per capita consumption	Rice consumption per person/year	Kg people^{-1}year^{-1}
Delay in exports	Export delay	Years
Rice import gap	Shortage of rice (rice demand-domestic production)	Kg year^{-1}
Rice imports required	Maximum or minimum rice imports required	Kg year^{-1}
Rice import	Rice import from overseas per year	Kg year^{-1}
Change in rice imports	Import gap due to delay (Rice import gap/Delay in imports)	Kg year^{-1}year^{-1}
Rice demand gap	Rice demand-domestic production	Kg year^{-1}
Productivity per ha	Rice production per hectare per year	Kg ha^{-}
Domestic production	Total production at the national level (Productivity per ha*Rice harvest)	Kg year^{-1}
Disease and pest	Loss of crop yield due to disease and pest condition (5% assumption)	Dimensionless
Rice harvest	Area harvested after deducting disease and pest loss (Crop area – (disease and pest loss*Crop area)	ha
Crop area	Area planted in a year	ha
Crop area expansion rate	Area expansion rate per year (Average area expansion rate*crop area)	ha year^{-1}
Average area expansion rate	Annual rice area expansion percentage	1 year^{-1}
Crop Area conversion rate	Area reduction rate per year (Average area conversion rate*crop area)	ha year^{-1}
Average conversion rate	Annual rice area reduction percentage	1 year^{-1}

Stock and flow model is created based on the causal loop diagram birth fraction, death fraction, and population data were taken from the Central Beaurau of Statistics (CBS) Nepal and imported. Similarly, crop area, productivity, per capita consumption, and export data were imported from the Ministry of Agriculture and Livestock Development, publicly available resources. These data are given in the appendix. The assumption was made for average area expansion rate and average area conversion rate.

In Nepal rice is mainly grown in a single season, planted in June/July, and harvested in October/November. However, there is another possibility for growing rice, plating at March/April and harvesting at June/July, also called spring rice. The government of Nepal is facilitating farmers for spring rice production. However, there is limited opportunity for area expansion therefore, 1.5% area increment and 1% area conversion was assumption was assumed. As the population has been growing at an exponential rate, rice area conversion for settlements or areas of other crop has also increased. Rice demand, domestic production, and rice import gap are the interested sub-system of the model.

5. Model testing

Model testing is carried out to follow up on the results and observe the system's behaviour over the time horizon. The simulation period is set to run from 1980 to 2050 to see if the rice sufficiency objective can be met in the next 29 years. Model is tested of the crop area, population growth, import and rice demand. Per capita, milled rice requirement during the 1980s was 105 Kg person^{-1}year^{-1} (Barker et al 2014). Study shows milling recovery of paddy accounts 66.2% (Pant and Aryal 2014). Based on milled rice requirement and milling recovery percent volume of unmilled rice requirement was calculated. Initially assigned values are provided in table 1.

Table 2: Initial values assigned in the model

Time	Crop Area (ha)	Productivity ha (Kg)	Population	Birth fraction	Death fraction	Rice Import (kg/year)	Per capita consumption (kg)	Average area expansion rate	Average area conversion rate	Disease pest loss
1980	1275520	1932.00	15016402	0.041	0.018	0	159	0.015	0.010	0.05

Values are imported in the model and tested which is given in figure 5.

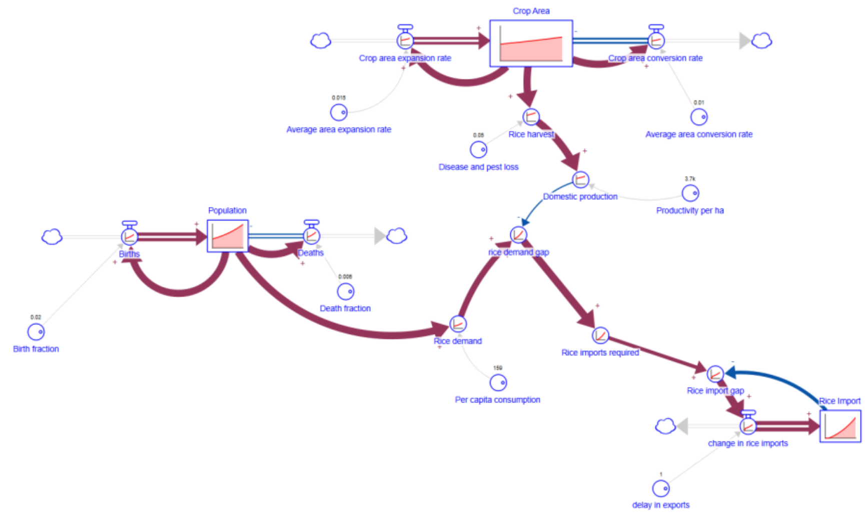

Figure 5: Behaviour of the model

The model behaves as follows when the initial values and actual data are imported. Figure 12 shows overall crop area will be increased if the average land expansion rate is 1.5% per annum and the land conversion rate will be 1.2% per annum. However, this increment rate is lower than the population growth rate. Figure 13 shows population growth is expected to increase exponentially during the simulation period. Figure 14 depicts exponential growth of rice demand because more food will be demanded in the future to feed the growing population. It also shows demand is higher than domestic production. Figure 15 indicates rice imports will be further increased in the future, graph also shows there were no imports between 2019-2021 because real data was not available for that period. This model represents the articulated problem and gap between domestic production and demand.

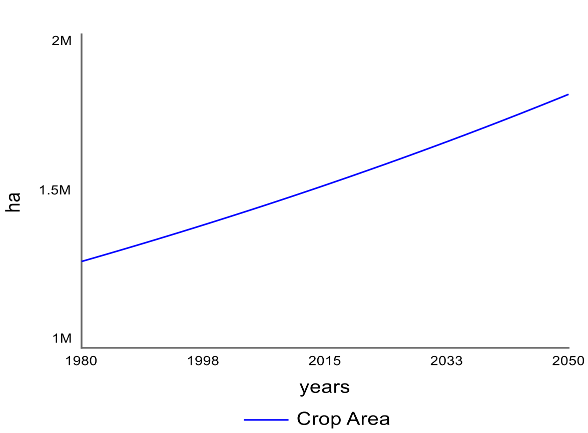

Figure 6: Crop area growth

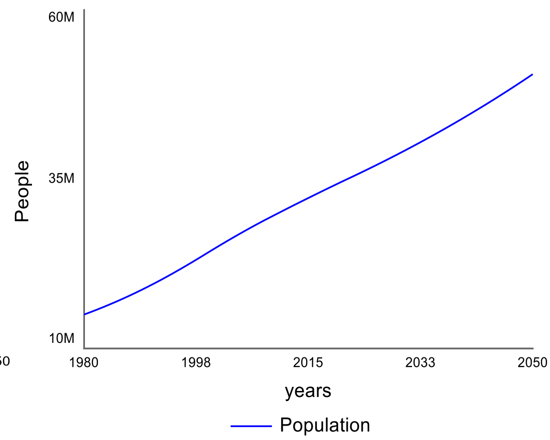

Figure 7: Population growth

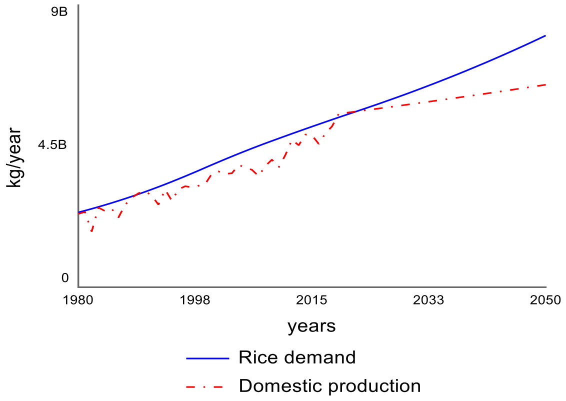

Figure 2: Rice demand and production growth

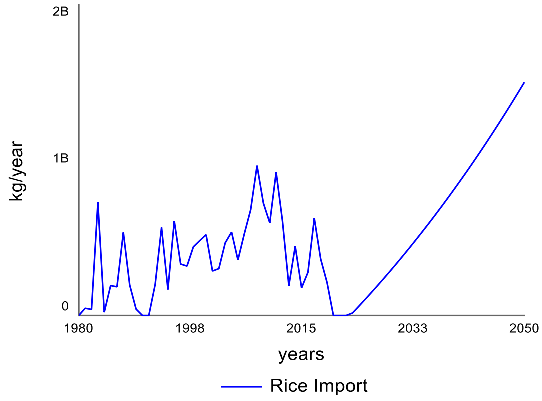

Figure 3: Rice import growth

Figure 4: Rice demand and production growth

Figure 5: Rice import growth

5.1 Sensitivity analysis

Sensitivity analysis is done to see the uncertainity in the expected shape and non linear functional values.

5.1.1 Sensitivity analysis for per capita consumption

To see the result, ad hoc values (Run 1-5) of 90, 120, 150, 170, and 200 were assigned. There would be no need for imports if per capita consumption was 90-120 kg per year. The remaining three scenarios, on the other hand, call for rice imports. Subsequently, rice demand would increase with the increasing per capita consumption of rice.

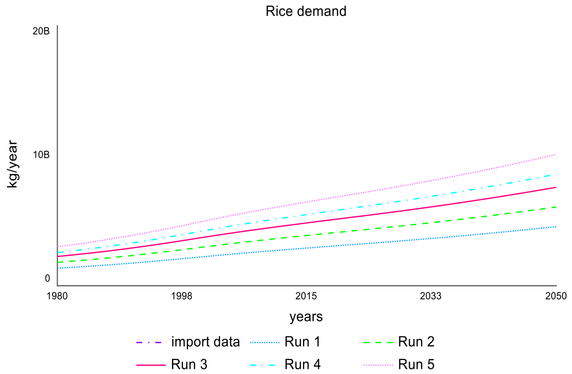

Figure 6: Rice total demand at a different level of per capita consumption

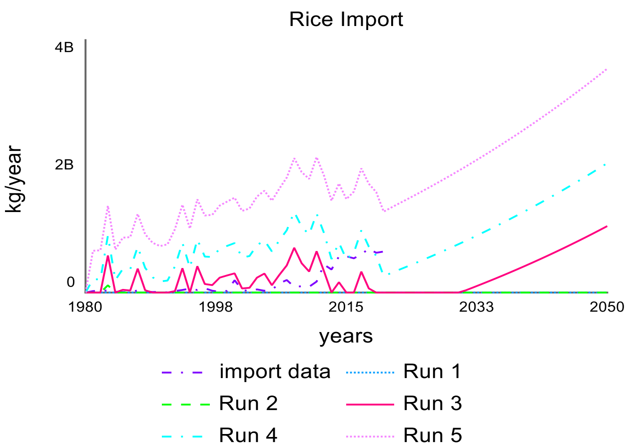

Figure 11: Rice import demand at a different level of per capita consumption

5.1.2 Sensitivity analysis for average area expansion rate

Fives runs having values starts from Run 1 to Run5 is assigned: 0, 0.01, 0.015, 0.020, 0.025 and domestic production is evaluated. Greater the average area expansion rate shows higher the domestic production.

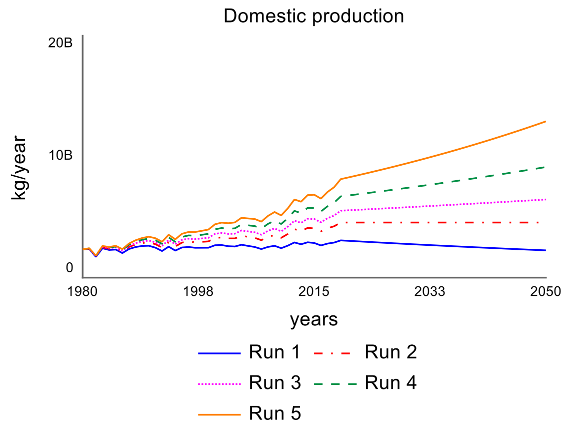

Figure 12: Domestic production at 0%, 1%, 1.5%, 2% and 2.5% average area expansion rate

6. Scenario testing and policy implication

For the rice self-sufficiency goal, the following scenario is tested: 1) An increase in cultivated area, 2) Increase in productivity, and 3) Increase productivity and decrease per capita consumption

6.1 Policy1: Area expansion

In this scenario, is tested for 2% increase in the present crop harvest area each year, while keeping all other variables constant, will result in a reduction in imports, with domestic production sufficient to meet demand, as shown in the figure 19 and 20. In real context, the overall rice area in 2019 was 1491744 ha, with the least chance for area increase in the main season. However, there may be an opportunity for area expansion in the spring season, as more than half of the land remains fallow due to a lack of irrigation. Though the spring rice has area expansion opportunity, 1.5 times more productivity than main season rice, it is only cultivated in 112313 ha due to lack of irrigation facilitiy (Bhandari et al 2015). Spring rice could captivate the production increment opportunity, thus investment on irrigation is needed.

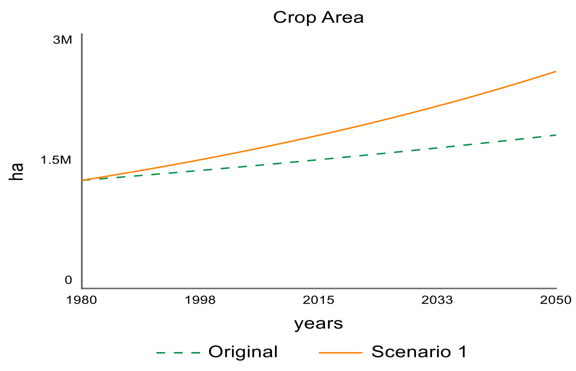

Figure 7: Behaviour of area growth at the existing condition and 2% area expansion

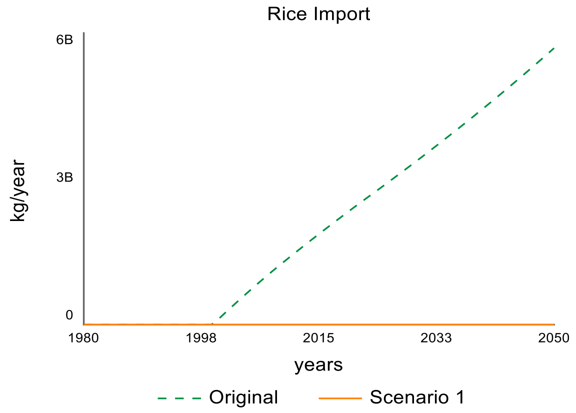

Figure 14: Rice import at the existing condition and after 2% area expansion

6.2 Policy 2: Increase in productivity

Model is tested for the productivity 3000 kg ha^{-1}, 3500 kg ha^{-1}, 4000 kg ha^{-1}, 4500 kg ha^{-1} and 5000 kg ha^{-1}. Results show productivity should keep at 5000 kg ha^{-1} $year^{-1}$ to eliminate the import requirement. In 2019 rice productivity was 3700 kg ha^{-1} , self-sufficiency from domestic production demands more than one ton per ha yield achievement from the existing cropping area.

Table 3: Yield comparison of different countries (data 2016)

Name of the country	Production ton	Yield kg ha^{-1}
China	211,090,813	6,932.4
India	158,756,871	3,695
Indonesia	77,297,509	5,414.8
Bangladesh	52,590,000	4,618.8
Vietnam	43,437,229	5,581
Nepal	4,299,079	3,154.3

Source: https://www.atlasbig.com/en-au/countries-by-rice-production

Nepal's rice productivity is low when compared to other major rice-producing countries. Nepal could increase the current level of productivity by increasing inputs such as fertiliser use, irrigation, improve seed, new varieties, and managing diseases and pests. The government of Nepal has a subsidised program for inputs however it is only more than 50% of the farmers do have access to the subsidy. In contrast, some of the rice-producing countries in world are able to achieve higher productivity from the higher amount of fertiliser application. For instance, In china N, P_2O_5 and k_2O were used 198.07 kg, 76.14 kg, 76.29 kg ha^{-1} $year^{-1}$ while in Nepal 52.24 kg, 23. 91 kg, 3.17 kg ha^{-1} $year^{-1}$ (FAOSTAT 2021). There there is scope for an increment of fertiliser use rate in rice production in Nepal. In addition, the seed replacement rate for rice 12% (Gauchan et al 2014) that should be increased, national seed vision 2013-2015, envisioned 25% seed replacement rate by 2025 (SQCC 2013). Achieving the seed replacement target current programs should pay their attention to the promotion of improved seed use. Furthermore, being one of the major factors of productivity irrigation is being overlooked. Per unit rice production would improve if the irrigated area was extended. Currently, just 29.7% of the cultivated land is irrigated in Nepal (WB 2021). Therefore, programs and policies should pay attention to key contributors influencing the productivity of rice.

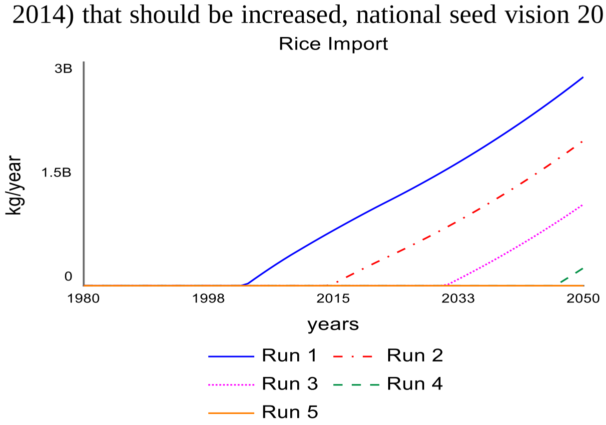

Figure 8: Increment of productivity at various levels and import scenario

6.3 Policy 3: Increase productivity and decrease per capita consumption

The original scenario shows when the per capita consumption was 200 kg and productivity 3700 kg ha^{-1}, there was rice imports in Nepal. If we could increase productivity from 3700 to 3900 and reduce the consumption from 200 kg to 130 kg, we can eliminate the import dependency by reducing the import gap. Moreover, studies show due to the food aid program, farmers give up their local crop production and become aid-dependent. Food aid programs such as supporting the poor with rice solved the food security in short term however, increased nutrition insecurity and people have relied on the monotonous rice-based dietary pattern in the Himalayan region of Nepal (Gautam 2019). Due to the less diversification of diets and over-dependence on a rice-based diet people have encountered nutritional deficiencies such as vitamin A, iron, and zinc (Parajuli et al 2012). Bhandari et al (2015) report that milled rice consumption has been increased from 105 kg person^{-1} year^{-1} in 1979 to 122 kg person^{-1} year^{-1} in 2015. The policy should also focus on food diversification such as the inclusion of commonly available other cereals like maize, wheat, barley, and millets in the dietary pattern and reduction of daily rice intake.

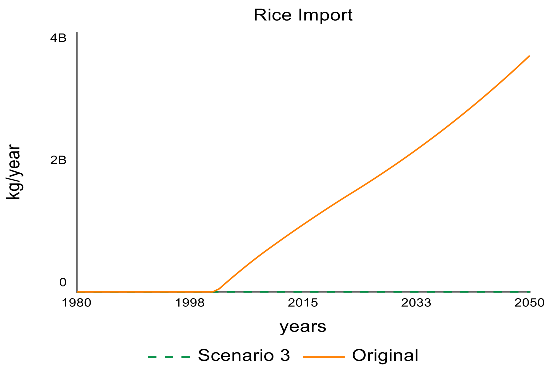

Figure 16: Import or rice at original and desired consumption level

CONCLUSION

Being major staple food, rice is being hugely imported in Nepal to fulfill domestic demand and address food security. The primary driver of imports is population expansion which creates more demand, delayed domestic production growth, and changes in dietary patterns. Therefore, population growth, government-initiated subsidized program, rice demand, area harvest, domestic production, food insecurity, and self-sufficiency are the key interacting variables in the development of a causal loop diagram. The government had initiated subsides scheme based on the national programs and policies mainly focused on seed, fertilizer, variety to increase domestic production and to reduce import. The system reflects that subsidized programs were considered as a quick fix approach to achieve the desired production goal. Problem has been intenfied and corrective action is needed to slove the rice dependency and food insecurity.

A simulation model is developed by selecting key variables from the causal loop diagram to test the problematic scenario. Rice demand is dependent on population, per capita consumption, productivity per ha, and harvest area. The dynamic model provides the following insights for managers:

1) Increase land area by 2% each year satisfy the rice-self sufficiency from domestic production.

2) Increasing current productivity 3700 kg ha^{-1} to 5000 kg ha^{-1} can meet the goal, therefore future programs need to focus on increasing productivity.

3) Increase productivity from 3700 to 3900 kg ha^{-1} and reduce per capita rice consumption from 200 kg year^{-1} to 130 kg year^{-1}. Consumption of rice can be replaced with other cereals such as maize, wheat, and barley.

Therefore, the aforementioned insights should consider making the country self-sufficient in rice production to achieve the food security goal for the next 29 years.

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AUTHORS' CONTRIBUTION

The author Mukunda Bhusal is solely responsible the data collection, review, and manuscript preparation.

CONFLICT OF INTEREST

The author has no any conflict of interest to disclose.

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