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Modelling the dynamics of economic development driven by agricultural growth in Patna Region, India

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Abstract

Regional planning primarily aims at reducing the disparity in socio-economic status of the people, and the wide gulf between urban and rural life. A planning region or an area comprises of many complex structures and behavioural phenomena which more or less change with time due to some external forces acting upon or the internal forces acting within the regional system. While planning for the development of a region, the well-known phenomena and structures within the regional system can be considered. Further, the sustainable economic development of a region can only be achieved by ensuring the optimum utilization of resources. This requires plausible policy planning guidelines and feasible development plan, for which thorough grassroots level investigation is essential. In this present investigation, an attempt has been made to evolve a set of plausible policy guideline and recommendations for the sustainable economic development of Patna region, by considering it as a system, and considering the important control parameters of its subsystems.

Keywords: Agriculture, Regional development, Forecasting, System dynamics, GDP, Simulation

1 Background

Agriculture sector occupies the centre stage in shaping India's socio-economic status. The economy of the second most populous country in the world is inextricably linked to the pulse of its agricultural success or failure. India has witnessed a significant increase in food grain production after green revolution, oilseeds production after yellow revolution, milk production after white revolution, fish production after blue revolution, and fruits and vegetables production after golden revolution, since independence. The agricultural development has been achieved due to the application of science and technology coupled with the positive policy implementation, and hard work of Indian farmers (Ahuja 2000). However, after nearly three and half decades in the post-green revolution period, the country still faces crisis each year in trying to meet the burgeoning demand for food by its growing population. Thus, the need of research and development in the field of agriculture for increasing the application of frontier technologies (i.e. information technology application in agriculture, precision farming, post-harvest technologies, mechanized farming and organic farming) cannot be denied, which is a feasible approach to achieve sustainable agriculture (Rao and Jeromi 2000; Ray et al. 2001; Srinivasan 2001). The best way to meet the increasing food demand for the rapidly growing population is to increase the production of crops using new agricultural technologies which can increase productivity of limited land resource and preserving its soil quality as well (Ray et al. 2001; Sarkar et al. 2013; Spiertz 2013; Wilson and Scot 1982). Studies suggest that agricultural productivity plays a key role in the process of industrialization and development, and there is a linkage between increase in agricultural productivity and poverty reduction (Ludena 2010; Prasad 1971; Schneider and Gugerty 2011; Lindh and Malmberg 2007; Weintraub 1976). Thus, regional development, which primarily aims at reducing the disparity in socio-economic status of the people, can be achieved by agricultural development (Mandal and Peters 1990; Mcloughlin 1970; Miller et al. 2009).

The aim of the present research is to characterize the role of agriculture in economic development and identifying ways in which this role can be enhanced. In India, agriculture is the main source of resources that can be utilized in the emerging activities. Hence, successful industrialization requires a solution to the problems associated with the generation, transfer, and use of an agricultural resource surplus (Griffin and Enos 1970; Grabowski 2015; Kachru 2006). Generation of growing surplus demands a rising productivity of resource use in agriculture (Dasgupta 1974). This is achieved by successful agricultural and rural development, more specifically through technological and institutional development (Chand and Puri 2009; Winters and Stamoulis 1997). The use of modern varieties of irrigation and fertilizers is important aspects of higher growth in crop production. Studies suggest that modern inputs, such as improved seeds (HYVs), mechanized farm inputs, and organic manures, play an important role in agricultural development in a region (Kannan and Sundaram 2011; Letourneau and Goldstein 2001; Wilson and Scot 1982). The crop diversification with the adoption of modern technologies has boosted Indian agriculture to move from subsistence farming to intensive and technology-based cultivation for enhancing the productivity (Chattopadhayay and Roy 2011; Fontes et al. 2009).

2 Trend of agricultural production in India

Despite all the natural advantages, India's productivity of food grains per hectare is no more than three-fourths of the world average and less than half of that in agriculturally advanced countries. The per capita food grain availability has been less than two-thirds of the world average, even after the green revolution. Only five states in India, namely Himachal Pradesh, Punjab, Haryana, Uttar Pradesh, and Madhya Pradesh, produce more grain than their populations can consume (Bhide 2015; Rao and Jeromi 2000). The combined population of these five states is less than one-third of the total of the country. More than two-thirds of the population live in states that are still food deficit (Rao and Jeromi 2000). This requires transport of millions of tonnes of food grain, involving high costs and time. The effort should have been to make all the states self-sufficient with respect to food grains, and if some disturbances occurred due to unnoticed natural calamities, the nation must be in an ever ready position to mitigate such challenging tasks. The Indian green revolution is also associated with negative ecological and environmental consequences. Besides, India shares 17% of world's population with two and half per cent of geographical area, 1% of gross world product, 4% of world carbon emissions, and hardly 2% of world forest area. The Indian status of environment, though not alarming when compared to developed countries, gives an early warning to take appropriate precautionary measures.

The growth rate of grain production has been higher than the population growth rate in the post-independence era, but still the growth is much less to fulfil the domestic need (Table 1). Per capita availability of grain and per capita calorie intake, which were less than the minimum required for adequate nutrition, have further declined. According to Human Development Report 2003, the percentage of the undernourished in India, which was twenty-one a few years ago, has now reached twenty-four (Rao and Jeromi 2000).

The value of agricultural output in India has grown significantly during past few decades (Table 2; Fig. 1). The government claims that India has emerged as the seventh largest exporter of food grains in the world. However, we take into account that the total

Table 1 Population growth versus agricultural growth. *Source*: Agricultural Statistics at a Glance, GOI, New Delhi, 1993

Year	Population growth		Period	Agricultural growth (annual compound growth rate)		
	Total population	Annual compound growth rate (%)		Area	Yield	Production
1951	361.1	1.25	1949–1950 to 1964–1965	1.61	1.50	3.13
1961	439.2	1.96				
1971	548.2	2.20	1967–1968 to 1980–1981	0.54	1.83	2.38
1981	685.2	2.22				
1991	844.3	2.11	1980–1981 to 1991–1992	0.05	3.16	3.21
2000	987.3	1.09				

Census of India, 2000

Table 2 Value of agricultural output (in Rs. millions) 44 crops: India. *Source*: Government of India, Area and Production of Principal Crops in India (various issues), Ministry of Agriculture

Year	1963	1973	1983	1993	2003
Value	560,923	662,358	831,846	1,167,785	1,450,096

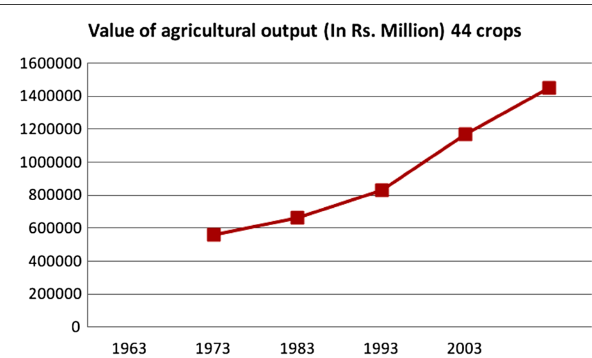

Fig. 1 Agricultural output in India. Graph showing decadal growth of agricultural output from the year 1963 to 2003, of crops in India

Indian grain export in 2002–2003 did not add up to even 4% of the total world exports, and the value of our grain exports did not add up to even the value of our imports of vegetable oils and pulses. The more crucial question, however, is whether it is morally justifiable to export grain when 24% of the population remains undernourished (Rao and Jeromi 2000). The main reason for the poor performance of the farm sector has been the long persisting adverse terms of trade policies for agriculturists; in addition, the mismanagement of natural resources leads to never-ending crisis.

Even though India has shown remarkable progress in recent years and has attained self-sufficiency in food staples, the productivity of Indian farms for the same crop is very low compared to farms in Brazil, the USA, France, and other nations. It implies there is a vast scope of agriculture growth. Indian wheat farms, for example, produce about a third of wheat per hectare per year in contrast to wheat farms in France (Tables 2, 3; Figs. 1, 2). Similarly, at forty-four million hectares, India had the largest farm area under rice production in 2009; yet, the rice farm productivity in India was less than half the rice farm productivity in China (Rao and Jeromi 2000). Other food staples productivity in India is similarly low, suggesting a major opportunity for growth and future agricultural prosperity potential in India. Indian total factor productivity growth remains below 2% per annum; in contrast, China has shown total factor productivity growths of about 6% per annum, even though China too has a small land holding farmers (Table 4) (Rao and Jeromi 2000). If India could adopt technologies and improve its infrastructure, several studies suggest India could eradicate hunger and malnutrition within India, and be a major source of food in the world.

3 About the study area

The study area of Patna region, India, has been selected for the present research, keeping in view the potential of agricultural growth in the region as explained in the above section. The study area has an area of 16,873 km^2 (according to Directorate of Economics

Table 3 Crop yield (value output Rs. per hectare of gross cropped area): India. *Source*: Government of India, Area and Production of Principal Crops in India (various issues), Ministry of Agriculture

Year	1963	1973	1983	1993	2003
Crop yield	3738	4257	5090	6957	8460

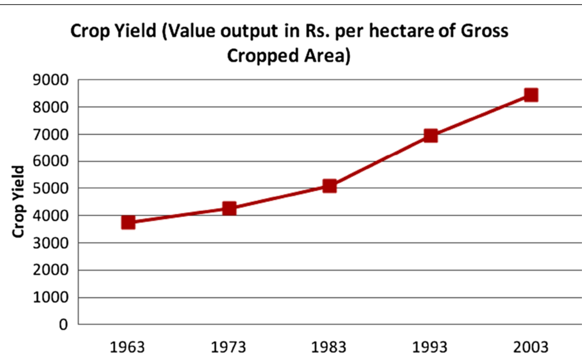

Fig. 2 Crop yield in India. Graph shows the value output of crops per hectare of gross cropped area in India, from the year 1963 to 2003

Table 4 Agriculture productivity in India, growth in average yields from 1970 to 2010. *Source*: Government of India, Area and Production of Principal Crops in India (various issues), Ministry of Agriculture

Crop	Average yield, 1970–1971 (kilogram per hectare)	Average yield, 1990–1991 (kilogram per hectare)	Average yield, 2010–2011 (kilogram per hectare)
Rice	1123	1740	2240
Wheat	1307	2281	2938
Pulses	524	578	689
Oilseeds	579	771	1325
Sugar cane	48,322	65,395	68,596
Tea	1182	1652	1669
Cotton	106	225	510

and Statistics Bihar 2007 and Directorate of Statistics and Evaluation Bihar 2007). The study area of Patna region, an administrative geographical unit of Bihar state, India, is located in the eastern part of the country (between latitude 24°30′50″N to 25°44′00″N and longitude 83°19′30″E to 86°00′00″E) (Fig. 3). The region is least prone to flood hazard among all the regions of Bihar and has same soil type as Gangetic alluvial plane; agro-climatic conditions are same as it comes under one zone (zone iii) among three agro-climatic zones of Bihar, India. Similar kind of agricultural production, similar language, socio-economic condition, and demographic condition persists in the region (according to *Economic Survey* 2014). The above-mentioned homogeneous characteristics were taken into consideration while delineating the Patna region. The region consists of Patna District, Nalanda District, Bhojpur District, Rohtas District, Buxar District, and Kaimur District, also called Bhabhua District (according to Directorate of Statistics and Evaluation Bihar 2007).

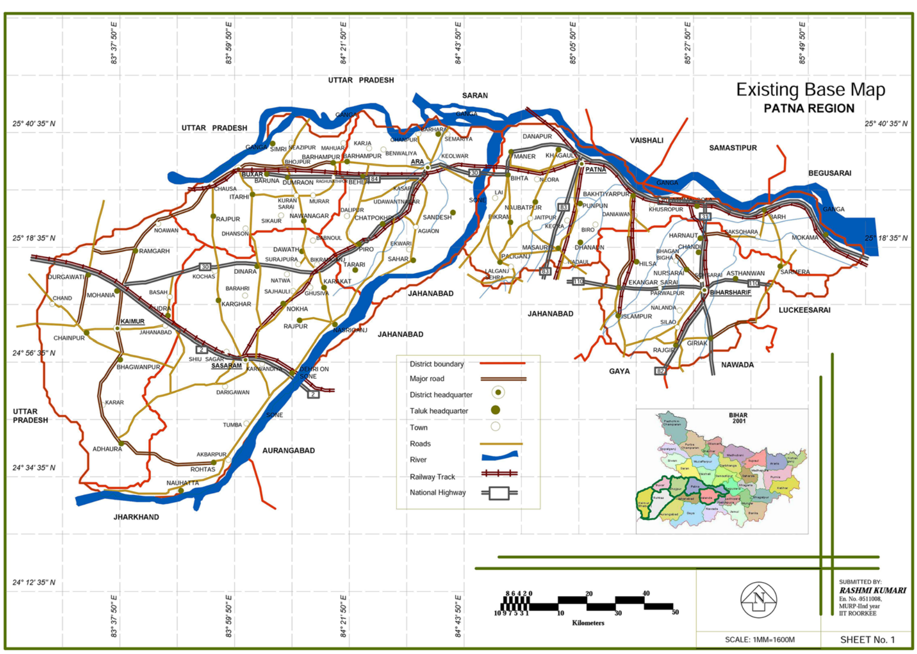

Fig. 3 Map of Patna region. Existing base map of the study area, Patna region, India

4 Justification of the study area

The study area of Patna region, India, is facing higher degree of poverty, unemployment, and overall deprivation in the region. According to studies, the agricultural productivity potential of the region is very high; thus, there is a need to harness the region's agricultural resources judiciously, not only to liberate the region from its socio-economic and ecological glooms, but also to trigger the process of overall regional development, as agriculture sector has been called as the precursor of economic growth process. The percentage of working population employed in agricultural operations in the region is estimated to be 85%, which is much higher than the national average (according to Directorate of Economics and Statistics Bihar 2007). Two-third of the total land area of Patna region is used for agricultural purpose (according to Directorate of Economics and Statistics Bihar 2007). High concentration of population, largely dependent on agriculture coupled with low infrastructure and technological development, is main reason for high poverty ratio in the region. Further, the study area, with abundance of water bodies, has very high potential for fisheries and aquaculture, but it has not been fully realized till today. Livestock is also a major resource in this region (according to Directorate of Economics and Statistics Bihar 2007 and Directorate of Statistics and Evaluation Bihar 2007). Despite the strength of the agriculture sector, it is a paradox that this sector is much below the potential. The region's development is much needed, by reducing un-utilization and/or underutilization of rural resources, in turn reducing unemployment, regional imbalances and disparities, inequalities in the distribution of income and wealth, for the development of whole nation. There is need of sustainable development of the region ensuring the proper utilization of region's resources including human resource to help in minimizing the pressure on other urban centres outside the region, which have their own acute problems of traffic congestion, in migration, housing shortage, slum formation, water scarcity, etc. Having above knowledge in mind, the study area has been selected for the present investigation to evolve a set of policy guidelines for the sustainable economic development of the region.

5 Methods

In this present investigation, an attempt has been made to evolve plausible policy guidelines and recommendations for the sustainable economic development of Patna region, by considering it as a system. It has been observed that lack of comprehensive plan and integrated approach became a deterrent in the development process in the study area. Therefore, a thorough grassroots level investigation has been carried out through conducting primary survey at the household level and exploration and analysis of available literature and collected data from secondary sources, to understand the important control parameters, which influence the function of the system. Further, by considering the important control parameters of various subsystems of the system, system dynamic model for sustainable development in the system has been evolved. The projections, for the year 2031, from the base year 2011, have been made to understand the behaviour of the system. The functions of the system under various alternative conditions are closely examined by developing various scenarios and tested to arrive at alternative policy option for taking decisions. Finally, a set of plausible policy guidelines has been prepared screening phasewise requirements and achievements in alternative conditions.

It is anticipated that if the proposed planning model is implemented successfully in the study area, it will ensure sustainable development in the system, definitely.

6 Application of system dynamics model

System dynamics (SD) is one of the numerical simulation techniques. The fundamentals of System dynamics were defined by Forrester (1958) as a method for the modelling of industrial dynamics which was later, in the early 1980, renamed as system dynamics (SD) (Rozman et al. 2013). System dynamics is an effective tool for simulating and analysing complex systems in which various factors are interrelated. Sterman (2000) writes 'System Dynamics is a perspective and set of conceptual tools that enable us to understand the structure and dynamics of complex systems. System dynamics is also a rigorous modeling method that enables us to build formal computer simulations of complex systems and use them to design more effective policies and organizations'. According to Tang and Vijay (2001), 'Simply stated, system dynamics is a method. A method, that permits the analyst to decompose a complex social or behavioural system into its constituent components and then integrate them into a whole that can be easily visualized and simulated'.

The literature suggests that system dynamics (SD) is considered to be an appropriate approach for predicting results of the dynamic interactions and analysing the effects of different policies for given complex systems. The method can effectively incorporate individual components of a system within a general framework and then comprehensively analyse their interactions (Guan et al. 2011). These interactions are complex because they simultaneously involve various system components and they dynamically change over time (Guan et al. 2011). The SD approach revealed considerable advantages over other approaches. One of the major advantages is that there is possibility of experimenting with model scenarios even though limited data are available to find out system's potential response to different policies prior to making any decision (Rozman et al. 2013). In system dynamics, simulation is completely governed by the passage of time and is referred to as 'time-step' simulation (Coyle 1999).

The available literature describes the steps involved in system dynamic modelling process (Fig. 4). The thorough study of available literature suggests that the steps involved in the system dynamics modelling process can be taken as follows:

In the present investigation, system dynamics theory has been implemented to develop system dynamics model consisting of various submodels, for plausible policy planning for sustainable economic development of the study area. The model has been validated to generate policy scenarios in alternate conditions. The forecast has been done for the year 2031.

The system dynamics model has been developed for the present investigation, considering region as a system consisting of seven subsystems, which are physical subsystem, social subsystem, economic subsystem, ecological subsystem, environmental subsystem, infrastructure subsystem, and institutional subsystem (Devadas et al. 2008; Kumari and Devadas 2014) (Fig. 5). Attempts have been made to develop system dynamics model based on the survey data and historical data, to understand the influence of the most important controlling parameters that decide the function of the system for evolving optimal strategies for integrated development of the system. The simulation results have been generated from the model to evolve set of plausible policy guidelines for the sustainable development of the study area.

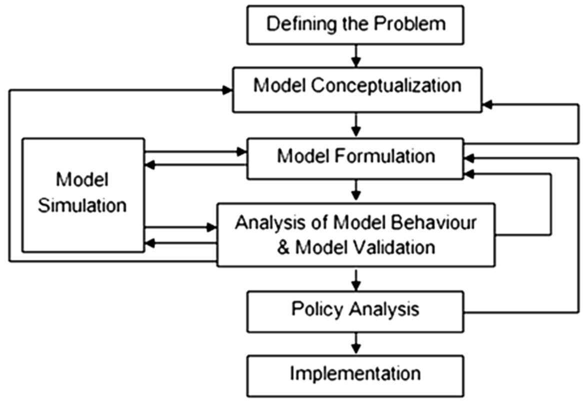

Fig. 4 Model development as an iterative process. The flow chart shows the system dynamics model development process

6.1 System dynamics model for GDP in Agriculture and Allied Sector

The GDP in Agriculture and Allied Sector has been considered as an important parameter, which influence the system. A system dynamic model is built to calculate GDP in Agriculture and Allied Sector by considering the influential variables, cereals production, pulses production, vegetables production, fruits production, flowers production, milk production, egg production, fish production, and meat production. A functional flow diagram is developed and presented in Fig. 6. The GDP in Agriculture and Allied Sector have been considered as the level variables, whereas GDP AAL rate has been taken as rate variable. The model equation used for the above purpose is presented as follows. The definitions of each variable and mathematical (algebraic) equation are described in the model equations; they are:

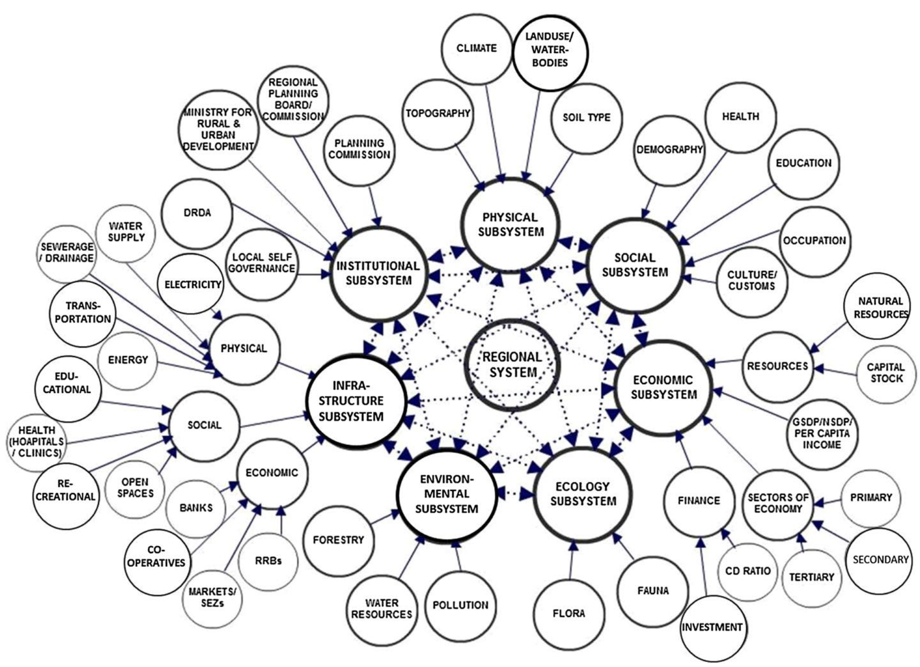

Fig. 5 Regional system. The chart explains the region as a system, comprising of seven subsystems, which comprise of various sub-subsystems

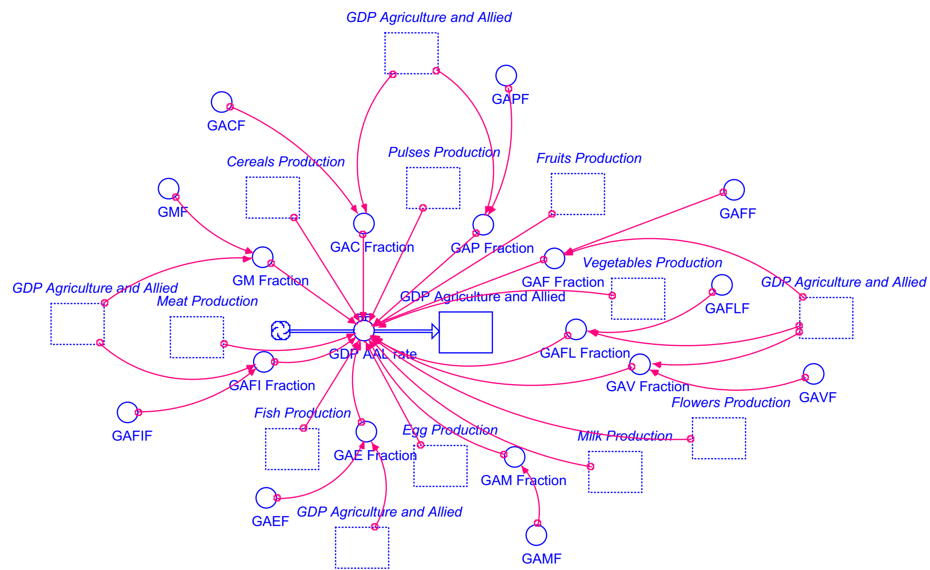

Fig. 6 Diagram showing system dynamics model for GDP from agriculture and allied sector

$$\text{GDP Agriculture and Allied}(t) = \text{GDP Agriculture and Allied}(t - \mathrm{d}t) + (\text{GDP AAL rate}) * \mathrm{d}t,$$

where 'GDP Agriculture and Allied' represents the GDP from Agriculture and Allied Sectors (a stock). 'GDP AAL rate' is the annual increase in GDP from Agriculture and Allied Sectors (a flow).

$$\begin{aligned}\text{GDP AAL rate} = f(&\text{Cereals Production},\\ &\text{GAC Fraction, Pulses Production},\\ &\text{GAP Fraction, Fruits Production},\\ &\text{GAF Fraction, Vegetables Production},\\ &\text{GAV Fraction, Flowers Production, GAFL Fraction, Milk Production},\\ &\text{GAM Fraction, Egg Production, GAE Fraction, Fish Production},\\ &\text{GAFI Fraction, Meat Production, GM Fraction}),\end{aligned}$$

where 'Cereals Production' is yield of Cereals (wheat, rice, maize, and barley) (a stock). 'GAC Fraction' is GDP from Cereals Production Fraction (a converter). 'Pulses Production' is yield of Pulses (gram, pink lentil, split black gram, and khesari pulse) (a stock). 'GAP Fraction' is GDP from Pulses Production Fraction (a converter). 'Fruits Production' is yield of Fruits (mango, guava, and jackfruit) (a stock). 'GAF Fraction' is GDP from Fruits Production Fraction (a converter). 'Vegetables Production' is yield of Vegetables (potatoes, peas, onion, brinjal, cauliflower, etc.) (a stock). 'GAV Fraction' is GDP from Vegetables Production Fraction (a converter). 'Flowers Production' is yield of Flowers ((rose, marigold, jasmine, tuberose, etc.) (a stock). 'GAFL Fraction' is GDP from Flowers Production Fraction (a converter). 'Milk Production' is Annual Milk Production (a stock). 'GAM Fraction' is GDP from Milk Production Fraction (a converter). 'Egg Production' is Annual Production of Eggs (a stock). 'GAE Fraction' is GDP from Eggs

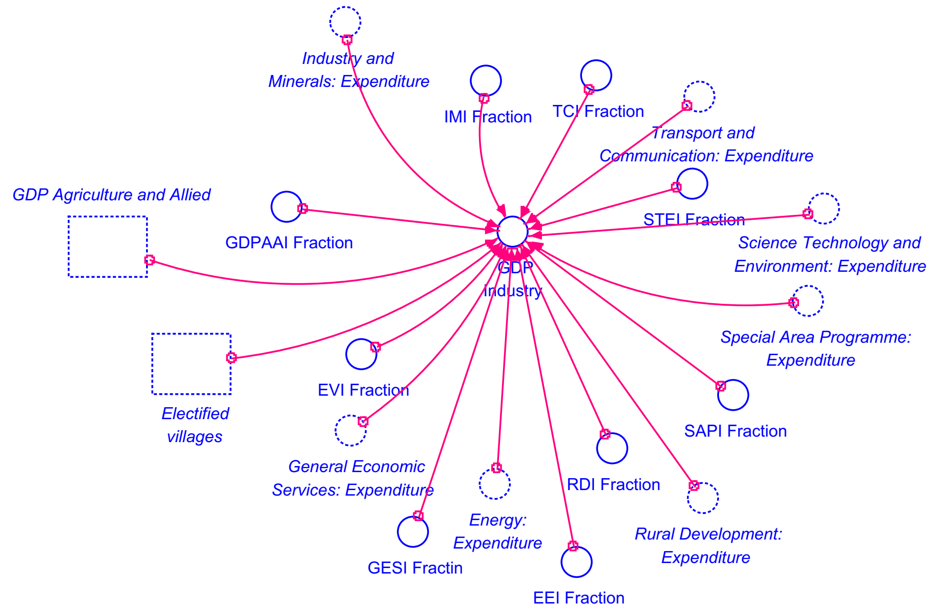

Fig. 7 Diagram showing system dynamics model for GDP from industrial sector

Production Fraction (a converter). 'Fish Production' is Annual Production of Fish (a stock). 'GAFI Fraction' is GDP from Fish Production Fraction (a converter). 'Meat Production' is Annual Production of Meat (a stock). 'GM Fraction' is GDP from Meat Production Fraction (a converter).

6.2 System dynamics model for GDP in Industrial Sector

The GDP in Industrial Sector has been considered as an important parameter, which influence the system. A system dynamic model is built to calculate GDP in Industrial Sector by considering the influential variables, expenditure on industry and minerals, expenditure on transport and communication, expenditure on science, technology and environment, expenditure on special area programme, expenditure on rural development, expenditure on energy, expenditure on general economic services, electrified villages, and GDP in agriculture and allied services. A functional flow diagram is developed and presented in Fig. 7. The model equation used for the above purpose is presented as follows. The definitions of each variable and mathematical (algebraic) equation are described in the model equations; they are:

$$
\begin{aligned}
\text{GDP Industry} = f(&\text{Electrified villages, EVI Fraction, Energy: Expenditure,}\\
&\text{EEI Fraction, GDP Agriculture and Allied,}\\
&\text{GDPAAI Fraction, General Economic Services: Expenditure,}\\
&\text{GESI Fraction, Industry and Minerals: Expenditure,}\\
&\text{IMI Fraction, Rural Development: Expenditure,}\\
&\text{RDI Fraction, Science Technology and Environment: Expenditure,}\\
&\text{STEI Fraction, Special Area Programme: Expenditure, SAPI Fraction,}\\
&\text{Transport and Communication: Expenditure, TCI Fraction}),
\end{aligned}
$$

where 'Electrified Villages' represents the percentage of villages electrified (a stock); 'EVI Fraction' is Electrified Village Fraction (a converter); 'Energy: Expenditure' represents the Expenditure in Energy Sector (a converter); 'EEI Fraction' is the Expenditure in Energy Sector Fraction (a converter); 'GDP Agriculture and Allied' is Gross Domestic Product in Agriculture and Allied Sector (a stock). 'GDPAAI Fraction' is GDP in Agriculture and Allied Sector Fraction (A convertor). 'General Economic Services: Expenditure' is Government Expenditure on General Economic Services (a converter). 'GESI Fraction' is Expenditure on General Economic Services Fraction (a converter). 'Industry and Minerals: Expenditure' is Government Expenditure on Industry and Mineral Sector (a converter). 'IMI Fraction' is Expenditure on Industry and Minerals Fraction (a converter). 'Rural Development: Expenditure' is Government Expenditure on Rural Development (a converter). 'RDI Fraction' is Expenditure on Rural Development Fraction (a converter). 'Science Technology and Environment: Expenditure' is Government Expenditure on Science Technology and Environment (a converter). 'STEI Fraction' is Expenditure on Science Technology and Environment Fraction (a converter). 'Special Area Programme: Expenditure' is Government Expenditure on Special Area Programme (a converter). 'SAPI Fraction' is Expenditure on Special Area Programme Fraction (a converter). 'Transport and Communication: Expenditure' is Government Expenditure on Transport and Communication (a converter). 'TCI Fraction' is Expenditure on Transport and Communication Fraction (a converter).

6.3 System dynamics model for GDP and per capita income

The Gross Domestic Product (GDP) has been considered as an important parameter, which influence the system. A system dynamic model is built to calculate GDP by considering the influential variables, GDP in Agriculture and Allied Sector, GDP in Secondary Sector (GDP SS), and GDP in Tertiary Sector (GDP TS). The GDP in Tertiary Sector has been influenced by the GDP in Primary Sector and GDP in Primary Sector; the GDP in Secondary Sector has been influenced by the GDP industry; and GDP in Primary Sector (GDP PS) has been influenced by the GDP in Agriculture and Allied Sector. Further, per capita income has been derived by dividing GDP planned by the total population. A functional flow diagram is developed and presented in Fig. 8. The model equation used for the above purpose is presented as follows. The definitions of each variable and mathematical (algebraic) equation are described in the model equations; they are:

$$\text{GDP Planned} = f\left(\text{GDP Agriculture and Allied, GDP SS, GDP TS}\right)$$
$$\text{GDP PS} = f\left(\text{GDP, GDP PS without AAS Fraction, GDP Agriculture and Allied}\right)$$
$$\text{GDP SS} = f\left(\text{GDP, GDP SS without Industrial Sector Fraction, GDP Industry}\right)$$
$$\text{GDP TS} = f(\text{GDP PS, GDP TSPS Fraction, GDP SS, GDP TSSS Fraction}),$$

where 'GDP Planned' is Gross Domestic Product as per Planning Proposal (a converter). 'GDP Agriculture and Allied' represents the GDP from Agriculture and Allied Sectors (a stock). 'GDP PS' is GDP in Primary Sector (a converter). 'GDP SS' is GDP in Secondary Sector (a converter). 'GDP TS' is GDP in Tertiary Sector (a converter). 'GDP PS without AAS Fraction' is GDP in Primary Sector excluding Agriculture and Allied Sectors (i.e. mining and quarrying) Fraction (a converter). 'GDP SS without Industrial Sector Fraction' GDP in Secondary Sector excluding Industrial Sector Fraction (a converter).

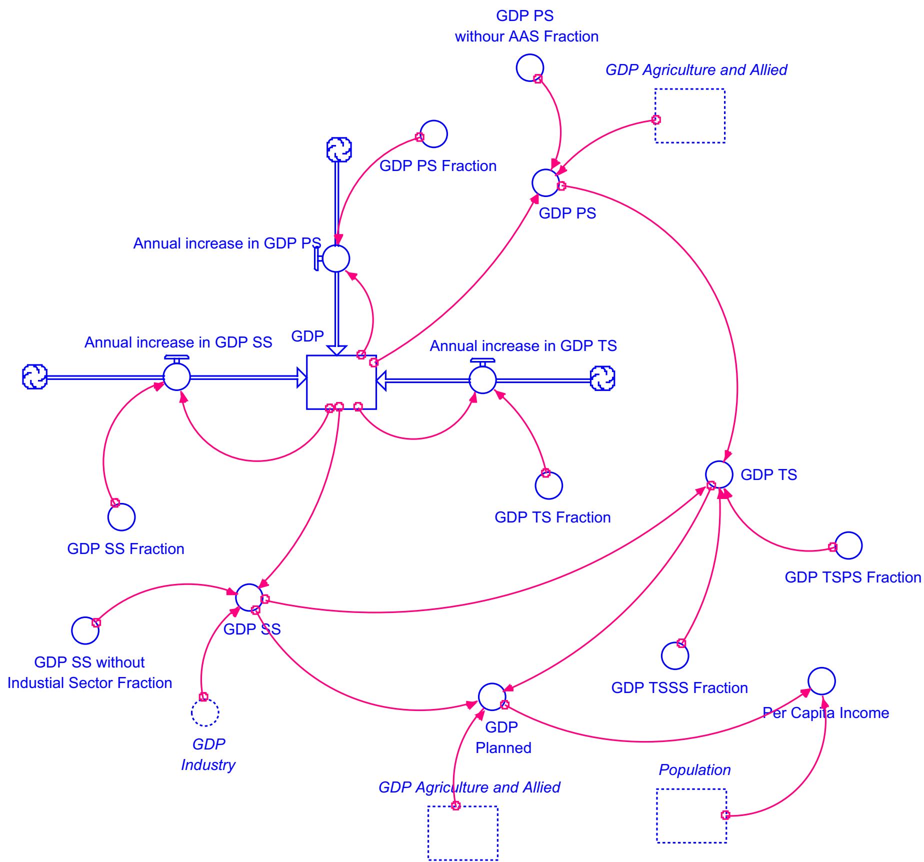

Fig. 8 Diagram showing system dynamics model for sectorwise Gross Domestic Product, and per capita income

'GDP Industry' is GDP from Industries (a converter). 'GDP TSPS Fraction' is GDP in Tertiary Sector due to development of Primary Sector Fraction (a converter). 'GDP TSSS Fraction' is GDP in Tertiary Sector due to development of Secondary Sector Fraction (a converter).

7 Model result

The system dynamics model has been formulated to understand the functions of the regional system and its subsystems. The year 2011 has been considered as the base year for the present model. The base year model results are summarized in Table 5.

8 Model validation

The evolved system model has been employed to find outputs using set of inputs of the parameters considered as the indicators of different subsystems of the regional system. The existing data available from the secondary sources for the major parameters have been considered for the model validation. The outputs of the particular parameters generated from the model have been closely examined and compared to the data available in the real system, and it has been observed that there are high R square values as well as low percentage differences (<5%) (Tables 6, 7 and 8). Thus, the similar values and trends

Table 5 Base year (2011) model result

Sl. no.	Name of parameters	Base year model result (2011)
1.	Population (in numbers)	1,76,62,618
2.	Population density (numbers/km^2)	1047
3.	Per capita income (in Rs./year)	32,101
4.	Yield of cereals (in 000′ kg/km^2)	302
5.	Yield of pulses (in 000′ kg/km^2)	124
6.	Yield of fruits (in 000′ kg/km^2)	2021
7.	Yield of vegetables (in 000′ kg/km^2)	1691
8.	Yield of flowers (in 000′ kg/km^2)	1291
9.	Milk production (in million kg per annum)	812
10.	Egg production (millions in number per annum)	103
11.	Meat production (million kg per annum)	20
12.	Fish production (million kg per annum)	41
13.	GDP (Rs. in millions)	5,66,990
14.	GDP in Primary Sector (Rs. in millions)	71,449
15.	GDP in Secondary Sector (Rs. in millions)	56,778
16.	GDP in Tertiary Sector (Rs. in millions)	4,60,269
17.	GDP in Agriculture and Allied Sector (Rs. in millions)	49,943
18.	GDP in Industrial Sector (Rs. in millions)	55,023

of the model results and the real system data establishing structural and behavioural validity of the model, as the model is evidently reflecting the real system (Forrester and Senge 1980).

The comparison between model results and the real system data is presented in Tables 6, 7 and Figs. 9, 10.

9 Result and discussion

In this present investigation, various control parameters of different subsystems of the system, which influence the functions of the system largely, which are population, per capita income, GDP, GDP in Primary Sector, GDP in Secondary Sector, GDP in Tertiary Sector, GDP in agricultural and allied sector, and GDP in Industrial Sector, have been considered for forecasting their value up to 2031 for strategic planning. The period for projections is considered up to 2031 by keeping in mind the very dynamic and volatile nature of socio-economic subsystem. Forecasts were done in the validated integrated

Table 6 Population (in numbers)

Sl. no.	Year	Real system value	Model result	Percentage difference (%)
1.	2001	14,588,984	1,45,88,984	0.00
2.	2002	14,940,865	1,49,21,958	0.13
3.	2003	15,302,411	1,52,59,470	0.28
4.	2004	15,672,577	1,56,01,411	0.45
5.	2005	16,051,584	1,59,47,654	0.65
6.	2006	16,441,624	1,62,98,060	0.87
7.	2007	16,777,330	1,66,52,473	0.74
8.	2008	17,215,002	1,70,10,721	1.19
9.	2009	17,506,781	1,73,72,613	0.77

Table 7 GDP (Rs. in millions) (at current prices)

Sl. no.	Year	Real system values	Model result	Percentage difference (%)
1.	2002	182,446	181,759	0.38
2.	2003	207,784	207,132	0.31
3.	2004	223,962	235,724	5.25
4.	2005	255,468	267,937	4.88
5.	2006	289,160	304,225	5.21
6.	2007	354,319	345,097	2.60

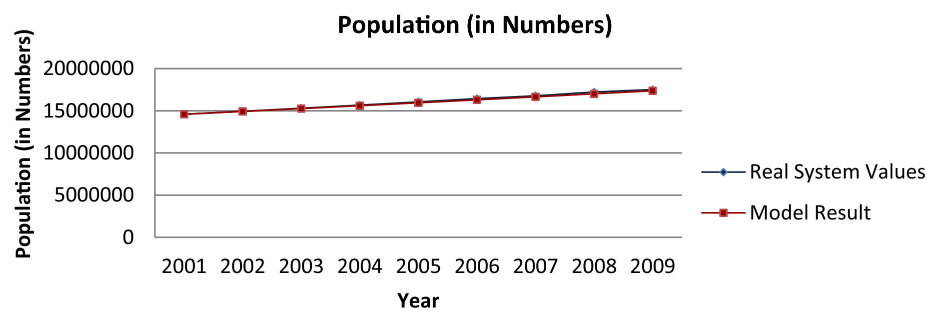

Fig. 9 Population (in numbers). The graph showing the comparison between real system values and the model generated values from the year 2001 to 2009. The line in *blue colour* represents the real system values, and the line in *red colour* shows the model values of population growth trend

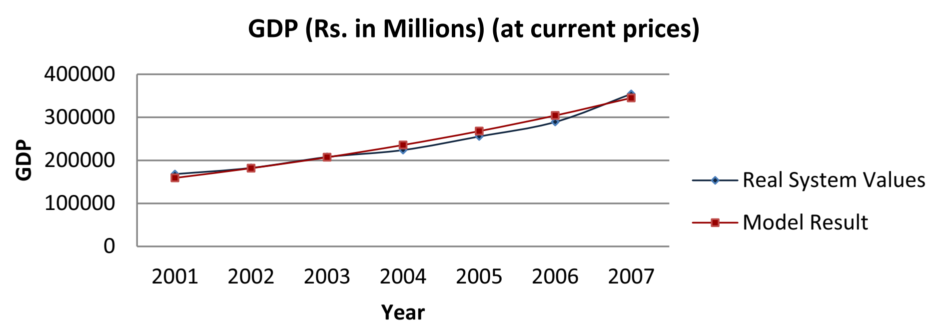

Fig. 10 GDP (Rs. in millions) (at current prices). The graph showing the comparison between real system values and the model generated values from the year 2001 to 2009. The line in *blue colour* represents the real system values, and the line in *red colour* shows the model values of Gross Domestic Product

the base year model by employing STELLA software by considering the time series data available in the system (Table 8).

9.1 Population projection

The projected population and population density in the study area are presented in Table 9 and Fig. 11. The model results reveal that the population in the study area would increase from 1,76,62,618 in 2011 to 2,49,74,770 in the year 2031.

Table 8 Model validation using percentage difference and regression analysis method

Sl. no.	Name of parameters	Percentage difference between real value and model result (%)	*R* value	R^2
1	Population	≤1.19	1.00	1.00
2	Sex ratio	≤0.10	0.99	0.99
3	Birth rate	≤2.08	0.97	0.94
4	Literacy rate	≤4.78	1.00	1.00
5	IMR	≤1.72	0.91	0.82
6	GDP	≤5.25	0.99	0.98
7	Percentage of villages electrified	≤4.17	0.99	0.98
8	Road length	≤4.24	1.00	0.99

Table 9 Projected population

Sl. no.	Year	Population (in numbers)
1.	2011	1,76,62,618
2.	2016	1,95,18,975
3.	2021	2,14,08,368
4.	2026	2,32,63,270
5.	2031	2,49,74,770

Fig. 11 Projected population and population density up to 2031

9.2 Projected per capita income

The projected per capita income in the study area is presented in Table 10 and Fig. 12. The model results reveal that the per capita annual income in the study area would increase from Rs. 32,101 in the year 2011 to Rs. 2,49,576 in the year 2031.

9.3 Projected yield of cereals, pulses, fruits, vegetables, and flowers

The projected yield of cereals, pulses, fruits, vegetables, and flowers in the study area is presented in Table 11 and Fig. 13. The model results reveal that the yield of cereals in the study area would increase from 302,000 kg/km^2 in the year 2011 to 667,000 kg/km^2 in the year 2031; yield of pulses would increase from 124,000 to 220,000 kg/km^2; yield of fruits would increase from 2,021,000 to 3,219,000 kg/km^2; yield of vegetables would increase from 1,691,000 to 2,173,000 kg/km^2; and yield of flowers would increase from 1,291,000 to 1,976,000 kg/km^2 during the same period of time.

9.4 Projected production of milk, egg, fish, and meat

The projected production of milk, egg, fish, and meat in the study area is presented in Table 12 and Fig. 14. The model results reveal that the annual production of milk in the study area would increase from 812 million kg in the year 2011 to 9530 million kg in the year 2031; the annual production of eggs would increase from 103 to 291 million; the

Table 10 Projected per capita income

Sl. no.	Year	Per capita income (in Rs./year)
1.	2011	32,101
2.	2016	53,372
3.	2021	88,659
4.	2026	1,47,899
5.	2031	2,48,981

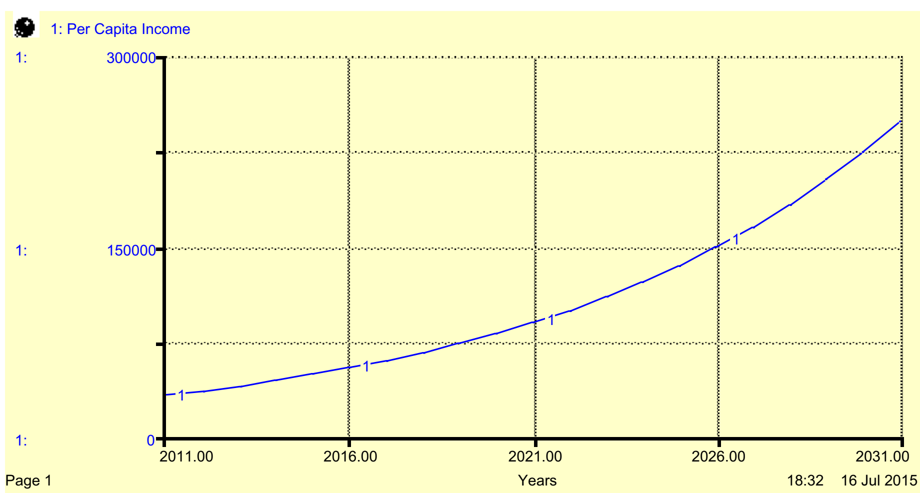

Fig. 12 Projected per capita income up to 2031

Table 11 Projected production of cereals, pulses, fruits, vegetables, and flowers

Sl. no.	Year	Yield of cereals (in 000′ kg/km^2)	Yield of pulses (in 000′ kg/km^2)	Yield of fruits (in 000′ kg/km^2)	Yield of vegetables (in 000′ kg/km^2)	Yield of flowers (in 000′ kg/km^2)
1.	2011	302	124	2021	1691	1291
2.	2016	381	144	2289	1841	1441
3.	2021	464	166	2568	1999	1599
4.	2026	557	191	2871	2173	1773
5.	2031	667	220	3219	2376	1976

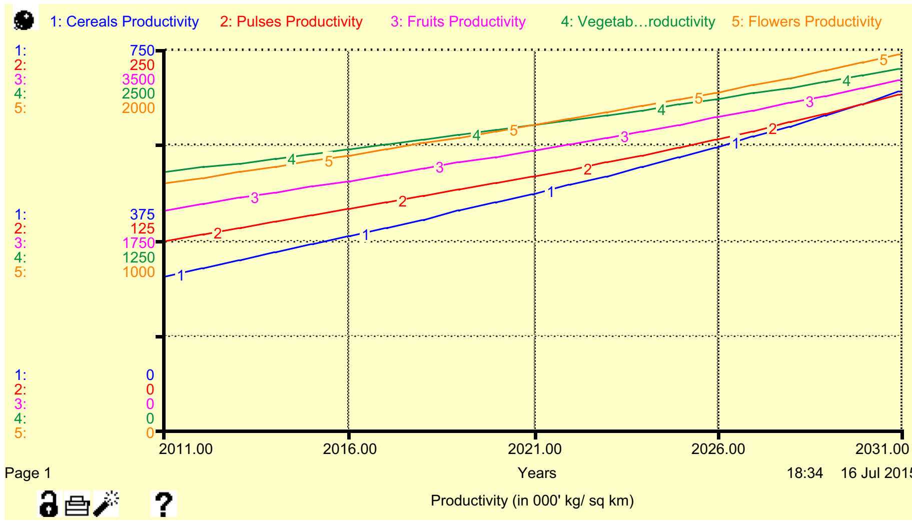

Fig. 13 Projected production of cereals, pulses, fruits, vegetables, and flowers up to year 2031

Table 12 Projected production of milk, egg, fish, and meat

Sl. no.	Year	Milk production (in million kg per annum)	Egg production (millions in number per annum)	Meat production (million kg per annum)	Fish production (million kg per annum)
1.	2011	812	103	20	41
2.	2016	1438	116	28	46
3.	2021	2688	143	45	55
4.	2026	5076	195	76	73
5.	2031	9530	291	134	106

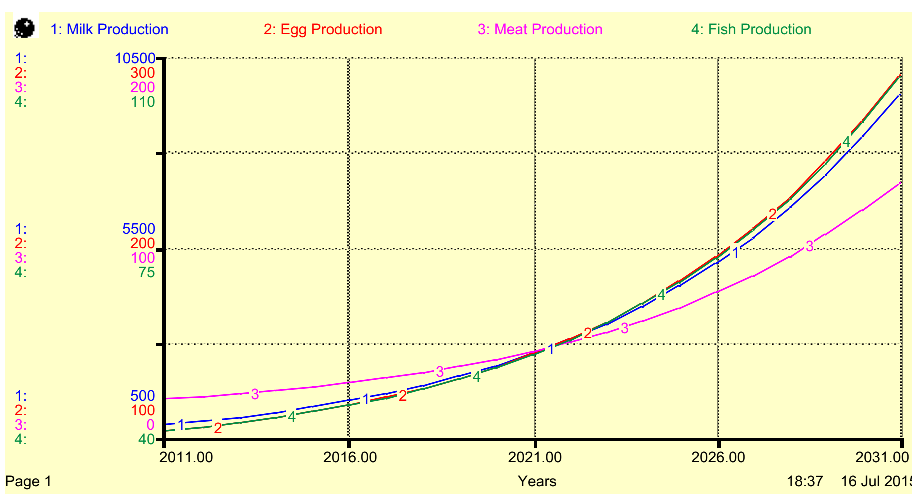

Fig. 14 Projected production of milk, egg, fish, and meat up to 2031

Table 13 Projected GDP, GDP in Primary Sector, GDP in Secondary Sector, GDP in Tertiary Sector, GDP in Agriculture and Allied Sector, and GDP in Industrial Sector

Sl. no.	Year	GDP (Rs. in millions)	GDP in Primary Sector (Rs. in millions)	GDP in Secondary Sector (Rs. in millions)	GDP in Tertiary Sector (Rs. in millions)	GDP in Agriculture and Allied Sector (Rs. in millions)	GDP in Industrial Sector (Rs. in millions)
1.	2011	5,66,990	71,449	56,778	4,60,269	49,943	55,023
2.	2016	10,41,767	1,01,385	1,11,854	8,69,609	60,304	1,11,920
3.	2021	18,98,036	1,50,235	2,11,958	16,12,042	74,037	2,15,291
4.	2026	34,40,608	2,32,471	3,93,155	29,54,182	93,271	4,02,348
5.	2031	62,18,231	3,74,194	7,20,358	53,75,907	1,21,966	7,40,066

annual production of meat would increase from 20 to 134 million kg; and the annual production of fish would increase from 41 to 106 million kg during the year 2011 to year 2031.

9.5 Projected GDP, GDP in Primary Sector, GDP in Secondary Sector, GDP in Tertiary Sector, GDP in Agriculture and Allied Sector, and GDP in Industrial Sector

The projected GDP, GDP in Primary Sector, GDP in Secondary Sector, GDP in Tertiary Sector, GDP in Agriculture and Allied Sector, and GDP in Industrial Sector in the study area are presented in Table 13 and Figs. 15 and 16. The model results reveal that the GDP in the study area would increase from Rs. 5,66,990 million in the year 2011 to Rs. 62,18,231 million in the year 2031; GDP in Primary Sector would increase from Rs. 71,449 million to Rs. 2,32,471 million; GDP in Secondary Sector would increase from Rs. 56,778 million to Rs. 3,93,155 million; GDP in Tertiary Sector would increase from Rs. 4,60,269 million to Rs. 53,75,907 million; GDP in Agriculture and Allied Sector would increase from Rs. 49,943 million to Rs. 1,21,966 million; and GDP in Industrial Sector would increase from Rs. 55,023 million to Rs. 7,40,066 million during the year 2011 to year 2031.

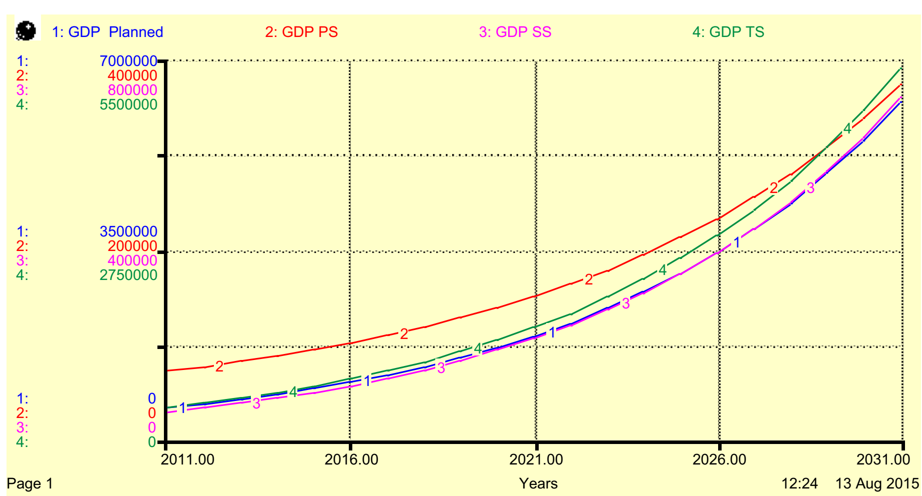

Fig. 15 Projected GDP, GDP in Primary Sector, GDP in Secondary Sector, and GDP in Tertiary Sector up to year 2031

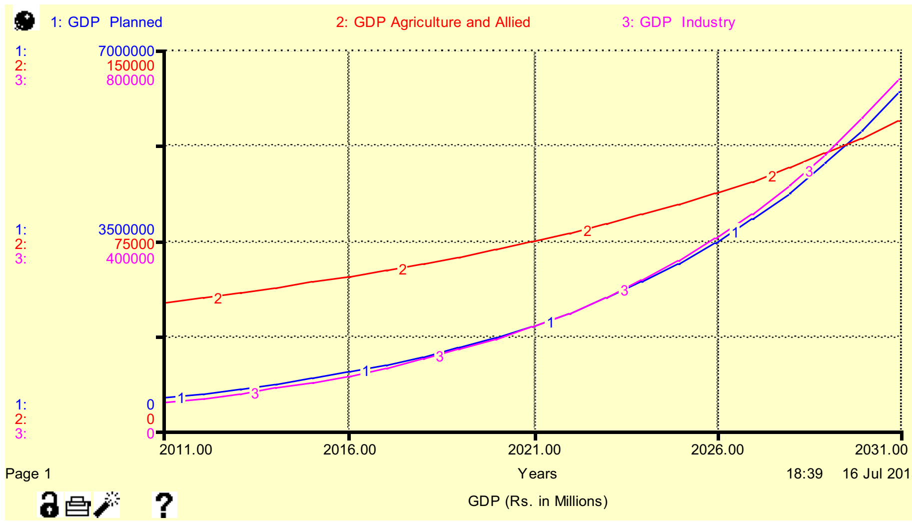

Fig. 16 Projected GDP, GDP in Agriculture and Allied Sector, and GDP in Industrial Sector up to year 2031

10 Recommendation

On the basis of detailed analysis of the evolved policies and their perceived outcomes, a policy would be more suitable for overall development of the regional system. The policy is developed on the basis of composite scenario, according to which there are 2.00% addition in the percentage expenditure on agriculture and allied sector; 2.00% exclusion from the percentage expenditure on rural development; 6.00% addition in the percentage expenditure on transport and communication; 4.00% exclusion from the percentage expenditure on irrigation and flood control; 6.00% exclusion from the percentage expenditure on social services; 2.00% addition in the percentage expenditure on energy; and 2.0% addition in percentage expenditure on science, technology and environment.

This policy has been considered for recommendation and phasewise development of all the subsystems of the regional system. Four phases has been considered for the recommended policy analysis, between 2011 and 2031, which are Phase 1 (2011–2016), Phase 2 (2016–2021), Phase 3 (2021–2026), and Phase 4 (2026–2031), and are presented in Table 14; Figs. 17, 18, 19, 20, 21, and 22. These tables and figures reveal that the achievements and thrust areas at different phases vary considerably in the study area. The phasewise socio-economic development have been presented as follows. They are:

10.1 Phase 1: (2011–2016)

It has been observed that the population would increase from 1,76,62,618 to 1,95,09,939 during this phase, the population density would increase from 1047 to 1156 per km^2, the birth rate would decrease from 29 to 27 per 1000 of mid-year population, the death rate would be 7 per 1000 of mid-year population, sex ratio would increase from 902 to 909 female/1000 males, the literacy rate would increase from 69.04 to 72.32%, the infant mortality rate would decrease from 59 to 56 per 1000 of mid-year population, and the per capita income would increase from Rs. 34,979 to 61,978 per annum. It has been observed in the production analysis that the production of cereals would increase from

Table 14 Perceived phasewise development

Sl. no.	Year	Birth rate (per 1000 of mid-year population)	Death rate (per 1000 of mid-year population)	Sex ratio (female/1000 males)	Literacy rate (%)	Infant mortality rate (per 1000 of mid-year population)
1.	2011	29	7	902	69.04	59
2.	2011–2016	27	7	909	72.32	56
3.	2016–2021	26	6	920	75.45	53
4.	2021–2026	24	6	940	78.51	46
5.	2026–2031	23	5	978	81.55	33

Sl. no.	Year	Population (in numbers)	Population density (numbers/km^2)	Per capita income (in Rs./year)
1.	2011	1,76,62,618	1047	34,979
2.	2016	1,95,09,939	1156	61,978
3.	2021	2,13,72,375	1267	1,09,943
4.	2026	2,31,58,074	1372	1,96,438
5.	2031	2,47,05,275	1464	3,55,883

Sl. no.	Year	Production of cereals (in 000′ kg/km^2)	Production of pulses (in 000′ kg/km^2)	Production of fruits (in 000′ kg/km^2)	Production of vegetables (in 000′ kg/km^2)	Production of flowers (in 000′ kg/km^2)
1.	2011	302	124	2021	1691	1291
2.	2016	381	145	2289	1842	1442
3.	2021	467	167	2570	2003	1603
4.	2026	567	193	2880	2185	1785
5.	2031	695	227	3247	2409	2009

Sl. no.	Year	Milk production (in million kg per annum)	Egg production (million in number per annum)	Meat production (million kg per annum)	Fish production (million kg per annum)
1.	2011	812	103	20	41
2.	2016	1838	125	33	49
3.	2021	4011	172	62	65
4.	2026	8416	267	119	98
5.	2031	17,142	455	234	163

Sl. no.	Year	GDP (Rs. in millions)	GDP in Primary Sector (Rs. in millions)	GDP in Secondary Sector (Rs. in millions)	GDP in Tertiary Sector (Rs. in millions)
1.	2011	6,17,828	71,449	62,917	5,04,968
2.	2016	12,09,188	1,01,562	1,32,047	10,16,660
3.	2021	23,49,738	1,51,431	2,66,326	20,08,179
4.	2026	45,49,114	2,36,785	5,26,366	39,25,164
5.	2031	87,92,197	3,86,724	10,29,287	76,28,414

Sl. no.	Year	GDP in Agriculture and Allied Sector (Rs. in millions)	GDP in Industrial Sector (Rs. in millions)
1.	2011	49,943	61,163
2.	2016	60,482	1,32,113
3.	2021	75,232	2,69,659
4.	2026	97,585	5,35,559
5.	2031	1,34,497	10,48,994

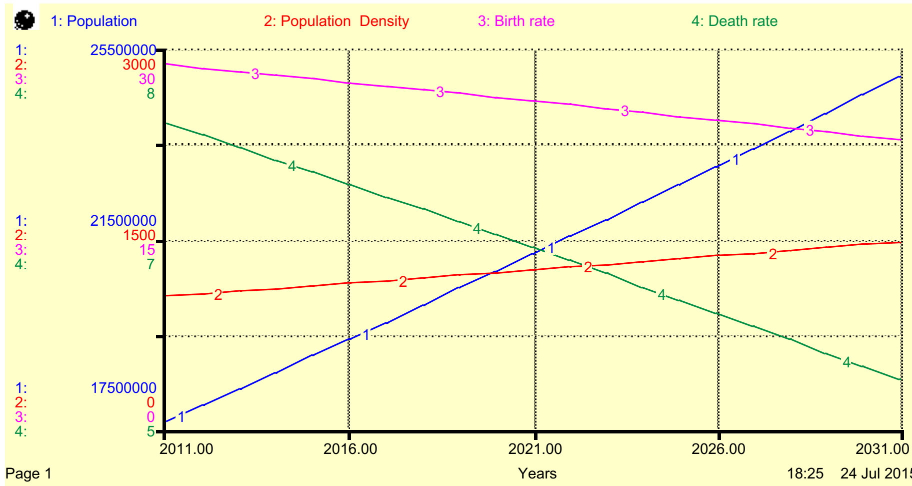

Fig. 17 Perceived projected population, population density, birth rate, and death rate

Fig. 18 Perceived projected sex ratio, literacy rate, infant mortality rate, and per capita income

302 thousand to 381 thousand kg/km^2, the production of pulses would increase from 124 to 145 thousand kg/km^2, the production of fruits would increase from 2021 thousand to 2289 thousand kg/km^2, the production of vegetables would increase from 1691 thousand to 1842 thousand kg/km^2, the production of flowers would increase from 1291 thousand to 1442 thousand kg/km^2, the production of milk would increase from 812 million to 1838 million kg per annum, the production of eggs would increase from 103 million to 125 million per annum, the production of meat would increase from 20 million to 33 million kg per annum, the production of fish would increase from 41 million to 49 million kg per annum. It has been further observed in the economic analysis that the GDP would increase from Rs. 6,17,828 million to 12,09,188 million, the GDP in Primary Sector would increase from Rs. 71,449 million to 1,01,562 million, the GDP in Secondary Sector would increase from Rs. 62,917 million to 1,32,047 million, the GDP in Tertiary Sector would increase from Rs. 5,04,968 million to 10,16,660 million, the GDP in

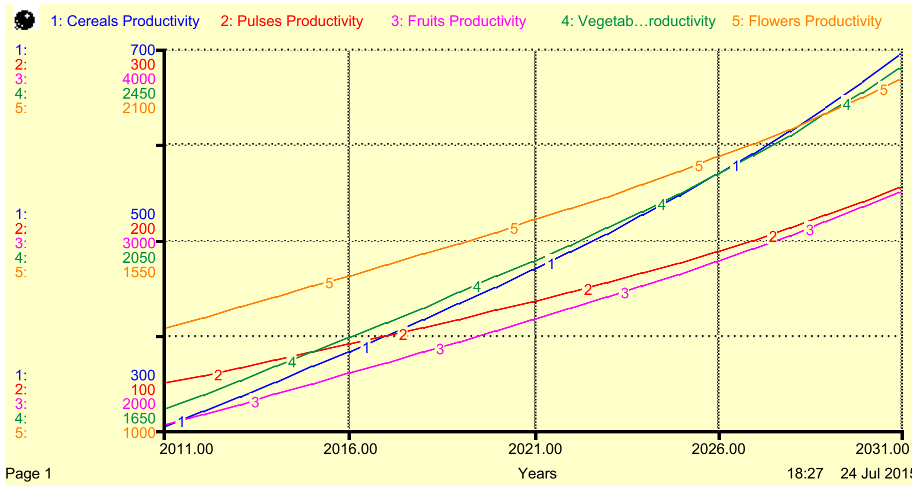

Fig. 19 Perceived projected production of cereals, pulses, fruits, vegetables, and flowers

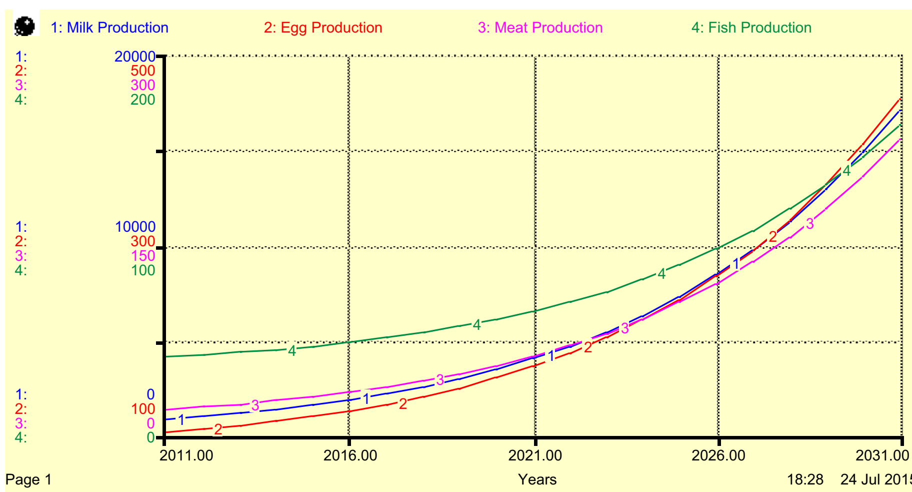

Fig. 20 Perceived projected production of milk, egg, meat, and fish

Agriculture and Allied Sector would increase from Rs. 49,943 million to 60,482 million, and the GDP in Industrial Sector would increase from Rs. 61,163 million to 1,32,113 million..

10.2 Phase 2: (2016–2021)

It has been observed that the population would increase from 1,95,09,939 to 2,13,72,375 during this phase, the population density would increase from 1156 to 1267 per km^2, the birth rate would decrease from 27 to 26 per 1000 of mid-year population, the death rate would decrease from 7 to 6 per 1000 of mid-year population, sex ratio would increase from 909 to 920 female/1000 males, the literacy rate would increase from 72.32 to 75.45%, the infant mortality rate would decrease from 56 to 53 per 1000 of mid-year population, and the per capita income would increase from Rs. 61,978 to 1,09,943 per annum. It has been observed in the production analysis that the production of cereals

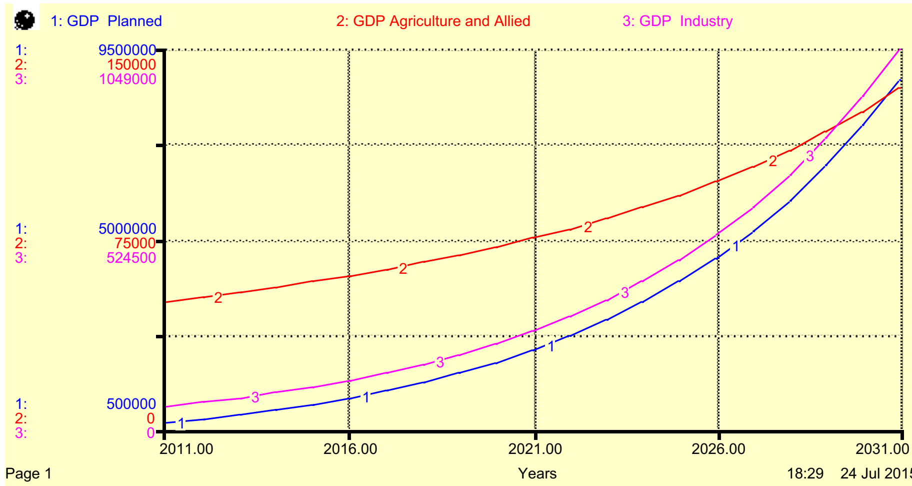

Fig. 21 Perceived projected GDP, GDP in Agriculture and Allied Sector, and GDP in Industrial Sector

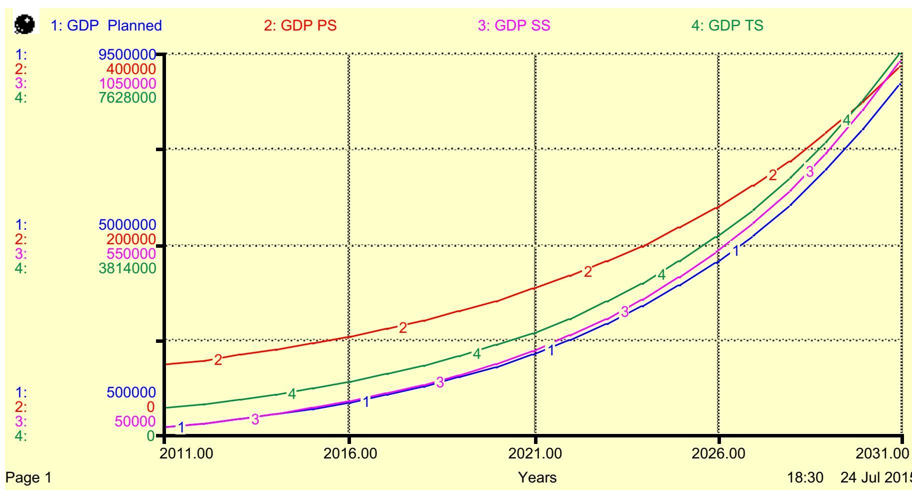

Fig. 22 Perceived projected GDP, GDP in Primary Sector, GDP in Secondary Sector, and GDP in Tertiary Sector

would increase from 381 thousand to 467 thousand kg/km^2, the production of pulses would increase from 145 thousand to 167 thousand kg/km^2, the production of fruits would increase from 2289 thousand to 2570 thousand kg/km^2, the production of vegetables would increase from 1842 thousand to 2003 thousand kg/km^2, the production of flowers would increase from 1442 thousand to 1603 thousand kg/km^2, the production of milk would increase from 1832 million to 4011 million kg per annum, the production of eggs would increase from 125 million to 172 million per annum, the production of meat would increase from 33 million to 62 million kg per annum, the production of fish would increase from 49 million to 65 million kg per annum. It has been further observed in the economic analysis that the GDP would increase from Rs. 12,09,188 million to 23,49,738 million, the GDP in Primary Sector would increase from Rs. 1,01,562 million to 1,51,431 million, the GDP in Secondary Sector would increase from Rs. 1,32,047 million to 2,66,326 million, the GDP in Tertiary Sector would increase from Rs. 10,16,660 million to 20,08,179 million, the GDP in Agriculture and Allied Sector would increase from Rs. 60,482 million to 75,232 million, and the GDP in Industrial Sector would increase from Rs. 1,32,113 million to 2,69,659 million.

10.3 Phase 3: (2021–2026)

It has been observed that the population would increase from 2,13,72,375 to 2,31,58,074 during this phase, the population density would increase from 1267 to 1372 per km^2, the birth rate would decrease from 26 to 24 per 1000 of mid-year population, the death rate would be same as 6 per 1000 of mid-year population, sex ratio would increase from 920 to 940 female/1000 males, the literacy rate would increase from 75.45 to 78.51%, the infant mortality rate would decrease from 53 to 46 per 1000 of mid-year population, and the per capita income would increase from Rs. 1,09,943 to 1,96,438 per annum. It has been observed in the production analysis that the production of cereals would increase from 467 thousand to 567 thousand kg/km^2, the production of pulses would increase from 167 thousand to 193 thousand kg/km^2, the production of fruits would increase from 2570 thousand to 2880 thousand kg/km^2, the production of vegetables would increase from 2003 thousand to 2185 thousand kg/km^2, the production of flowers would increase from 1603 thousand to 1785 thousand kg/km^2, the production of milk would increase from 4011 million to 8416 million kg per annum, the production of eggs would increase from 172 million to 267 million per annum, the production of meat would increase from 62 million to 119 million kg per annum, the production of fish would increase from 65 million to 98 million kg per annum. It has been further observed in the economic analysis that the GDP would increase from Rs. 23,49,738 million to 45,49,114 million, the GDP in Primary Sector would increase from Rs. 1,51,431 million to 2,36,785 million, the GDP in Secondary Sector would increase from Rs. 2,66,326 million to 5,26,366 million, the GDP in Tertiary Sector would increase from Rs. 20,08,179 million to 39,25,164 million, the GDP in Agriculture and Allied Sector would increase from Rs. 75,232 million to 97,585 million, and the GDP in Industrial Sector would increase from Rs. 2,69,659 million to 5,35,559 million.

10.4 Phase 4: (2026–2031)

It has been observed that the population would increase from 2,31,58,074 to 2,47,05,275 during this phase, the population density would increase from 1372 to 1464 per km^2, the birth rate would decrease from 24 to 23 per 1000 of mid-year population, the death rate would decrease from 6 to 5 per 1000 of mid-year population, sex ratio would increase from 940 to 978 female/1000 males, the literacy rate would increase from 78.51 to 81.55%, the infant mortality rate would decrease from 46 to 33 per 1000 of mid-year population, and the per capita income would increase from Rs. 1,96,438 to 3,55,883 per annum. It has been observed in the production analysis that the production of cereals would increase from 567 thousand to 695 thousand kg/km^2, the production of pulses would increase from 193 thousand to 227 thousand kg/km^2, the production of fruits would increase from 2880 thousand to 3247 thousand kg/km^2, the production of vegetables would increase from 2185 thousand to 2409 thousand kg/km^2, the production of flowers would increase from 1785 thousand to 2009 thousand kg/km^2, the production of milk would increase from 8416 million to 17,142 million kg per annum, the production of eggs would increase from 267 million to 455 million per annum, the production of meat would increase from 119 million to 234 million kg per annum, the production of fish would increase from 98 million to 163 million kg per annum. It has been further observed in the economic analysis that the GDP would increase from Rs. 45,49,114 million to 87,92,197 million, the GDP in Primary Sector would increase from Rs. 2,36,785 million to 3,86,724 million, the GDP in Secondary Sector would increase from Rs. 5,26,366 million to 10,29,287 million, the GDP in Tertiary Sector would increase from Rs. 39,25,164 million to 76,28,414 million, the GDP in Agriculture and Allied Sector would increase from Rs. 97,585 million to 1,34,497 million, and the GDP in Industrial Sector would increase from Rs. 5,35,559 million to 10,48,994 million.

11 Conclusion

The economic development of a region can be achieved by ensuring the sustainable agricultural growth. This requires plausible policy guidelines and feasible plan, for which thorough grassroots level investigation is essential. The available literature in this field reveals that much work has not been done in this regard, particularly in the Patna region, India. In this present investigation, an attempt has been made to evolve plausible policy guidelines and recommendations for the economic development of Patna region, by considering it as a system. Further, by considering the important control parameters of various subsystems of the system, system dynamic model for economic development in the system has been evolved. The evolved model is validated and used for projections. Subsequently, projections, for the year 2031 AD, have been made to understand the behaviour of the system. The functions of the system under various alternative conditions are closely examined by developing various scenarios and tested in the model to arrive at alternative policy option for taking plausible decisions. Finally, a set of plausible policy guidelines has been prepared screening phasewise requirements and achievements in alternative conditions. It is evident that the approach of increase in agricultural production for sustainable economic development is feasible in the study area. Close examination of the findings suggests that secondary steps, technological advancement along with conservation of basic, are imperative to achieve economic development. It is anticipated that if the proposed planning model is implemented successfully in the study area, it will ensure sustainable development in the system, definitely.

12 Suggestions for further research

The present investigation has ample scope for further research and extension. A few of further research scopes are:

1. Survey at large scale shall be conducted to have more accurate picture of the socio-economic status, institutional scenario, and infrastructure condition of the system.
2. Microlevel studies shall be conducted to evolve integrated development plans in various regions, for the period of five years by employing location analysis, optimization techniques, statistical methods, input and output models, etc.
3. The physical plan can be developed for optimum spatial location of infrastructure, industries, etc. in the study area.
4. Impact of the region's development on overall growth of the nation may be attempted.

Additional file

Additional file 1. Projected data pertaining to the indicators of development for Patna region.

Authors' contributions

The research work and methodology is guided by Dr. V. Devadas (Ph.D. thesis supervisor and author). The selection of study area, data collection, analysis, and employing system dynamics to get the result is done by Dr. Rashmi Kumari (corresponding author). The discussion and conclusion part is the outcome of both authors' contribution. Each author contributed extensively to the research work presented in this paper. The corresponding author made substantial contributions to conception and design, acquisition of data, and analysis and interpretation of data. The second author has been involved in revising the manuscript critically for important intellectual content and given final approval of the version to be published. Both authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

The dataset supporting the conclusions of this article is available in the supplementary excel spreadsheet (Additional file 1).

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