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Quantitative Analysis of Critical Population Load on Food Sustainability in Different Scenarios: A Comparative Analysis

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Abstract

Food sustainability of a nation is primarily dependent on food production and food demand. With limited and even declining primary resources like arable land and water, increasing demand due to population growth, and potential impact of climate change, food sustainability has become a major concern especially for the populous countries. Food sustainability is a complex function of several variables and the overall sustainability is restricted by these factors and need to examine from regional to global scale. A major gap is a consistent and quantitative formulation for assessment and projection of food sustainability. Here, we present a mathematical model to estimate food sustainability in different scenarios of population growth and consumption pattern. We have also estimated the technology demand for sustainable food supply in different scenarios of population and per capita food consumption by considering world as global, and India, China and the USA as regional for analysis of food sustainability.

Keywords Agricultural sustainability, Food sustainability, population growth, food consumption, Sustainability Index, Technology demand

Introduction

Food sustainability of a nation primarily depends on domestic production as well as external associated import. With declining primary resources, world-wide declining/saturation trend in agricultural productivity and increasing food demand; food sustainability has emerged as major problem in the present decade (Godfray et al. 2010; Gahukar 2011; Funk and Brown 2009; Goswami and Nishad 2014; Cohen, 1995a,b). There is a challenge to feed the growing population with their changing consumption pattern and diets. Although some regions have shown increasing trend in agricultural production but not sufficient to provide the adequate food to the growing population. World-wide declining primary resources (like arable land and water) and increasing food demand along with changing socio-economic and climatic conditions, there is challenge to feed the growing population with limited primary resources with changing food consumption pattern and it now appears to be getting close to the limits of global food production capacity (Fresco 2009; Doos 2002; Gregory and Timothy 2011; Higgins et al 1983;Fereres et al 2011; Kendall and Pimentel 1994). Food sustainability is also limited by the overall production, demand and the limits of food production capacity (Hanjra and Qureshi 2010; Singh 2009; Hamdy and Trisrio-Liuzzi 2009; Regmi and Meade 2013; Lutz et al. 1997; Goswami and Nishad 2015). The increasing demand combined with limited and even declining primary resources (arable land and water) can create criticality even if productivity increases (Goswami and Nishad 2018; Xie et al. 2005; Yang et al. 2003). In addition, several studies have shown the potential impact of climate change on availability of food and primary resources from regional to global scale (Gregory et al.

2005; Smith and Gregory 2013; Brown and Chunk 2008; Goswami and Nishad 2015). Therefore, quantitative assessment of food sustainability has become a necessity for providing adequate food and other essential human needs for current and future generations (Cohen 1995; Gretchen and Ehrlich 1992; Arrow et al. 1995; Harris and Kennedy 1999; Hugo 2009; Hern 1999; Rahnema 2002; Hopenberg and Pimentel 2001).

Food sustainability primarily is determined by agricultural production and food demand, and hence assessment of food sustainability is of considerable interest (Goswami and Nishad 2015). Food sustainability, defined as the ratio of total food availability to the total food demand, is a very complex function of several changing parameters. The complexity in quantitative analysis of food sustainability arises from the fact that the production and demand depend on several changing parameters like arable land, water resources (Gleick 1996; Brown and Matlock 2011; Zhao 2012), agricultural productivity, population, nutritional requirement, diets and supply (Hamdy and Trisrio-Liuzzi 2009; Wirsenius et al. 2010; Gerbens-Leenes and Nonhebel 2005; Imhoff et al. 2004; Yang and Zehnder 2002).

External sources like import (if surplus anywhere) is also a major factor for achieving Food sustainability (Wirsenius et al. 2010, Goswami and Nishad 2014). External sources basically depends on the availability of surplus and bilateral relationship between countries. Due to population growth and their own food demand with several challenges, the import of food commodities may not possible in near future. However, virtual water trade is an additional factor for loss of water sustainability (Goswami and Nishad 2015) that may restrict to some countries to export food commodities to other countries due to their own demand and limitations like water scarcity. Another major factors that affect food sustainability is food loss and wastage from production, retails and consumer.

According to FAO, about 33% of produced food of the world is wasted every year, which has become a major concern for food sustainability

Analyses with different population and consumption scenarios, assessments of food sustainability at regional and global scale show that while a relatively small fraction of the world population is sub-critical in terms of availability of the food, but much larger fractions are becoming sub-critical in terms of food production (Goswami and Nishad 2018). Further, changing climate can introduce more severe constraints and vulnerability through droughts and extremes. The projection of climate change have shown significant impact on food and availability of primary resources like arable land and water. It is clear that the dynamics of the primary resources, and their effects, will vary with region and will emerge at different times; there are, however, definite indications of such emerging regional stress. These regional stresses, especially for countries of having large populations, can affect the global food sustainability as a whole through change in demand and surplus. It needs to be emphasized, however, that production of food will be constrained by the simultaneous availability of both land and water in a region (Goswami and Nishad 2018).

Therefore, the objective of the present study is to examine the food sustainability from regional to global scale through a synthesis of available of primary resources and food, agricultural productivity, population growth and changing consumption pattern. This analysis is then apply to assessment of food sustainability in different scenarios of population growth and consumption pattern. We also quantify technology demand (in terms of agricultural productivity) to maintain agricultural sustainability in different scenarios of population growth and consumption pattern. We have considered world as global, India, China and the USA as regional.

Formulation of the problem

Food sustainability index

In general, Food sustainability index is defined as

$$S(i,t) = \frac{F_A(i,t)}{F_D(i,t)} \qquad (1)$$

Where $F_A(i,t)$ and $F_D(i,t)$, respectively, represent the food available and food demand of the i^{th} country in the year t. $S(i,t)$ represents the agricultural sustainability of the i^{th} country. We have state of agricultural sustainability in case of $S(i,t) > 1$ and loss of sustainability otherwise.

Primary resources: arable land

It is considered world, India, China and the USA for which annual data is available on public domain (FAOSTAT and AQUASTAT). The amount of arable land in the year t and the country i is calculated

$$A_g(i,t) = A_{Max}(i) - A_U(i) * N(i,t) \qquad (2)$$

Where $Ag(i,t)$ represents arable land of the i^{th} country or the world in the year t. $A_{max}(i)$ represents maximum available arable land available of the i^{th} country or the world. $A_{max}(i)$ is for the India: 165 million hectare, China: 124 million hectare, USA: 189 million hectare and world: 1400 million hectare. The second term on the right hand side of the equation (2) represents loss of agricultural land due to land use for non-agricultural activities like habitat, infrastructure and industries. $A_U(i)$ represents the minimum per capita land required for non-agricultural purposes and varies among the countries. However, we have assumed this demand to be proportional to the population ($N(i,t)$) of i^{th} country or the world in the year t.

Production, demand and availability of Food

We define agricultural production, $F_P(i,t)$, and total food demand, $F_D(i,t)$ as

$$F_P(i,t) = A_g(i,t) * A_P(i,t) \qquad (4)$$

$$F_D(i,t) = F_{CP}(i,t) * N(i,t) \qquad (5)$$

Here $F_P(i,t)$ and $F_D(i,t)$, respectively, represent the total food production and the total food demand of the country i for the year t.

The total food available for consumption, $F_A(i,t)$, is estimated as

$$F_A(i,t) = F_P(i,t) + F_I(i,t) - F_E(i,t) - F_L(i,t) \quad (6)$$

Here $F_E(i,t)$ and $F_I(i,t)$ denote, respectively, total export and the total import of food commodities. The term $F_L(i,t)$ represents the total loss of food that accounts for both avoidable and unavoidable losses. The avoidable (equivalent) loss accounts for the fraction of food production used to account for costs of irrigation, seed, feed, fertilizers and transport

The current per capita food consumption, F_{cp}, of the world: 470 kg/year, India: 350 kg/year, China: 630kg/year and USA: 510 kg/year (Table 1).

Parameter	**Unit**	**World**	**India**	**China**	**USA**
Arable land (A_{max})	10^{10} m^2	1400	165	124	189
Current population	Million	6900	1220	1300	300
Saturation population (UN estimates)	Million	9000	1540	1460	--
Current per capita food consumption	kg/capita/year	450	350	650	510
Current agricultural productivity	kg/m^2	0.4	0.3	1.2	0.3
Total food loss by consumer sector	Kg	57	15	80	110
food loss through production and retail sector	Kg	153	110	160	185
Coefficient of total food loss (fraction of total food production) (α_P)	Average(1960-2009)	0.23	0.37	0.28	0.15

Table 1 Description of parameters used in this study.

The term $F_L(i,t)$represents the total loss of food and wastage due to inevitable losses associated with the processes of distribution and consumption. We, thus, estimate the food loss as

$$F_L(i,t) = F_{LC}(i,t) + F_{LP}(i,t) \quad (7)$$

The loss of food is sum of losses through consumers ($F_{LC}(i,t)$), production and retail sectors($F_{LP}(i,t)$). The food loss due to consumers may be defined as

$$F_{LC}(i,t) = \alpha_C(i) * N(i,t) \quad (8)$$

Here $\alpha_C(i)$ represents the per capita food loss during consumption time of the i[th] country. Similarly, The food loss due to production and retail sector may be defined as

$$F_{LP}(i,t) = \alpha_P(i) * F_P(i,t) \quad (9)$$

Here $\alpha_P(i)$ represents the fraction of food loss during production and retail of the i[th] country.

The per capita food loss by consumers for Southeast Asia is in the range 5-11 kg/capita/year. While per capita food loss and wastage by production and retails sector is 100 kg/capita/year. As the food loss due to production and retails cannot be accurately estimated separately, we have assumed the combined loss of food due to retails and production processes. The values of α_c and α_p, respectively, represent the per capita food waste by consumers and by production & retail sector, which varies all over the world.

Observed data for agricultural area, fallow land, irrigated area, food production, food consumption, population, per capita food consumption, agricultural productivity, and export, import and food wastes from FAOSTAT. The observed data for land used for non-agricultural purposes for India has taken from Dept. of Agriculture & Cooperation. Observed data of population is taken from FAOSTAT and United Nations Population Projection Division while the observed data of water sources and water consumption is taken from AQUASTAT (Table 1). The data for food waste and food losses for India, China, USA and world has been taken from the Gustavsson et al (2011).

For the calculation of critical population that can support food sustainability, we consider a scenario of maximum possible agricultural area and higher value of the agricultural productivity. Impact of population load on availability of arable land is calculated as the ratio of current arable land and different scenarios of population and per capita land use for non-agricultural purposes. Potential agricultural production is calculated as the product of higher possible agricultural productivity to current arable land.

For the calculation of food sustainability, we consider the maximum possible agriculture area and current agricultural productivity of the countries India, China, USA and world and estimated the state of agricultural sustainability as function of population in different scenarios of per capita food consumption and per capita land use for non-agricultural purposes. We have also projected the state of food sustainability as function of population in different scenarios of per capita food consumption. We have also estimated the technology demand to maintain agricultural sustainability as a function of population in different scenarios of per capita food consumption. We have considered maximum agricultural area and current agricultural productivity for technology demand (agricultural productivity).

The external sources like import and surplus of the countries, we have calculated as a percentage of the world surplus. The surplus of food is the extra available of food after consumption, which can be defined as the difference between productions to the demand with condition production should be more that demand. The food import is defined as the difference between food demand and food production with condition that food demand is more than food production. In the recent time, many countries are importing food from other countries, although they have enough food production than demand for an example, India.

Results

Primary resources: arable land and water

Primary resources like arable land and water are the major constraints for the carrying capacity of a nation. There are declining trend in availability of the primary resources worldwide that affect the agricultural sustainability and put the pressure on policy makers to maintain the sustainability. The per capita arable has declined world-wide due to increasing demand to feed the growing population. The per capita arable land of the world has declined from 4000 m^2/year to 2000 m^2/year in the last 55 years (Figure 1, solid line). Similarly, the per capita land availability for India has declined from 3400 m^2 to 1300 m^2 in the period 1961-2015 (Figure 1, solid line). While the per capita arable land of China and USA, respectively, has reduced from 1600 m^2 to 775 m^2 and 9543 m^2 to 4993 m^2. The overall picture is the per capita arable land has reduced half of its during last 55 years (Figure 1, left panels).

Similarly, per capita water availability of the world has reduced from 18000 m^3 to 6000 m^3 during the last 55 years. Similar trends also have shown for the per capita fresh water availability of India and China. The per capita water available has reduced from 4000 m^3 to 1200 m^3 while it has declined from 4200 m^3 to 2000 m^3 from the years 1961 to 2015. On the other hand, the rate of declining in the USA is much lower than India and China (Figure 1, right panels).

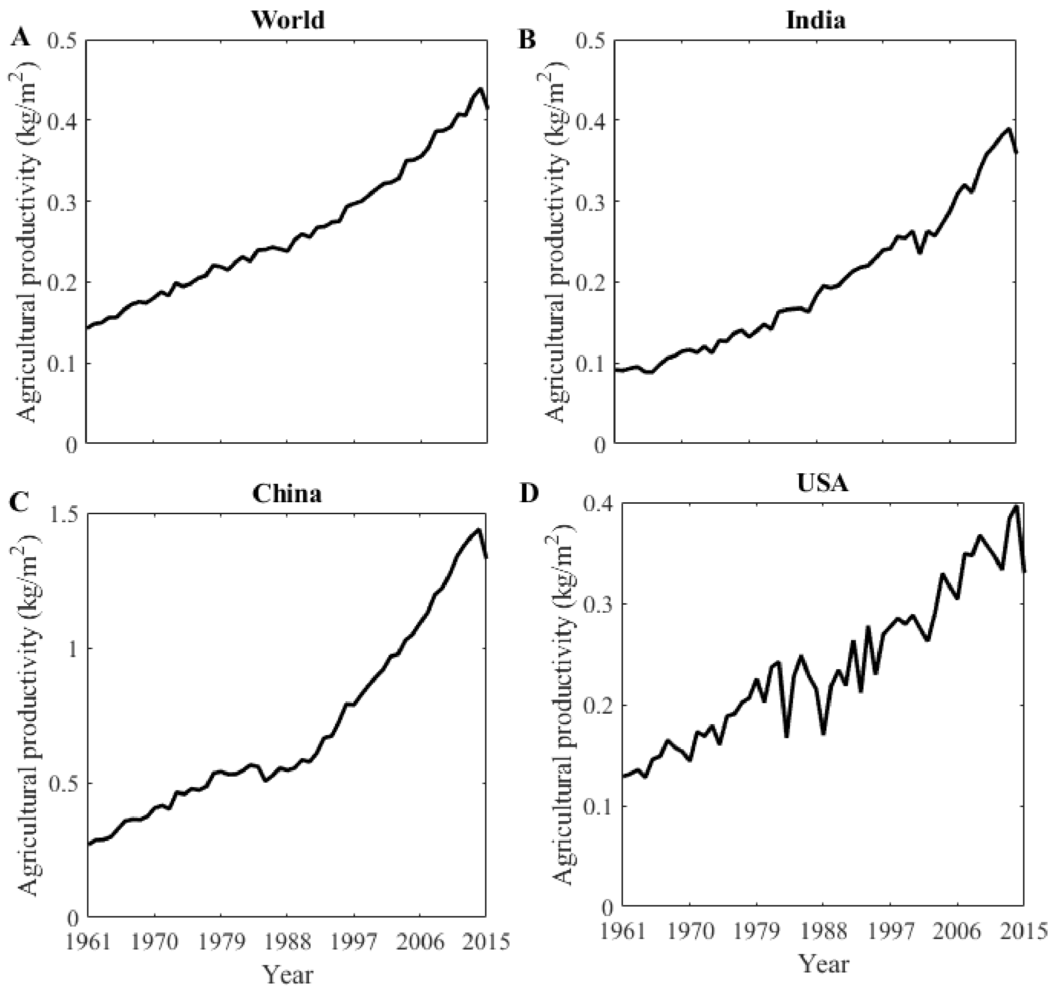

Figure 1: Per capita arable land (A_{PC}, left panel) and per capita water availability (W_{APC}, right panel) of the world, India, China and the USA. The observed data of agricultural area is adopted from FAOSTAT and the data of total water available is adopted from AQUASTAT

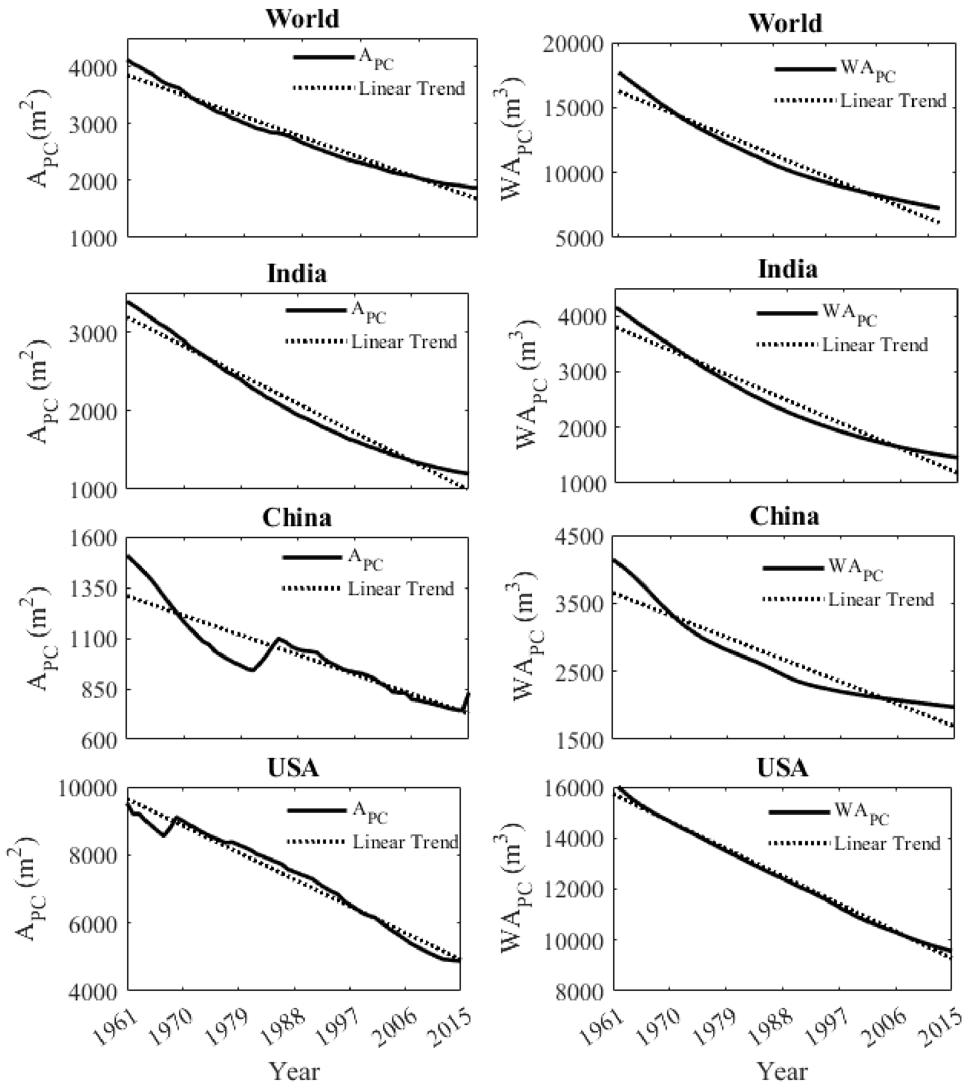

Figure 2: Agricultural productivity for the world (a), India (b), China (c) and the USA (d) for the period 1961 to 2015. The observed data of food production and food consumption is adopted from FAOSTAT.

Agricultural productivity

Agricultural productivity is one of the major constraints that affects food sustainability, which is dependent on available inputs like land, water etc. Declining water resources and increasing demand to meet the needs of increasing population, there is much pressure on increasing agricultural productivity. Many parts of the world have shown declining trend in agricultural productivity and have potential impact of several factors. Although, there are increasing trend in overall agricultural productivity in some regions. The agricultural productivity of the world, India and the USA has increased from 0.15 kg/m^2 to 0.4 kg/m^2 from the year 1961 to 2015. While the agricultural productivity of the China has increased from 0.3 kg/m^2 to 1.4 kg/m^{2}from the year 1961 to 2015. The recent trend from 2010 onwards have shown the declining trend in the agricultural productivity (Figure 2).

Population, food production and demand

World population has increased from 3 billion in 1961 to 7.5 billion in the year 2015 (Figure 3a, long dash line). For India, the population has increased from 459 million to 1300 million in the last 55 years (Figure 3a, thick solid line) while the population of China and USA, respectively is 1438 million and 325 million in the year 2015. The declines in the primary resources for each region are consistent with the growing demands that are beginning to approach and exceed production (Fig. 3b). The agricultural production have saturated due to decline in primary resources and agricultural productivity. The total production of food, for the world, has become double in the last 50 years which keep pace with demand; the current agricultural production is about 3 times, while it was about 2000 million tons in the year 1961 for the world (Fig 3, solid line). Similarly, the food demand, for the world, has also increased two times in the last 50 years from 1200 million tons to 3200 million tons (Fig 3b). Similar conclusions also hold for India (Fig 3b) and China (Fig 3b).

Similarly, the global food supply has increased from 1000 million tons to 3000 million tons in the last 55 years. The food supply of India, China and the USA, respectively, were 109.74 million tons, 204 million tons and 60 million tons in the year 1960 that has increased 433 million tons, 948 million tons, 124 million tons respectively in the year 2013 (Figure 3c). In terms of per capita food supply, the global per capita food supply is about 479 kg/capita/year in the year 2013 (Figure 3d). While the per capita food supply of India, China and the USA, respectively, are 378 kg/capita/year, 690 kg/capita/year and 483 kg/capita/year (Figure 3d).

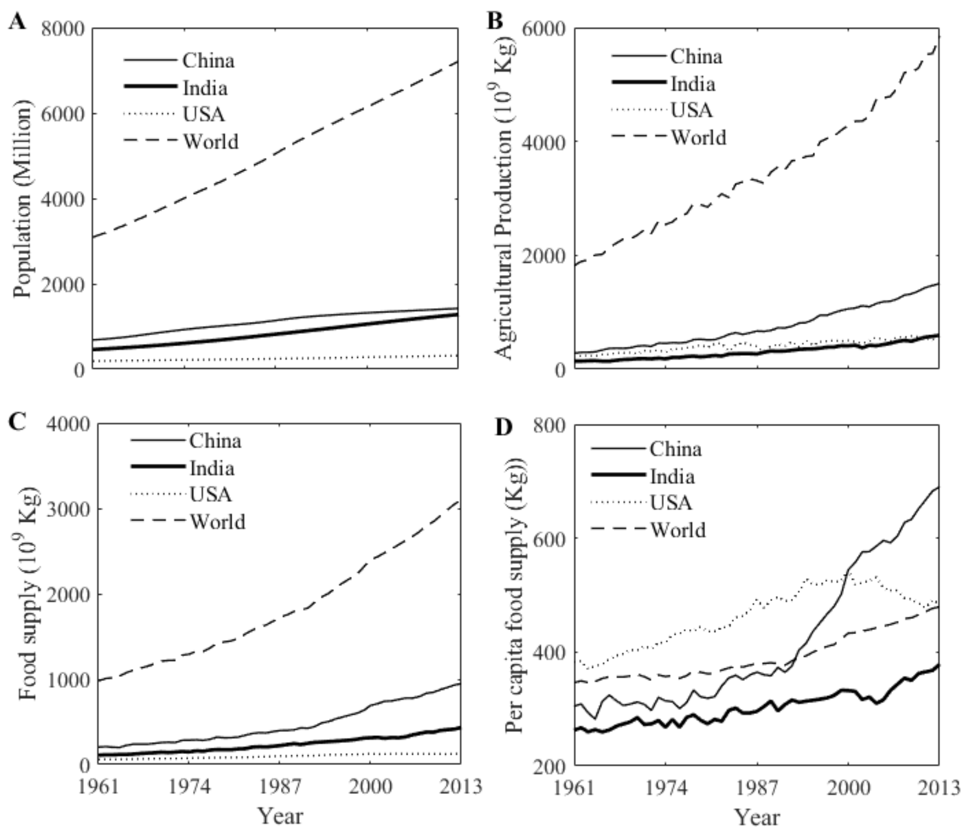

Figure 3: Food production (solid line) and the food supply (dash line) for the world (a), India (b), China (c) and the USA (d) for the period 1961 to 2015. The observed data of food production and food consumption is adopted from FAOSTAT.

Assessment of external sources

Agricultural sustainability depends on food available and food demand. The food available depends on domestic production as well as external sources like import. The external sources is possible with the condition of surplus available anywhere and bilateral relationship among the countries. As the data from FAOSTAT, there is declining trend in exports of food commodities in many major food exporting countries due to their own demand or other factors. In the recent years, India has become major food exporter country while in the 1960s, it was major food importing country. In contrast, there is a decreasing trend in the food export in China (Fig 4b, solid line, right y axis) and the USA (Fig 4c, solid line, right y axis) recent years, although the actual export may sometimes show a growing trend due to enhanced production (Fig 4a, solid line, left y axis). On the other hand, the fraction of food demand met from import has increased (Fig 4, dash line) for India, China and the USA. China is major food importing country; the import of food commodities (Fig 4b, dash line) is higher than export Fig 4b, solid line). While USA is a major food exporting country; the food export (Fig 4c, solid line) is higher than food import (Fig 4c, dash line).

The trade balance (export – import) of India is started positive in the recent years (Fig 4d, solid line, right panel). While China is major food –importing countries, around 10% of its food demand that met through external sources like import of the food commodities. The trade balance, for China, is about -90 million tons which met through import (Fig 4e, dash line). Only USA is the major food exporting country; the trade balance of the USA is about 100 million tons in the recent time. (Fig 4f, long dash line).

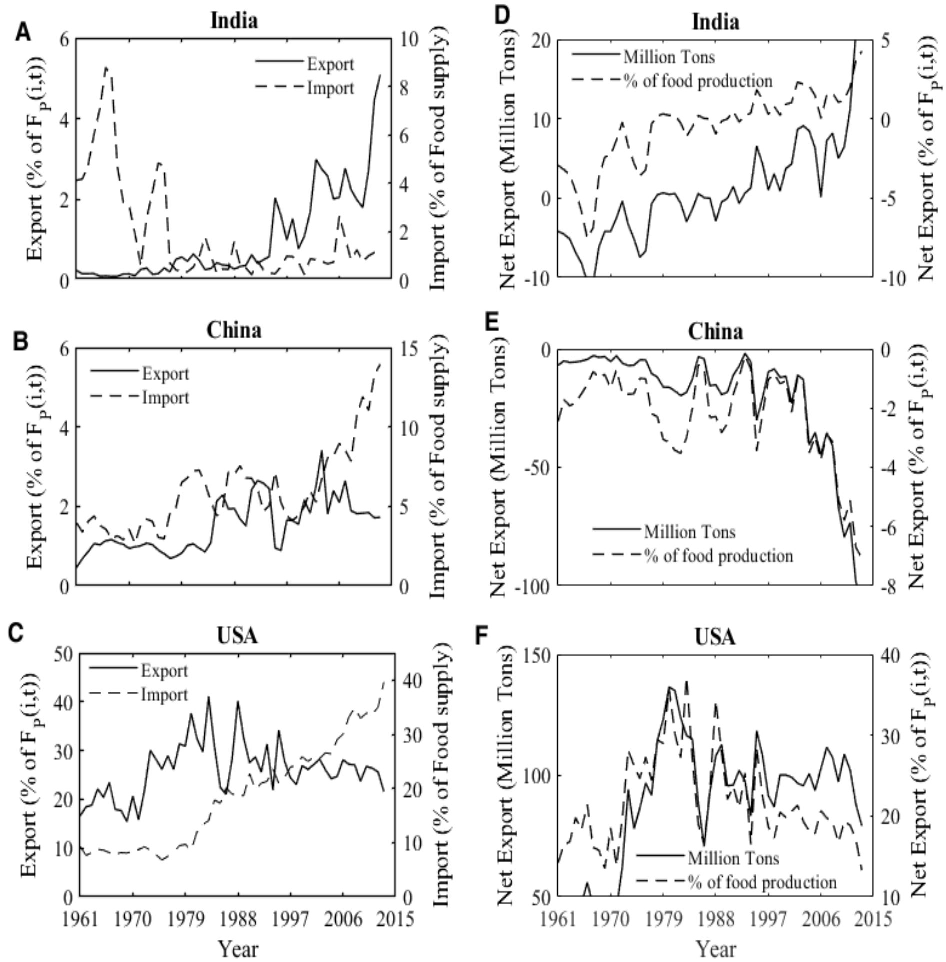

Figure 4: Food export as percentage of food production (solid line, left y axis) and food import as percentage of food demand (dash line, right y axis) for the India (top panel), China (middle panel) and the USA (bottom panel) for the period 1961 to 2013. The observed data is adopted from Food and Agricultural Organization.

Food losses

Food loss and wastage in also a major constraints for food sustainability that have large effect on availability of resources and economy. Based on the data available in the FAOSTAT, the total food loss of India is about 50 million tons equivalent to 8% of total food production in the year 2015. While, total food loss of China, USA and the world, respectively, is about 100 million tons, 30 million tons and 400 tons. In terms of percentage of total production, it is 6%, 4% and 6% of total food production of respective nation (Figure 5).

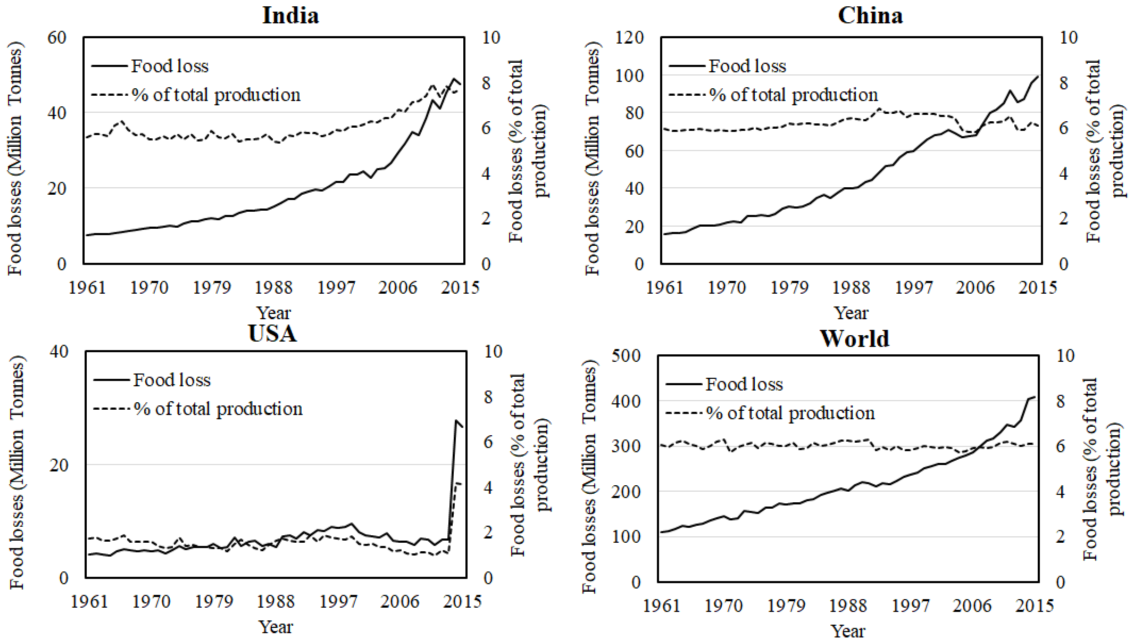

Figure 5. Food losses through storage and transportation for the period1961 to 2015. The data is adopted from FAOSTAT.

Critical population load on carrying capacity

Agricultural sustainability in the current scenario of annual rainfall, per capita food consumption and per capita land use for non-agricultural purposes as a function of population (Fig 6) indicates a critical population load for India around 1250 million (Fig 6 b). The critical population load for the world is approximately 10000 million for the current per capita food consumption 450 kg/year (Fig 6a) while for the China is approximately 1500 million for the current per capita food consumption 650 kg/year (Fig 6c). USA is more sustainable than India, China and the world (Fig 6d). Higher consumption implies lower critical population load (Fig 6) and the carrying capacity declines in the higher population and higher per capita food consumption.

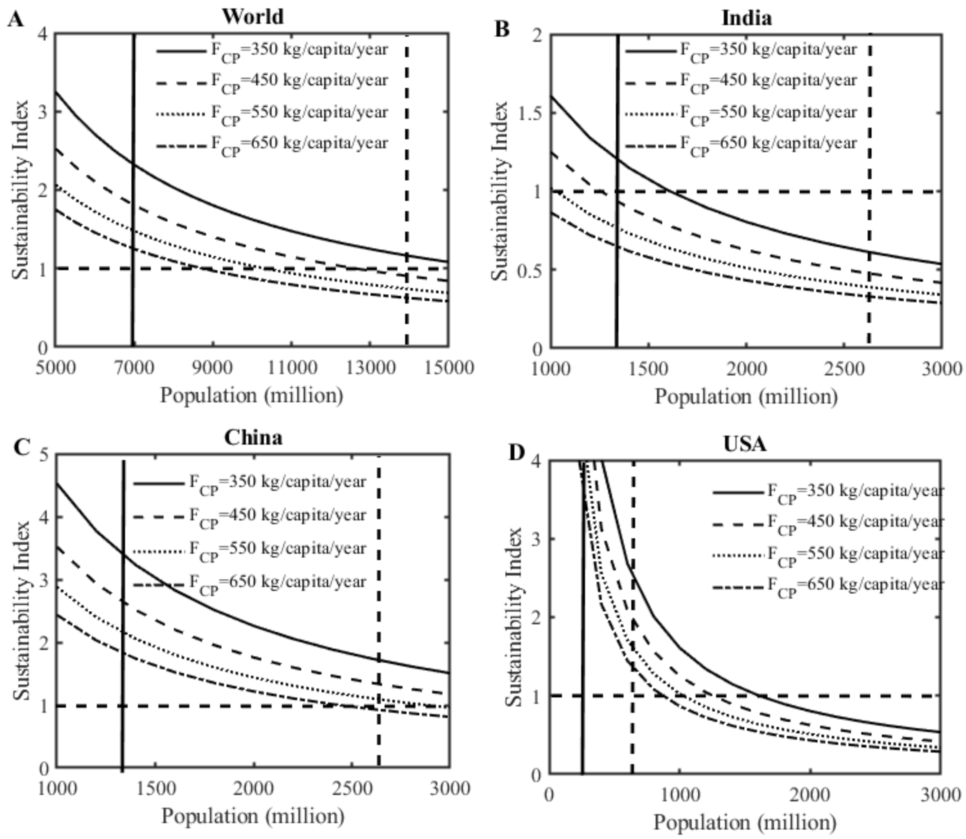

Figure 6: Variation of the index of agricultural sustainability with population load in different scenarios of per capita food consumption for the world (left top panel), India (right top panel), China (left bottom panel), and USA (right bottom panel). The food consumption scenarios, considered here, are 350 kg/cp (solid line, India's current per capita food consumption); 450 kg/capita (dash line; world current per capita food consumption) and 650 kg/capita (dotted line with; USA & China's current per capita food consumption). The horizontal line represents the states of sustainability. The vertical solid and dash line, respectively, represent the current population and doubling population scenario.

Critical population load and technology demand

An important question is the possible mitigation solutions for maintaining agricultural sustainability, such as through assessment of technology demand and technology innovation. One parameter is likely to change through technology design is the agricultural productivity. One application of our formalism is application to design of mitigation solutions for maintaining agricultural sustainability and carrying capacity. In the current population scenario, the technology demand for the world, India, China and USA, respectively, are 0.35 kg/m^2, 0.4 kg/m^2, 0.8 kg/m^2 and 0.03 kg/m^2 for current per capita food consumption of respective country (Fig 7). While, the technology demand for doubling population is also double: 0.6 kg/m^2, 0.65 kg/m^2, 2.0 kg/m^2 and 0.25 kg/m^2 (Fig 7) for respective country. The technology demand, in terms of current per capita food consumption, varies for the world, India, China and the USA 0.2 kg/m^2-0.65 kg/m^2 (Fig 7a, long dash line), 0.35 kg/m^2-1.0 kg/m^2, and 0.03 kg/m^2-1.0 kg.m^2. Demand of technology is higher for higher per capita food consumption scenarios as expected. Similar results also hold for increment in population (Fig. 7).

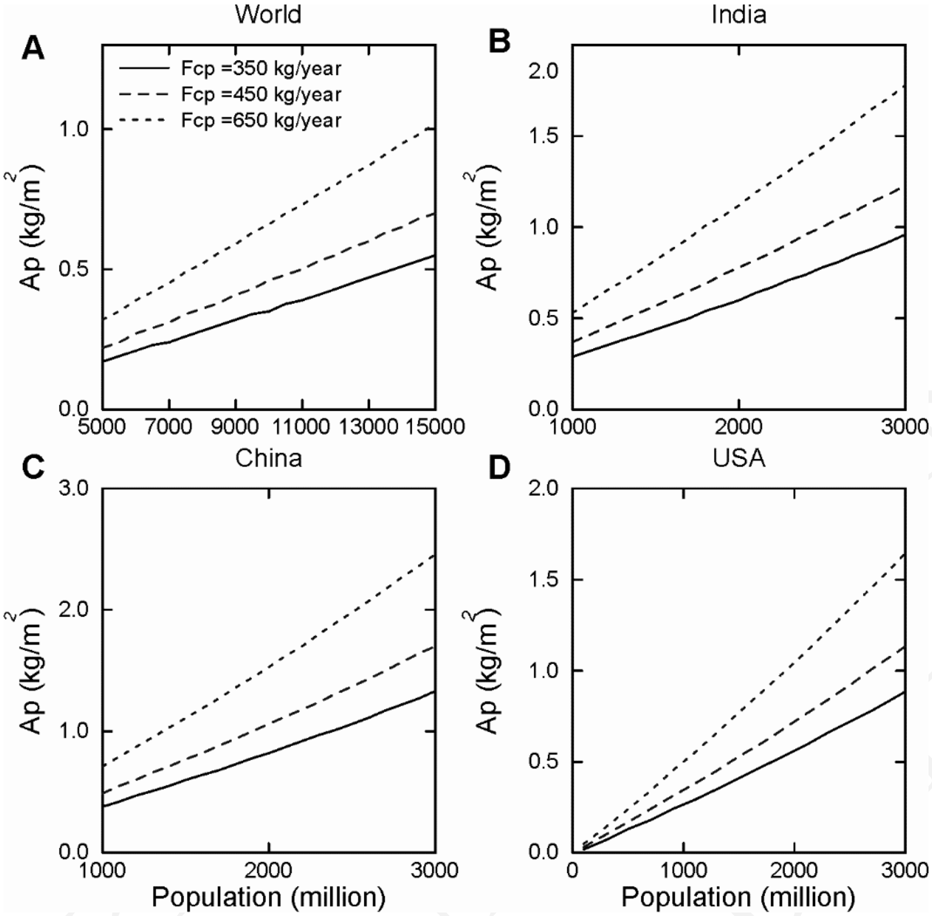

Figure 7: Quantification of technology demand (agricultural productivity) to maintain agricultural sustainability as a function of population in the different scenarios of food consumption per capita for the world (left top panel), India (right top panel), China (left bottom panel), and USA (right bottom panel). The food consumption scenarios, considered here, are 350 kg/cp (solid line, India's current per capita food); 450 kg/cp (dash line; world current per capita food consumption) and 650 kg/cp (dotted line; USA & China's current per capita food consumption).

Discussion and Conclusion

The basic objective in the present study is to provide a comparative and quantitative analysis of carrying capacity in different scenarios of population growth and per capita food consumption. The population growth and demand of capita land use for non-agricultural purposes indicate the larger impacts on arable land and thus decline in carrying capacity of a country or region. A primary conclusion from our study is that there is a declining trend in the primary resources like arable land and water that may have large impact on carrying capacity. Per capita availability of water resources for India and China is less than the standard minimum water requirement for one person; this may worsen in the future due to population growth and demand for primary resources. The land uses for non-agricultural purposes for habitat, infrastructure and industries also play important role in the reduction of arable land result in loss of food sustainability. There is significant effect of per capita land use for non-agricultural purposes on agricultural sustainability. However, external sources of food can become less effective due to world-wide saturation and even decline in arable land and water resources with potential climate change and increasing demand due to increasing population and changing consumption pattern. Therefore, the external sources like import may not be always available due to their own demand of exporting countries and constraints.

The present analysis provides present assessment and possible future projections for carrying capacity and availability of primary resources. This analysis also provides the impact of per capita food consumption on carrying capacity. The criticality of the population load in determining carrying capacity is not surprising; however, our results show that the carrying capacity can change in a complex manner due to various factors. In accordance with our concept of agricultural sustainability, the estimates are essentially for basic survival (minimal agricultural product requirement); they will have to be accordingly revised if increases in nutritional and dietary demands are considered. An important result from our study is that there is a critical situation for the world, India and China.

We have considered for the study a wealthy-country scenario, in which the agricultural products are not used to support associated costs like fertilizer, irrigation, transport etc (except perhaps seeds); further constraints will be implied for agricultural sustainability if a nation depends on its income from agriculture to support these activities. Trends in rainfall due to climate change, productivity, consumption, and population, all play important roles in the carrying capacity; an important contribution of our study is the quantification of the carrying capacity as function of population and changing per capita food consumption. Another important result from our study is the quantification of technology demand for maintaining carrying capacity and agricultural sustainability in different scenarios of population growth and per capita food consumption. The climate change can put additional pressure on carrying capacity.

The analysis has been applied to the world, India, China and the USA; however, the methodology is quite generic, and can be applied to any country. Such estimates and projections can be important inputs for long-term policy planning for estimates of carrying capacity and regional sustainability.

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Author Contribution

The contributions of S. Nishad are in conceptualization, methodology, formal analysis, writing, review and editing of manuscript, visualization, validation. The contributions of N. Kumar are investigation, analysis and review the manuscript.

Conflict of Interests

Authors declare no conflict of interest.

References

AQUASTAT http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en FAO 2020.

Arrow, K, Bolin, B, et al. (1995). "Economic Growth, Carrying Capacity, and the Environment." Science 268: 520–521.

Brown, A, Matlock, MD. (2011). "A review of water scarcity index and methodologies." White paper 106, the Sustainability Consortium, University of Arkansas.

Brown, M, Chunk, S. (2008). "Climate. Food security under climate change." Science 319: 580-581.

Cohen, J. E. (1995). "How Many People Can the Earth Support?" Norton, New York.

Cohen, J. E. (1995). "Population Growth and the Earth's Human Carrying Capacity." Science 269: 341–346.

Doos, B.R. (2002). "Population growth and loss of arable land." Global. Environ. Chang. 12: 303-311.

FAOSTAT. http://faostat.fao.org/ Rome: FAO 2020.

Fereres, E, Orgaz, F., Gonzalez-Dugo, V. (2011). "Reflections on food security under water scarcity." J. Exp. Bot. 62: 4079-4086.

Fresco, LO (2009). "Challenges for food system adaptation today and tomorrow." Environ. Sci. Policy 12: 378-385.

Funk, C.C., Brown, M. E. (2009). "Declining global per capita agricultural production and warming oceans threaten food security." Food Security 1: 271-289.

Gahukar, R.T. (2011). "Food Security in India: The Challenge of Food Production and Distribution." J. Agri. Food. Information. 12: 270-286.

Gerbens-Leenes, W, Nonhebel. S. (2005). "Food and land use. The influence of consumption patterns on the use of agricultural resources." Appetite 45: 24–31.

Gleick, PH. (1996). “Basic Water Requirements for Human Activities: Meeting Basic Needs.” Water International 21: 83-92.

Godfray, HCJ, et al. (2010). “Food security: The challenge of feeding 9 billion people.” Science 327: 812-818.

Goswami, P, Nishad, S. (2014). “Assessment of agricultural sustainability in changing scenarios: A case study for India.” Curr. Sci. 106: 552-557.

Goswami, P, Nishad, S.N. (2015a). “Virtual water trade and time scales for loss of water sustainability: A comparative regional analysis.” Scientific Report 5: 9306

Goswami, P, Nishad, S.N. (2015b). “Dynamical formalism for assessment and projection of carrying capacity in different socio-climatic scenarios.” Current Science 109(2): 280-287.

Gregory, PJ, Ingram, J, Brklacich, M. (2005). “Climate change and food security.” Phil. Trans. Roy. Soc. 360: 2139-2148.

Gregory, PJ, Timothy, SG. (2011). “Feeding nine billion: the challenge to sustainable crop production.” J. Exp. Bot. 62: 5233-5239.

Gretchen, C.D., Ehrlich, P.R. (1992). “Population, sustainability, and Earth’s Carrying capacity.” BioScience 42: 761-771.

Gustavsson, J, Cederberg, C, Sonesson, U, Van Otterdijk, R, Meybeck, A. (2011). “Global food losses and food waste: extent causes and prevention”. FAO, Rome.

Hamdy, A, Trisrio-Liuzzi, G. (2009). “How to achieve the required food production to meet the growing demand?” New. Medit. 8: 4-12.

Hanjra, MA, Qureshi, ME. (2010). “Global water crisis and future food security in an era of climate change.” Food Policy 35: 365-377.

Harris, J, Kennedy, S. (1999). “Carrying capacity in agriculture: global and regional issues.” Ecol. Econ. 29: 443-461.

Hern, W. (1999). “How Many Times Has the Human Population Doubled? Comparisons with Cancer.” Population and Environment 21 (1): 59–80.

Higgins, GM, Kassam, AH. Naiken, L, Fischer, G, Shah, MM. (1983). "Potential population supporting capacities of lands in the developing world." Technical report of project INT/ 75/P13, "Land resources for populations of the future," FPA/INT/513. Rome: Food and Agricultural Organization of the United Nations.

Hopfenberg, R, Pimentel, D. (2001). "Human Population Numbers as a Function of Food Supply." Environ Develop Sustain 3 (1): 1–15.

Hugo, G. (2009). "Projections of global carrying capacity". In Squires VR. The Role of Food, Agriculture, Forestry, and Fisheries in Human Nutrition." Eolss Publishers Company Limited 3: 31-47.

Imhoff, ML, et al., (2004). "Global patterns in human consumption of net primary production." Nature 42: 870-873.

Kendall, H.W, Pimentel, D. (1994). "Constraints on the expansion of the global food supply." Ambio. 23(3): 198-205.

Regmi, A., Meade, B. (2013). "Demand side drivers of global food security." Global Food Security 2: 166-171.

Singh, S. (2009). "Global Food crisis: magnitude, causes and policy measures." Int J Soc Econ. 36: 23-36.

Smith, P, Gregory, PJ (2013). "Climate change and sustainable food production." Proc. Nutr. Soc. 72: 21-28.

Wirsenius, S, Azar, C, Berndes, G. (2010). "How much land is needed for global food production under scenarios of dietary changes and livestock productivity increases in 2030?" Agr. Syst. 103: 621-638.

Xie, Y.M., Guanjin, T, Xeurong, X. (2005). "Socio-economic driving forces of arable land conversion: A case study of Wuxian City, China." Global Environ. Change 15: 238-252.

Yang, H, Reichert, P, Abbaspour, KC, Zehnder, A.B. (2003). "A water resources threshold and its implications for food security." Environmental Science & Technology 37: 3048-3054.

Yang, H, Zehnder, JB (2002). "Water Scarcity and Food Import: A Case Study for Southern Mediterranean Countries." World Development 30: 1413-1430.

Zhao, W. (2012). "Arable land change dynamics and their driving forces for the major countries of the world." ShengtaiXuebao/ActaEcologicaSinica 32: 6452-6462.