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## Role of development policies in combating climate change issues in Indian Agriculture: A first order assessment of irrigation and fertilizer policies

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### *Abstract*

*The Government of India has pursued policies supporting intensive use of irrigation and fertilizer for the development of agrarian economy. A first order assessment of the impacts of these development policies on mitigation, adaptation, resilience and sustainability has been made quantitatively with the help of specific performance indicators. The analysis is based on the hypothesis that productivity enhancement serves better to deal with climate change as it minimizes deforestation and therefore reduces intensification of greenhouse gas emissions. The assessment establishes that development policies have been highly successful in reducing potential greenhouse gas intensification and increasing the adaptation capacity in terms of food grain production. The performance of policies, particularly of water resources development, with respect to sustainability is, however, questionable. The relatively new initiative on micro irrigation fares well in respect of most performance indicators, calling for further policy support for its scaling out.*

Keywords: Virtual mitigation, Adaptation, Sustainability, Irrigation, Fertilizers

JEL codes: O13, Q58

## 1. Introduction

The agricultural sector is reeling under concomitant problems of vulnerability to climate change and release of emissions from various activities in the sector. Across regions, these twin challenges are being addressed in different capacities through two distinct but complementary approaches—adaptation and mitigation. For developing economies such as India, which are still struggling to achieve food security and protect its vast agrarian population from production and market risks, adaptation measures for combating progressive climate change are in congruence with their overall development goals. With respect to mitigation activities, however, India and other developing countries have expressed dissidence in recent international climate negotiations (Bose, 2012; Dutta, 2013). India’s National Communications on Climate Change (NCCC) to the United Nations Framework Convention on Climate Change (UNFCCC) and the National Action Plan on Climate Change (NAPCC) (2008) also emphasise the need for adaptation in the sector “given the diversity of needs and concern of poor countries” (The Hindu, 2013) and suggest that mitigation can, at best, be considered a co-benefit (PMCCC, 2008; GoI, 2012).

In light of Indian government’s priorities, there is a pressing need to explore initiatives under the realm of ‘adaptation-led-mitigation’ in agriculture (Singh, 2013). Such measures, not only aim to improve agricultural production and sustainable management of natural resources, but also possess considerable mitigation potential (Nin–Pratt, et al., 2011). Recently, the Government of India as in fact introduced initiatives, such as the National Mission for Sustainable Agriculture (NMSA) (2010), which include a host of measures for adaptation, while also exploring strategies for mitigation in the sector.

The NMSA emerges as a landmark mission with respect to India’s strategies for adaptation and mitigation to climate change in agriculture. Though the document is a novel one in its vision and approach, the broad areas under the mission’s interventions have been addressed through various government policies and programs in the last few decades. Even though these policies were not developed with a *climate lens*<sup>1</sup>, they have played a vital role in creating the basic infrastructure

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<sup>1</sup> An analytical tool to examine a strategy, policy, plan or policy measure that involves examining the extent to which a strategy, policy, plan or policy measure under consideration could be vulnerable to risks arising from climate variability or change; the extent to which climate risks have been taken into consideration in the course of

and institutions in the agricultural sector that are important for the establishment of any future response strategies for climate change.

We look at two such policy areas in the Indian agriculture, namely irrigation and fertilizer, and attempt to analyse their contribution—positive or negative—to adaptation-led-mitigation between 1990 and 2010. Our study is important in light of the following. First, irrigation and fertilizer are crucial inputs for agricultural intensification and food security, and are, hence, major determinants for adaptation and resilience to climatic variability. Second, these two sectors are also increasingly contributing to GHG emissions (Figure 1). Third, because of the importance they hold for intensification, the government unsurprisingly invests heavily in these sectors (Figure 2). An analysis of these policies from a *climate lens*, would therefore, help in exploring possible avenues for adaptation-led-mitigation in agriculture.

In this paper, we build a methodology for quantitatively assessing the impact of irrigation and fertilizer policies in India on: (i) greenhouse gas (GHG) emissions in the agricultural sector; (ii) adaptation; (iii) sustainability of the production systems; and (iv) resilience of the agricultural sector. Hitherto, several studies have studied the impact of irrigation and fertilizer policies on crop productivity and production, while a few have explored their implications separately for mitigation and sustainability. To the best of our knowledge, ours is the first study to holistically study irrigation and fertilizer policies with respect to all these parameters. These *non-climate policies*<sup>2</sup> (term borrowed from Urwin & Jordan (2008)), were not deliberately initiated to combat the challenges of climate change in the agricultural sector. Yet, they continue to have significant bearings on how the sector deals with climate change.

Few studies have explored the role of non-climate policies in adaptation or mitigation. Urwin and Jordan (2008) have studied the importance of non-climate policies for agriculture, water resources and nature conservation, in the European context. Their study builds on the premise that there is a limited understanding of the role of these policies in supporting or constraining the

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the formulation of the strategy, policy, plan or policy measure; the extent to which it could increase vulnerability, leading to maladaptation; and what amendments might be warranted to address climate risks (OECD, 2009).

scope for implementing adaptive responses. In another study, Smith et al. (2007) have probed the potential role of various non-climate policies in mitigation of GHG emissions from agriculture, in different regions of the world.

The government continues to invest huge amounts of money in irrigation and fertilizer programmes, besides investing in new initiatives for addressing issues of climate change in agriculture. The study provides a ground for establishing synergies between government's old and new initiatives, and making more informed investments in the agricultural sector, against the backdrop of climate change.

The paper is organized as follows. Section 2 provides an overview of the irrigation and fertilizer policies in India and traces their growth and impacts on food grain production, productivity, as well as sustainability. Section 3, describes the methodology adopted for the construction and the computation of indices, used for assessing the impact that irrigation and fertilizer policies have had on mitigation, adaptation, sustainability and resilience of the agricultural sector. Section 4 briefly presents the results, while a discussion on the results follows in Section 5. Section 6 provides policy recommendations stemming from the study and Section 7 concludes the paper with some final remarks.

## **2. Irrigation and fertilizer policies in the Indian agricultural sector**

Area under irrigation and fertilizer consumption, have both showed an overall increasing trend in the last few decades (Figure 3), leading to significant growth in agricultural production in India. The average food grain production increased from 175 Mt in early 1990s to 225 (metric tonnes) Mt in late 2010s, in spite of the fact that the area under food grains decreased from 127 (million hectare) Mha to 122 Mha during the same period (Indiastat, 2012). Data show that the productivity gains, in rice (26 per cent) and wheat (34 per cent) in this period, have been substantial (Table 3). This annual growth rate of 2.27 per cent was achieved entirely due to increase in food grain productivity by 0.56 tonnes per hectare (t/ha). It can be estimated that this increase prevented the potential conversion of 56.6. Mha of forest land (the additional land

required to produce 61 Mt at 1990 productivity level) to crop land<sup>3</sup>.

The following sections briefly discuss the driving points of irrigation and fertilizer policies that spurred such growth in Indian agriculture.

### *2.1. Policies for irrigation development*

***Surface water and Groundwater:*** The Indian government consistently made heavy investments in irrigation infrastructure, a trend that declined in the 1980s and 1990s (Fan, et al., 2008). The Accelerated Irrigation Benefit in Agriculture (AIBA), a centrally sponsored scheme was launched in 1996 (Planning Commission, 1995). More than five million hectare (Mha) was brought under irrigation through AIBA, by the end of 11<sup>th</sup> plan. Additionally, the government launched the National Watershed Development Programme for Rainfed Agriculture (NWDPA)<sup>4</sup> in 1990-91, which aimed at conservation, development and sustainable management of natural resources, among other things. Groundwater in fact remains the mainstay of Indian agriculture, with more than 60 per cent of the irrigated area being irrigated through this mode (Indiastat, 2012). The number of groundwater structures (shallow and deep tube wells and open wells) has rapidly grown 1990 onwards, with the groundwater abstraction in India exceeding 260 billion cubic meters (BCM) in 2010 (Indiastat, 2012).

***Micro-irrigation:*** Despite the initiatives in surface and groundwater development, problems of continued rise of agricultural water demand, the increasing gap between the realized and the created potential of irrigation projects and the steep rise in the cost of developing new water supplies persisted. Subsequently, the government initiated a special drive to introduce micro-irrigation in selected crops as a means of increasing irrigation intensity and crop productivity (INCID, 1994; INCID, 1998; Task Force on Micro Irrigation, 2004). As a result, micro-irrigation in India has been extended to 3.87 Mha of land of which 1.43 Mha is under drip and 2.44 Mha under sprinkler irrigation (Palanisami, et al., 2011).

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<sup>3</sup> The computational details are provided separately in an Appendix, which can be obtained from the authors upon request.

<sup>4</sup> Modified to National Watershed Development Project for Rainfed Areas in 1999-2000

Micro-irrigation, a triple benefit technology (water saving, increasing yields and energy saving) has given impetus to productivity enhancement, irrigation efficiency and land productivity improvements. Nevertheless, it is to be noted that there exist large variations in reported efficiencies (20 to 60 per cent) in the micro-irrigation systems (INCID, 1994; Narayanamoorthy, 2005; Kumar and Palanisami, 2011; Reddy et al. 2004; Tyagi, 2009). Based on global data, Spielman (2013), adopted an average value of 30 per cent, which appears to be reasonable under most farming situations. Currently micro-irrigation technologies are spread over an area of 3.87 Mha in the country, which can potentially be increased to 40 Mha by 2030. The ultimate target for micro-irrigation is 70 Mha (Task Force on Micro Irrigation, 2004). Table 2 provides the estimated range of benefits of micro-irrigation technologies with respect to water saving, food production, at three discrete levels of efficiencies (20, 30 and 40 per cent) for both current and potential area of micro-irrigation.

## *2.2. Fertilizer policies*

With the onset of green revolution, fertilizers have been an important ingredient of the Indian agriculture growth story. The government has consciously promoted fertilizer use through pricing policies. Fertilizers are supplied to the farmers at subsidized rates, referred to as the issue price. Initially, only nitrogenous fertilizers were subsidized but the policy was amended later to include complex fertilizers (1979) and superphosphate (1982). In 2008, the policy of nutrient based subsidy (NBS) was introduced and decontrol of non-urea fertilizer price was implemented (GoI, 2008). The fertilizer consumption or production in India increased from less than 6 Mt in 1980 to 12.5 Mt in 1990, and from 18.1 Mt in 2000 to 28.1 Mt in 2010 (Ministry of Agriculture, 2012). The per hectare use of Nitrogen (N), Phosphorous (P) and Potassium (K) was 95.4 kg during 1999-00; though it remained below 92 kg up to 2004, it reached 144 kg in 2011-12.

It becomes important to understand whether the unit price of fertilizer was lowered to a level at which farmers felt encouraged to observe profligacy in fertilizer use. The farmers would rationally increase input use only up to levels where, returns on investment would exceed the cost. Thus, the ratio of subsidized fertilizer price to minimum support price (MSP) of food grain produced serves as an indicator of the profitability of fertilizer use, whereas, an increase in quantity of fertilizer per unit area gives an indication of the impact of the pricing policy on

fertilizer consumption. Chand and Pandey (2008) have examined these issues, using the price data of subsidized fertilizers and the MSP of wheat and rice from 1980-81 to 2006-07. The ratios of price of fertilizers ( $P_n$ ,  $P_p$ ,  $N_k$ ) and MSP of rice ( $P_r$ ) and wheat ( $P_w$ ), during 1980-2007 have been plotted in Figure 4. It is seen that prices of N, P and K, relative to MSP of wheat and paddy declined sharply during the period between 1980-81 and 1990-91. 1995 onwards, however, the MSP offered for wheat and paddy remained higher than the price increase in N, P and K. This prompted increase in fertilizer usage by several folds, but the average use of P and K remained much below the recommended level. The inference is that higher subsidy on urea, as compared to phosphate and potash, biased fertilizer application. This resulted in low efficiency, poor soil health and reduced factor productivity of fertilizers (Prasad, 2009).

### **3. Data and methods: Assessing the impact of irrigation and fertilizer policies on adaptation, mitigation, sustainability, and resilience**

We construct a set of dimensionless indices for estimating the impact of irrigation and fertilizer policies on adaptation, mitigation, sustainability and resilience. Indices-based approach has increasingly been recognized as a tool to assess the impact of performance of a policy or project on environment (Balaban, 2011; Tanguay et. al, 2010). For construction of indices, we use publically available national level data, from FAOSTAT, Indiatat, along with various papers and reports. Table 1 details the figures we heavily employ in the analysis.

There are two key concepts we employ that are central to the analysis presented in this paper.

First, we determine the segregated impact of irrigation and fertilizer policies, by employing the factor productivity analysis by Chand & Pandey (2008). They determined the impact of fertilizer and irrigation on crop production in India, using data for increase in cultivated area, irrigation and fertilizers, along with the corresponding food grain production. Two important findings from the study, which are employed in this paper are as follows.

(i) An increase of one per cent in fertilizer use increased food grain production by 0.2 per cent. In other words, the fertilizer use would have to be increased by five per cent from the current level to increase the food production by one per cent.



(ii) Irrigation has had greater influence on food grain production as compared to fertilizers. An increase of one per cent in irrigated area would cause 0.40 per cent increase in production. Conversely, in order to increase the food grain production by one per cent over the current level, the irrigated area would have to be increased by 2.5 per cent.

Second, our analysis for mitigation rests on the fact that the net carbon balance after incorporating direct and indirect emissions released through various agricultural processes and operations, determines if the activity is a net ‘mitigator’ or ‘intensifier’ of carbon emissions. All plants intake carbon dioxide and therefore invariably create a mitigation effect. It is only the carbon intensity involved in the agricultural operations that makes the intervention a net ‘mitigator’ or ‘intensifier’. Some interventions do not directly mitigate, but lead to situations where their absence would lead to higher emissions. For instance, the yield increasing green revolution technologies, viz. irrigation and fertilizer (collectively referred to as GRTs in this paper) respectively lead to emissions due to energy consumption and nitrogen dioxide release. Yet, had these interventions not been implemented, forests would have been converted to crop lands to enable sufficient production to feed the burgeoning population; therefore, resulting in loss of carbon sequestration benefits of the forests.

We employ this reasoning in the construction and calculation of the mitigation index in Section 3.1. Section 3.2 and 3.4, respectively elaborate upon the construction of the adaptation and resilience index, respectively. For understanding the impact of GRTs on sustainability, however, we have not constructed indices but have instead utilized the indices available in literature, (Section 3.3).

### *3.1 Mitigation index*

The universally accepted measure of mitigation is the decrease in GHG emission accomplished by a technology either through reduction and sequestration. The term energy efficiency and energy efficiency gap reduction in energy intensity and carbon foot prints are often used to evaluate success of mitigation efforts (Schellnhuber et al., 2013). These are sound indices of the effectiveness of an intervention on a unit basis for choosing a technology. But, for evaluating the contribution of technology adopted in large area and over a period of time, the per cent increase or decrease in GHGs emission, over the base year would be more appropriate. The per cent

reduction or the reduction from a benchmarked value can form the basis of index. With mitigation and intensification of GHGs being inversely related, the efficacy of policy intervention can be represented in terms of intensification index (II) or mitigation index (MI). We compute these two indices with and without the consideration of the benefits of emission reduction that would come from avoided deforestation due to increased productivity.

For construction of the mitigation index (MI), we assume that mitigation is effected through: (i) increase in agricultural productivity and (ii) consequent avoidance of conversion of forest land to crop land during the base year (1990) and the final year (2010). The degree of mitigation—positive or negative—achieved through the contribution of yield increasing technologies, can be estimated in terms of change in GHG emissions over the base year and is given by the intensification index (IIF). To account for the emissions that accompany land use change, the IIF can be computed with consideration of the emission reduction benefits from avoided deforestation (IIF<sub>AFC</sub>) or without consideration of the emission reduction benefits from avoided deforestation (IIF<sub>NAFC</sub>) (Equation 1).

$$\text{IIF}_{\text{AFC}} \text{ (or } \text{IIF}_{\text{NAFC}}) = \frac{(\text{ET}_{\text{FY}} - \text{ET}_{\text{BY}})}{\text{EMT}_{\text{FY}}} \quad (1)$$

In Equation 1,  $\text{ET}_{\text{BY}}$  refers to emissions in the base year (BY), while  $\text{ET}_{\text{FY}}$  refers to emissions in the final year (FY), with adoption of technology (T). The term  $\text{EMT}_{\text{FY}}$  denotes the maximum emission that would have been in the final year in the absence of any incremental technology adoption. Intensification of GHG emissions would be minimum (zero) if  $\text{ET}_{\text{FY}}$  is equal to  $\text{ET}_{\text{BY}}$ , and it would be maximum if  $\text{ET}_{\text{FY}}$  is equal to  $\text{EMT}_{\text{FY}}$ .

The mitigation index corresponding to  $\text{IIF}_{\text{AFC}}$  (or  $\text{IIF}_{\text{NAFC}}$ ), denoted by  $\text{MI}_{\text{AFC}}$  (or  $\text{MI}_{\text{NAFC}}$ ) can then be calculated as follows.

$$\text{MI}_{\text{AFC}} \text{ (or } \text{MI}_{\text{NAFC}}) = 1 - \text{IIF}_{\text{AFC}} \text{ (or } \text{IIF}_{\text{NAFC}}) \quad (2)$$

Though theoretically it is possible that the emissions are reduced even below the selected base

year by changes in land use and application of transformative technology, but the practice may not be economically desirable.

### *3.2 Adaptation index*

Greater food production does not necessarily translate into greater food security due to inefficiencies in the distribution systems. Still, increase in food production is a step towards a food secure environment, which in turn enables adaptation. We thus use increase in food production with respect to the base year population, for the construction of adaptation index (AI), which is computed as follows.

$$AI = \frac{(FGP_{FY} - FGP_{BY})}{FGP_{BY}} \quad (3)$$

Where,  $FGP_{BY}$  indicates the per capita food grain production in the base year for the constant baseline population; and  $FGP_{FY}$  indicates the per capita food grain production in the target year, after the implementation of technologies for agriculture intensification.

### *3.3 Sustainability indices*

Agricultural sustainability encompasses social, economic and environmental dimensions. In this paper, however, we limit the scope of impacts of irrigation development and fertilizer subsidy policies, to environment sustainability. The premise for the analysis is as follows.

#### *3.3.1 Sustainable water resource development*

Development of water resources in India has acquired a new perspective in recent years, with most river basins in the country having reached the critical limits of water extraction (Ambast, et al., 2006; Shah & Lele, 2011). Common metrics employed for measuring water stress include the criticality ratio (ratio of water withdrawal to total renewable water, (CR)) (Alcamo, et al., 2000), the degree of development ratio (ratio of primary water supply to potentially useable supply (DD)) (Amarasinghe, et al., 2004), and the groundwater abstraction ratio (ratio of groundwater withdrawal to groundwater availability (GWAR)). DD and CR values, greater than 0.5 indicate

high water stress, while values greater than 0.8 represent situations of extreme water stress. Groundwater development is considered safe up to a GWAR of 0.65, moderately stressed between 0.65-0.85 and unsafe beyond 0.85 (GoI, 2009).

We borrow these three measures from literature, to reiterate the sustainability of water resource development in India. Considering that more than 90 per cent of groundwater draft is for agricultural purposes, these indices give us an indication of the impact that irrigation policies have had on the sustainability of water resources.

### 3.3.2 Sustainable consumption of fertilizers

It is widely established that the sustainability of crop production system is adversely impacted by imbalanced fertilizer use. Mehta (2007) uses the following imbalance index (FL<sub>ib</sub>I) to capture the imbalance in fertilizer usage.

$$FL_{ibI} = \sqrt{\frac{\{(N_a - N_n)^2 + (P_a - P_n)^2 + (K_a - K_n)^2\}}{3}} \quad (4)$$

Equation 4 measures the deviation from the recommended use of N, P and K, where the subscripts ‘a’ and ‘n’ denote the actual and recommended fertilizer usage, respectively. If FL<sub>ib</sub>I equals zero, it represents a state of balanced fertilizer use and if it equals one, it will represent a state of maximum imbalance.

### 3.4 Resilience

In the context of food security, resilience at the household level is defined as “the ability of a household to keep up with a certain level of well-being (i.e. being food secure) by withstanding shocks and stresses” (Alinovi, et al., 2010, p. 3). Factors that influence resilience include income, access to food, assets such as land and livestock, social safety nets and so on. If we extrapolate the concept of resilience at household level to national level, resilience would then be a function of the capacity of the country to produce food without significant fluctuations in times of floods, droughts and other natural calamities. The degree of fluctuations can be measured by first

determining the variance of food production in two time periods (denoted by  $V_{P1}$  and  $V_{P2}$ ; where P1 and P2 denote the first and the second time period, respectively), and then calculating the deviation of the variance (Equation 5). This change in the variance of food production, is a reflection of the change in resilience in the two time periods, P1 and P2, assuming that the net area impacted by various natural disasters in the two time periods is essentially equal.

$$\text{Per cent change in resilience} = \frac{(V_{P1}-V_{P2}) * 100}{V_{P1}} \quad (5)$$

## 4. Results

### 4.1 Mitigation

**Case 1: Emission balance impacted by incremental adoption of GRTs:** For mitigation, results have been presented for aggregated impact of incremental GRTs adoption, along with the segregated impact of irrigation and fertilizer policies. For irrigation policies, we calculate the mitigation index for surface and groundwater together, groundwater separately and micro-irrigation.

As discussed in Section 2, agricultural policies between 1990 and 2010, which directed incremental adoption of GRTs, resulted in production and productivity increases. Had there been no productivity improvements from 1990 levels, an additional 56.6 Mha of land would have needed to be brought under cultivation, to achieve food grain production of 232 Mt. The productivity gains thus, not only saved the forest tracts from going under the plough in an already under-forested country, but also reduced the area under food grain production from 127 Mha to 122 Mha.

For a holistic analysis of the mitigation benefits offered by GRTs, it becomes imperative to visualize the load of emissions which would have come without the adoption of technologies in this period. The emission scenarios with and without the incremental adoption of technology (Figure 5) suggests that under the latter, emissions from land under food grains would have

increased from 180.8 MtCO<sub>2</sub>eq in 1990, to 430 MtCO<sub>2</sub>eq. But, after the implementation of these technologies, the estimated emissions have in fact increased by a minimal 6.6 per cent in the same period. The virtual reduction of 249 MtCO<sub>2</sub>eq may further be attributed to the avoidance of forest land conversion into cropland.

The computed values of intensification index (using Equations 1 and 2), with and without the consideration of AFC benefits, are 2.8 per cent (IIF<sub>AFC</sub>) and 46.1 per cent (IIF<sub>NAFC</sub>) respectively. The corresponding values of MI<sub>AFC</sub> and MI<sub>NAFC</sub> are 97.2 per cent 53.9 per cent, respectively.

**Case 2: Emission balance impacted by irrigation development:** The productivity of rainfed agriculture in India hovers around 1 t/ha as compared to 3 t/ha in the case of irrigated agriculture (Ministry of Agriculture, 2012). If we consider contributions to productivity and benefits of avoidance of the forestland conversion to cropland, irrigation (surface and groundwater) has contributed to net virtual mitigation of the order of 87.32 MtCO<sub>2</sub>eq (Table 4). However, if we do not consider these benefits, there has been a net addition of 7.64 MtCO<sub>2</sub>eq due to irrigation development.

Groundwater has played a key role in irrigation expansion, but it also simultaneously added to the GHG emission pool, due to the consumption of energy used in pumping groundwater. Taking the average carbon intensity of electricity as 0.406 kg CO<sub>2</sub>eq per kilo watt hour (kWh) (Shah, 2009), the emission load generated by groundwater irrigation was estimated to be 28 MtCO<sub>2</sub>eq as compared to a net reduction of only 12 MtCO<sub>2</sub>eq. Thus, if avoided deforestation benefits are neglected groundwater irrigation increased emissions by about 16 MtCO<sub>2</sub>eq.

The micro-irrigation technology, on the other hand, was found to be a net mitigator. Though at present, micro-irrigation occupies only about 4 Mha, it offers mitigation benefits of 2.15 MtCO<sub>2</sub>eq. As discussed before there lays a major scope for the expansion of micro-irrigation systems. If micro-irrigation could be extended to 40 Mha in next 15 years, the irrigation sector would prove to be a stronger mitigator of GHG emissions.

**Case 3: Emission balance impacted by fertilizer sector policies:** Fertilizer consumption between 1990 and 2010 has increased by almost two and half times. Consequently, there has been a net increase in GHG emissions (Figure 1). As in the case of irrigation, mitigation benefits from fertilizer consumption are also realized through increase in food grain production and productivity and the subsequent avoidance of forest land conversion to crop land. A notable difference between these two sub-sectors lies in that fertilizer consumption contributes to direct as well as indirect emissions. Taking this into account, the increase in fertilizer use from 48.8 to 106.8 MtCO<sub>2</sub>eq during the period from 1990 to 2010 generated an intensification load of 58.0 MtCO<sub>2</sub>eq (FAO, 2014). The specific contribution of fertilizer consumption to GHG mitigation was 47.48 MtCO<sub>2</sub>eq, with avoided deforestation of 11.3 Mha. With only a marginal reduction of 8.96 MtCO<sub>2</sub>eq on account of productivity increase, fertilizer application proved to be a net intensifier with a positive carbon balance of 35.22 MtCO<sub>2</sub>eq. If emission reduction benefit due to avoidance of forest to crop land conversion is ignored, the intensification reaches a much higher level of 71.94 MtCO<sub>2</sub>eq.

#### *4.2 Adaptation*

As discussed in Section 2, in this paper, we have taken increased food production as a measure of adaptation. The per capita food grain production due to the combined effect of incremental adoption of green revolution technologies improved from 202.8 kg/year in 1990-91 to 274.6 kg/year (with population base of 1990-91), yielding an adaptation index (AI) of 26 per cent (Table 5).

For determining the contribution of irrigation separately to food productivity, we consider the share of irrigation in food productivity to be 40 per cent. Irrigation thus contributed 28.74 kg/capita/year towards improvement in food production of which, 17.24 kg/capita/year was due to groundwater and the rest 11.5 kg/capita/year was due to surface irrigation. If there were no expansion of irrigation beyond 1990, the production in 2010 would have been only 204 Mt, reducing food production to 242.1 kg/capita/year. Since, micro-irrigation largely runs on groundwater and as it covered only 4 Mha, it was not feasible to separately assess its share. The

contribution of fertilizer to adaptation was found to be fair, as it added 14.37kg/capita/year to food grain production, i.e. 5.29 per cent above the base line.

#### *4.3 Sustainability*

Maintaining the sustainability of the agricultural systems is important for maintaining the long term viability of agriculture. In the following two sections, sustainability has been examined in respect of water resources development and fertilizers.

***Sustainability of water resources development for irrigation:*** The present (2010) and projected (2050) level of water resources development and degree of stress are given in Table 6.

Moderation of this stress would require both structural (augmentation of water supply through increased storage during monsoon season, provision of groundwater recharge structures, improved irrigation application systems etc.) as well as policy interventions such as water and energy pricing. Cost curve approach may be useful to decide the least cost and efficient combination of technology interventions (2030 WRG, 2009).

***Fertilizer imbalance and sustainability:*** As discussed earlier, the quantum jump in fertilizer use in India was largely due to increase in urea consumption (Figure 4) which was imparted a higher subsidy as compared to other fertilizers. This policy created led to greater use of nitrogenous fertilizers and the ratio of N:P:K use shifted from 5.5:1.8:1 to 7:2.6:1 between 1991 and 2001, against the generally accepted level of 4:2:1 (Table 7). This imbalance resulted in low fertilizer use efficiency (Brar & Pasricha, 1998) and reduced factor productivity, as the quantity of fertilizer required to produce unit quantity of food grains increased over the years (NAAS, 2006), adversely impacting the economic viability as well as the environmental sustainability of agriculture.

The computed value of  $FL_{iBI}$  during 1990-2010 falls in the range of 0.04 to 0.05 and though is not very high, has been sufficient to cause reduction in factor productivity; as the fertilizer response (in terms of quantity of grains produced with respect to quantity of fertilizer applied) has decreased from more than 10 in the 1900s to less than six in 2010.



#### 4.4 Resilience

In this paper, the variance in food production series between the two time periods, 1991-2000 and 2001-2010, has been adopted as measure of resilience. We computed the values of variance in food production for these two decadal periods (Table 8).

The values of variance in food production for 1991-00 ( $VP_{1991-2000}$ ) and 2001-10 ( $VP_{2001-2010}$ ) periods were 5334.7 and 5379.8, respectively with only 0.8 per cent difference between two periods, thus suggesting very high degree of resilience introduced due to adoption of GRTs.

### 5. Discussion

The analyses of irrigation and fertilizer policies presented in this paper provide some interesting insights into the role that non-climate policies have played with respect to climate change. The estimated values of the indices for mitigation, adaptation, sustainability and resilience, suggest that these development policies have had an overall positive impact, for developing the agrarian economy of India.

It is interesting to note that for these scaled out technologies, the intensification index with and without consideration of avoided forest conversion benefits, remained below 10 per cent and 50 per cent respectively, indicating that the potential intensification was reduced to the extent of 90 per cent to 50 per cent by what may be referred to as *virtual mitigation*. The *virtual mitigation* potential of micro-irrigation was found to be significantly high—a fact that future research and policies in this realm could potentially exploit.

Further, the goal of achieving food self-sufficiency has been adequately achieved by these policies. The adaptation index (AI) of 0.26, indicates an improvement of 26 per cent in food grain production over a period of 20 years. In the absence of incremental adoption of irrigation and fertilizer technologies, AI would have reduced to 0.19, indicating a fall of 27 per cent in the adaptation capacity of the baseline population.

The irrigation and fertilizer policies have also brought stability in food production with a marginal difference in the variance (0.8 per cent) of food grain production between the 1990-2000 and 2000-10 periods. The benefits of development policies in the agricultural sector, however, have been achieved at the cost of sustainability. Although these policies reduced user cost and increased affordability and access to farmers, they also resulted in over exploitation of ground-water, inefficient use of canal water and imbalance in fertilizer usage.

With increase in agricultural intensification, the management of irrigation systems has become difficult. DDS, the index for sustainable utilization of surface water stood at about 0.59 in 2010, while the projected value of DDS for 2050 is an extremely high value of 0.94. So is the case with groundwater, where the GVAR value in 2010 was 0.66 and is expected to be greater than one by 2050. In India, more than 1000 administrative blocks have GVAR greater than 95 per cent, giving rise to environmental problems such as depletion of water table, sea water ingress in coastal areas and deterioration in water quality due to arsenic and fluoride pollution (Shah, 2009). Fertilizer policies have also held negative consequences for sustainability while holding positive consequences for adaptation. Though farmers have increased fertilizer use to increase production to compensate for climatic fluctuations, the higher fertilizer specific subsidy led to imbalanced fertilizer (distorted N: P: K ratio) usage, affecting the soil health and partial factor productivity adversely.

## **6. Policy recommendations**

The assessment of irrigation and fertilizer policies has clearly established that they enabled the achievement of food sufficiency in India. The assessment strongly indicates that the performance of these policies was fair to good in respect of adaptation, but with respect to mitigation and sustainability there are visible shortcomings. New policy initiatives should build on the strength of these policies and modify them as per the current context. In last few years, the programmes undertaken under National Initiative on Climate Resilient Agriculture (NICRA) (ICAR, 2011) have generated wealth of information for adaptation to climate change through technology interventions such as conservation tillage, system of rice intensification (SRI), deficit irrigation, use of colour chart for fertilizer application and stress tolerant high yielding crop varieties and so

on. Our first order analysis of irrigation and fertilizer policies in India, paves way for similar analysis of the new technologies that are currently being promoted through various ongoing government programmes, so as to reassess the impact of agro-technology on reduction of GHGs emission in agriculture sector and adaptation.

The prevailing policies on irrigation, fertilizers and energy were shaped by green revolution requirements, with higher element of subsidies and were not unique to India. But, now there is a need of modifications in these policies to ensure greater sustainability of agricultural development. Suggested below are some new policy directions for climate friendly sustainable development.

***Water management policy:*** Farmers are at present are considered beneficiaries of canal irrigation water and electricity for groundwater pumping. This philosophy needs to be replaced with one that considers farmers as clients and public utilities as service providers. In view of the increased demands and prevailing all round depletion and degradation of water resources, adoption of water smart technologies should be considered as ecosystem service and should be appropriately incentivised.

***Fertilizer policy:*** Improving the existing highly skewed fertilizer use bias in favour of nitrogen remains one of the important agenda of policy reforms. A nutrient based subsidy policy adopted in 2010, but its implementation has been tardy. If implemented vigorously, this policy has the potential to reduce imbalance in fertilizer use and to lower the carbon footprint of increased fertilizer use by increasing productivity per unit of fertilizer use.

***Energy policy:*** Agriculture sector and particularly irrigation, is a major consumer of energy. In India, the irrigation pumps at present do not under fall under the category of ‘appliance’ under section 14 of the Energy Conservation Act. Appropriate categorisation by the government will promote replacement of inefficient agricultural pumps with the Bureau of Energy Efficiency (BEE) certified efficient pumps which save at least 30 per cent energy. Incentives for use solar energy energizing water pumps and micro irrigation systems and rationalization of power tariffs

to make power utilities financially viable are some other energy policy initiatives, which are needed to reduce energy foot prints.

## **7. Concluding remarks**

Our study sends out a strong message. Policies which led to incremental adoption of agronomic technologies might not have achieved absolute mitigation, but they did minimize the intensification of greenhouse gases, which may be referred to as *virtual mitigation*. This is amply proved by the fact that intensification index for all the scaled out technologies with and without consideration of benefits that come with avoidance of forest conversion to crop land, remained below 10 and 50 per cent respectively. Further, it can be inferred that irrigation has made the maximum contribution to increasing adaptation, mitigation and resilience in agriculture sector. Nevertheless, since water policies are weak on sustainability account, the governments should rise to the occasion to plug the policy loop holes and strengthen water governance. Amongst the policies evaluated the micro irrigation policy spears to have paid rich dividends and has fared well in terms of all the performance parameters. The 2030 WRG (2009) has rated micro-irrigation as a priority option for bridging the water supply and demand gap that is expected to prevail in 2050. Possibilities of area expansion through large private investments need to be explored.

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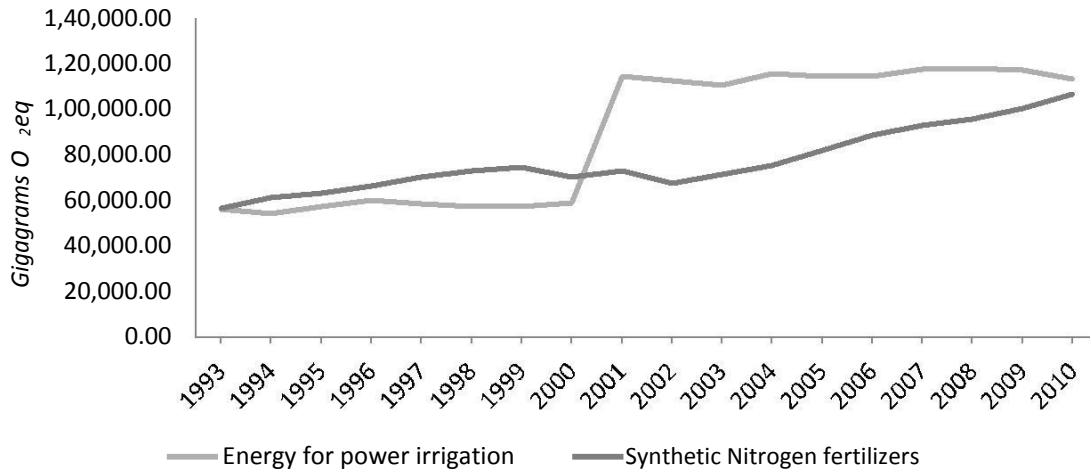
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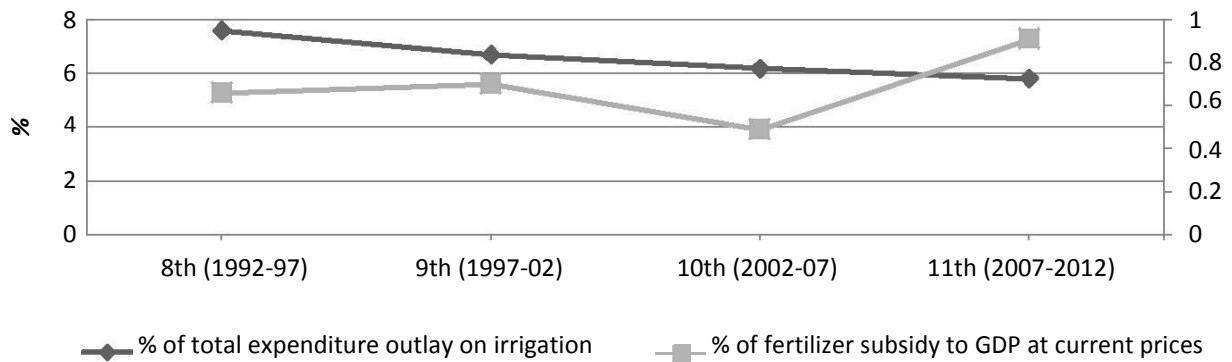
## Figures

**Figure 1 - Emissions released through power irrigation and nitrogenous fertilizers in India (Gigagrams CO<sub>2</sub>eq)**



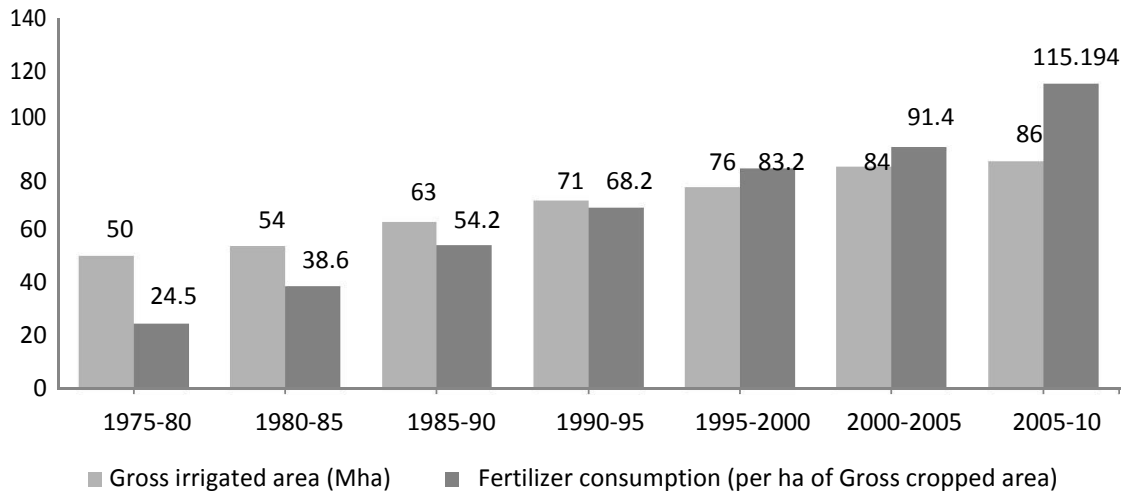
Source - FAO (2014)

**Figure 2 - Government spending on irrigation and fertilizer between 8<sup>th</sup> and 12<sup>th</sup> Five year plan periods (%)**



Source – GoI (2011); Planning Commission (2013) and Gulati & Narayanan (2003)

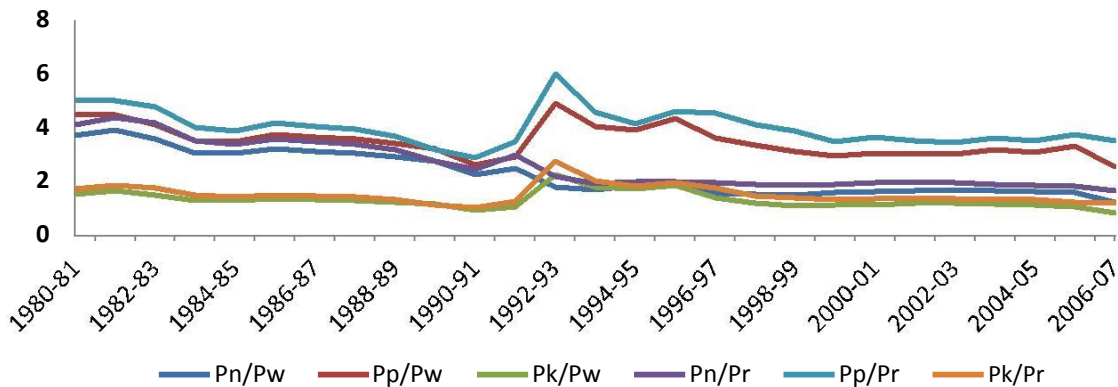
**Figure 3 - Area under irrigation (Mha) and fertilizer use (per ha) in India (five year averages from 1975-80 to 2005-2010)**



Source - GoI(2012c); Chand & Pandey (2008) and GoI(2011)

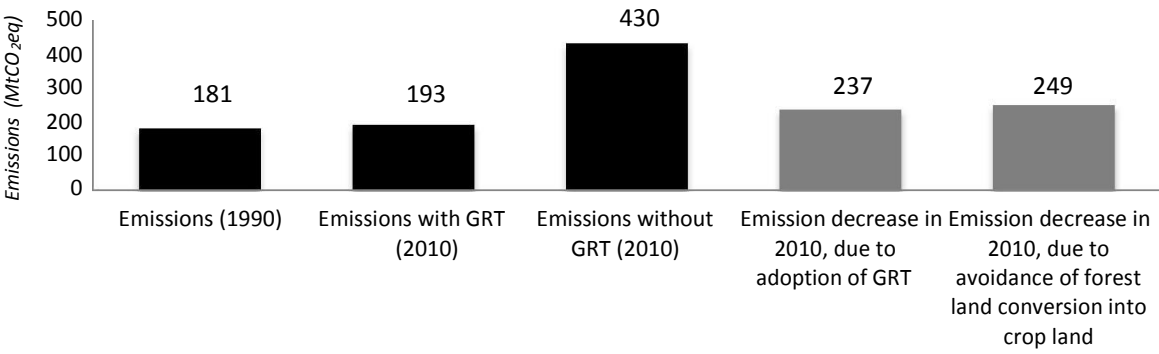
Data source - Authors' calculations

**Figure 4 - Prices of N, P, K (Pn, Pp, Pk) relative to MSP of wheat (Pw) and rice (Pr) in India (1980-81 to 2006-07)**



Source - Chand & Pandey (2008)

**Figure 5 - Estimated annual GHG emissions from land under food grains under two scenarios – (i) with adoption of GRTs and (ii) without adoption of GRTs**



Source - Authors' calculations

## Tables

**Table 1 - Data on area, production, unit GHG emissions from different land uses, efficiency of water application systems and carbon intensity**

Item	1990	2000	2010	Remarks
Gross area under crop (Mha)	165.8	190.1	195.1	1) Increase in productivity during 2010 and 1990=0.560 t/ha
Area under food grain crop (Mha)	127	123	122	
Area under forest (Mha)	68.4	68.4	68.4	2) Increase in emission due to conversion of forest land into crop land is calculated on two accounts: i) loss of mitigation benefit and additional emission from crop land
Emissions from agriculture (Mt CO <sub>2</sub> eq)	482	531	609	
Emission from land under food crops (Mt CO <sub>2</sub> eq)	180.8	176.1	192.7	
Emission from crop land (t/ha CO <sub>2</sub> eq)	1.424	1.545	1.600	
Net emission from forest (-t/ha CO <sub>2</sub> eq)	2.978	2.978	2.978	
Synthetic fertilizers emission (Mt CO <sub>2</sub> eq)	48.8	70.5	106.8	
Increase in emissions due to synthetic fertilizers emissions (Mt CO <sub>2</sub> eq)	-	21.7	58.0	
Food production (Mt)	151.2	190.6	212.5	
Emission (CO <sub>2</sub> eq/t of food grains)	1.196	0.926	0.907	
Productivity of food grains (t/ha CO <sub>2</sub> eq)	1.19	1.55	1.75	
Area required to produce 212.5 MT with 1990 productivity level (Mha)	127	165.4	178.2	
Additional land required to achieve 2010 level production (Mha)	-	41.4	56.2	
Emissions from land under food grain at 1990 productivity (Mt CO <sub>2</sub> eq) @ 1.424 t/ha	-	239.75	262.25	
Area under micro irrigation (Mha)	1		3.87	
Application efficiency of surface irrigation (%)	50-60			
Application efficiency of micro irrigation (%)	65-85			
Difference in crop productivity of surface and micro irrigation system (%)	20-40			
Carbon intensity of electricity	0.406 kg CO <sub>2</sub> eq per kWh			

Source: Tyagi, N.K. (2013)

**Table 2 - Water saving (Mha), production increase (MT) and food production (kg/capita/year) under the current and projected area under micro-irrigation (MI) in India (% increase in parameter values)**

Efficiency of MI systems	20%	30%	40%
Water saving (Mha)			
From current area (3.87 Mha)	0.49	0.73	1.47
From projected area (40 Mha)	6.20	9.30	12.57
Food production (MT)			
From current area (3.87 Mha)	2.52	3.48	4.64
From projected area (40 Mha)	24.01	35.98	47.98
Food production (kg/capita/year)			
From current area (3.87 Mha)	2.08	3.13	4.16
From projected area (40 Mha)	21.49	32.23	42.98

Source - Authors' calculation

**Table 3 - Growth in productivity of rice and wheat in India (t/ha)**

	Rice			Wheat		
	1990	2000	2010	1990	2000	2010
Productivity (t/ha)	2.61	2.85	3.36	2.12	2.78	2.84
Increase in productivity (t/ha)	-	0.24	0.75	-	0.66	0.72
Increase in productivity (%)		9.2	26.3		31.1	34

Data Source - FAO (2014)

**Table 4 - Intensification (IIF) and Mitigation (MI) indices for different GRTs**

Technology	With consideration of benefits avoided in conversion of forests to agricultural land (AFC)	Without consideration of benefits avoided in conversion of forests to agricultural land (NAFC)	Intensification Index (IIF) (%)		Mitigation Index (MI) (%)	
	Mitigation	Intensification	IIF <sub>AFC</sub>	IIF <sub>NAFC</sub>	MI <sub>AFC</sub>	MI <sub>NAFC</sub>
Irrigation (SW+GW)**	(-) 12.26	(+) 35.22	5.52	50.25	94.48	49.75
Irrigation (GW)	(-) 87.32	(+) 7.78	8.63	41.57	91.37	58.43
Micro-irrigation - Current area (4Mha)	(-) 41.20	(+) 15.72				
- Potential area (40Mha)	(-) 2.15	(+) 1.25				
Fertilizer	(-) 22.24	(+) 12.97				
	(-) 107.40*	(+) 141.80	2.80	97.20	46.10	53.90

(+) = Increase in emissions/intensification; (-) = Decrease in emissions/mitigation \*\*SW=Surface water;  
GW=Groundwater  
Source - Authors' calculations

**Table 5 - Estimated values of food grain production (kg/ha/year) and Adaptation indices (AI) for different GRTs**

Technology	Increase in food production(kg/ha/year)	Adaptation Index (AI) (%)
GRTs	72.00	26.10
Fertilizer	14.37	5.28
Irrigation (SW+GW)	28.74	10.56
Groundwater (GW)	17.24	6.34
Micro-irrigation	3.48(37.8)*	-

Food grain production for population of 846.3 million in 1990 was 202.8 kg/capita/year. \*Values within brackets represent increase in food production at 40 Mha of micro-irrigation.

Source - Authors' calculations

**Table 6 - Sustainability indices of water resource development in India**

Item	Level of development (BCM)		
	2000	2010	2050
Surface water	360 (690)*	404	647
Groundwater	210 (396)*	260	396
Degree of stress			
DDS	0.522 (High)	0.586 (High)	0.938 (Extremely high)
GWAR	0.530 (Normal)	0.657 (High)	1.00 (Extremely high)

\*Source - Water resources data are from NCIWRD Report, GoI (1999)

**Table 7 - Fluctuations in NPK consumption ratio in India**

Years	N:P <sub>2</sub> O <sub>5</sub> :K <sub>2</sub> O	Fertilizer use imbalance index (FLiBI)
1961-65	8.2:2.2:1	-
1971-75	5.5:1.8:1	-
1981-85	6.3:2:1	-
1991-95	7.6:7:1	-
2001-05	8.3:2.8:1	0.90-0.96
2006-10	7:2.6:1	0.04-0.05

Source - Mehta (2007)

**Table 8 - Food grain production in two decadal periods (1991-00 and 2001-10)**

Year	Food grain production (Mt)	Year	Food grain production (Mt)
1990-91	176.39	2000-01	196.81
1991-92	168.38	2001-02	212.85
1992-93	179.48	2002-03	174.77
1993-94	184.26	2003-04	213.19
1994-95	191.50	2004-05	198.36
1995-96	180.42	2005-06	208.60
1996-97	199.44	2006-07	217.28
1997-98	192.26	2007-08	230.78
1998-99	203.61	2008-09	234.47
1999-00	209.80	2009-10	218.11

Data Source - Directorate of Economics and Statistics (2012)