Climate Change and Agriculture Productivity

A Case Study of Maize in India

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Dissertation submitted in partial fulfillment of the requirements for the degree of Master of Philosophy in Applied Economics of the Jawaharlal Nehru University, New Delhi

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DECLARATION

I hereby affirm that the work for this dissertation, ***Climate Change and Agricultural Productivity: A Case Study of Maize in India,*** being submitted as part of the requirements of the M.Phil Programme in Applied Economics of the Jawaharlal Nehru University, was carried out entirely by myself. I also affirm that it was not part of any other programme of study and has not been submitted to any other University for the award of any Degree.

June 30, 2010 **Subhashree Banerjee**

Certified that this study is the bona fide work of Ms. Subhashree Banerjee, carried out under our supervision at the Centre for Development Studies, Thiruvananthapuram.

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To

My dear Thakhumaa

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Omissions are not deliberate and are sincerely regretted.

Subhashree Banerjee

ABSTRACT OF THE DISSERTATION

Climate Change and Agricultural Productivity : A Case Study of Maize in India

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The issues of climate change gained its momentum only in the latter part of the twentieth century, when the world started witnessing global warming. It has been addressed as the greatest and widest market failure ever occurred to mankind that has resulted due to externalities. Though all the consequences of such a change are yet to be fully understood, three main issues can be addressed in this regard. They are the impacts on agriculture, sea level rise, and the increase in number of frequency of extreme events, resulting in a serious threat to mankind. In our study we have concentrated only on the impact of climate change on agriculture. We have further narrowed down our study to the impact of climate change in India by studying the case of maize, a very sensitive crop to climate.

In India, agriculture mostly depends on the mercy of monsoons and the environment. Several factors directly connect the change in climate and agricultural productivity such as average increase in temperature, change in rainfall amounts and patterns, rising atmosphere concentration of carbon dioxide, change in climate variation and extreme events etc. These factors have their direct and indirect effects on crops, soils, livestock and pests.

The author with the help of metrological and agricultural data has attempted to give the aggregate picture of the change in climate in the past five decades in India. Various climate indicators have been examined using traditional (indexing and percentage change) and modern (spectral) methods. Cross spectral analysis is also carried out between climatic variables (temperature and precipitation) and maize yield (partial productivity), in order to understand the inter-relationship between them.

Our traditional analysis suggests Kerala is one of the states which has been quite stable in the past five decades with respect to climatic conditions. On the other hand Jammu and Kashmir is one among the worst affected State in India with respect to the increasing trend in temperature and decreasing trend in precipitation. A comparison of maize yield revealed that Jammu and Kashmir has been affected more than Andhra Pradesh, which was blessed by increase in precipitation and decrease in temperature. The results provide a strong support to our hypothesis that climate change does have a vital role to play in agricultural yield.

The spectral analysis results indicated that there are much cyclical or short term fluctuations in terms of temperature than in precipitation in India with an increasing spectral density curve. This is quiet uncommon in economic series. We also find that there is a significant long run relationship among yield and climatic variables, depicting the dependency of yield of maize on climatic variables.

In brief, our study suggests a strong long-run relationship, between climate change and yield. Since our study has mostly concentrated on temperature and precipitation, therefore, further in-depth analysis is required and a multivariate framework is needed for a much better understanding of the issue at hand. The need for similar analysis for other crops is also very urgent to initiate a comprehensive public policy to tackle the impact of climate change in food production in India.

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Preface

In October, 1999, Orissa became a victim to the super cyclone resulting in large scale devastation of human, animal as well as plant world. Belonging to Orissa which has witnessed various cyclones and floods and their aftermaths in the past few decades have always been the major reason for me to get myself involved in issues like climate change and natural disasters. The increase in global temperature between 0.3 and 0.6 degree Celsius (IPCC, 1996) and India witnessing thirteen warmest years in the past century (Indian Meteorological Annual Climate Survey, 2008) has invoked me to look further into the issue. The major questions that arises in the mind of many, is that climate change[1] as an issue belongs to school of physical science, and therefore not much can be done by the social scientist. I, therefore, prefer to start my thesis by bringing the relationship between climate change and social science particularly in economics since I am a student of economics.

The discovering of the anthropogenic[2] gasses by the physical scientist, were not necessarily concerned with the human implications of such changes, neither of choices that can be made. The physical scientists were only the forerunners of the discoveries of climate change and economists along with other social scientists were called in to fill in the data and knowledge gaps after physical scientist had outlined the physical dimensions of the issue. It was just like the physical scientist provided the skeleton and the social scientist were called for to provide the other vital parts of the body. The scientific consensus about climate change

[1] *It refers to changes in surface air temperature, rainfall, etc over a long period of time is known as climate change.*

[2] *Emission of greenhouse gasses through human activities. These emissions also include certain gasses that do not exist in nature like Chlorofluorocarbons (CFCs), Hydro fluorocarbons (HFCs), Perfluorocarbons (PFCs) and Sulphur hexafluoride (SF_6). Apart from these there are three major natural greenhouse gasses namely Carbon dioxide (CO_2), Methane (CH_4) and Nitrous oxide (N_2O). Among these gasses, carbon dioxide is the predominant gas leading to global warming as it traps long wave radiation and emit back to the Earth surface.*

helped us to extend our knowledge of human ecosystem whereas the sociological task was to identify, theorize and to model the anthropogenic sources of climate change, as well as to see the impacts of climate change on societies. It is only through a more refined understanding of the recursive relationships between climate and human activities that we can hope to anticipate broad societal impacts if the suspected warming of climate was realized. For example, some studies by social scientists reveal that civilization is only possible when climatic conditions are favorable (Huntington, 1915; Singh, 1997; Issar, 1995; Misra, 2007).

Sociological research in environmental science can be broadly classified into two types: the first type restricts itself to data and observations, which uses the findings of ecological science and integrate them with sociological insights to produce empirical results. The second category focuses on how people comprehend the meaning of scientific and other types of knowledge and how the social and political forces shape scientific and public recognition of climate change as a problem (Rosa and Dietz, 1998). Social science has always shaped the scientific knowledge claims and has helped in creating public awareness. Mitigation and adaptation strategies were the major reasons that bring social science research to climate change. Early contribution of social scientists to research in the field of climate and society focused mainly on the ways people directly coped with the hazards of natural climatic extremes and with the indirect economic effects of climate.

Economic approaches are the most widely applied social science tools in contemporary industrialised society and contributed much to our understanding of what climate change could mean and what could the efforts to reduce greenhouse gas emission mean for global and country-level societies. Broadly considering, economic activities is the source of greenhouse gas emissions, since economic activity includes everything that people do in their livelihoods and in the production of goods for their use. The Industrial revolution added fire to the fuel, the ability of economy to produce goods and services grew phenomenally due to invention of huge mills which produced more pollution.

The economic forces like markets and profits further led to dramatic changes, over the last two hundred years. It is evident from the four assessment reports published to date (1990, 1995, 2001 and 2007) by Intergovernmental Panel on Climate Change (IPCC) that economics has a major contribution in the science of climate change. Economic scientists and analysts have formed the principal bridge between physical science studies of the climate and its impacts on Earth systems, human causes and response choices. Quantitative studies of emissions associated with energy production came first from economic based models; these studies fed into climate studies that attempted to stimulate climate change via an increase in carbon dioxide emissions. Economists have also developed quantitative tools, called integrated assessment models (IAMs) for studying the whole issue, from emissions to climate change to impacts.

Thus, this study aims at looking at climate change through the lens of social sciences. By an empirical study, I try to extend our present knowledge on the impact of climate change and its relationship with agriculture, particularly maize.

1

Introduction

I. Raison d'etre of the study

"Warming of climate system is unequivocal" (IPCC, 2007)

The world environment has already started showing signs of a cancerous world environment which has been quite visible and evident in the past few decades. It is vividly noticeable by the increase in average air and ocean temperature as well as rise in sea level and increase in the melting of ice and snow. This change in climate is resulted due to externalities associated with green house gasses and is the greatest and widest ranging market failure ever seen (Stern, 2007). Apart from the global warming, lack/excessive of water like storms, droughts, floods, rising sea level, etc. can pose a threat from climate change. This may lead to severe impact on water availability, food, health, land, infrastructure and environment.

Of all potential impacts stemming from climate change, those to the agricultural sector stand out as among the most important and is likely to be unfavorable to developing countries[3], especially to Africa, Latin America, and India. Climate is the key factor in any operation of agricultural production right from field preparation to marketing. The success and failure of farming is closely associated with the prevailing weather conditions. Agriculture accounts for 24 per cent of world output employs 22 per cent of the global population and occupies 40 per cent of land areas (FAO, 2003). About 75 per cent of the poorest people in the world live in rural areas and rely on agriculture for their livelihood (FAO, 2003). Food Production will be particularly sensitive to climate change, because crop

[3] *A large portion of these countries are already vulnerable to a range of natural hazards and extreme weather events (e.g., floods or droughts).*

yields depends on the prevailing climatic conditions (temperature and precipitation). Long-term changes in temperatures and precipitation have direct implications on agricultural yields. It is true that, in some areas, some reduction in yields may be compensated by carbon fertilization and increased precipitation. However, this opportunity is likely to be limited in scope and only applicable to certain species.

According to IPCC (2007), increase in average temperature will adversely affect crops, especially in semi-arid regions, where already heat is a limiting factor of production and will also increase evapo-transpiration[4] rate and the chance of severe drought. It means that with warmer temperature plants will require more water. In India increase in temperature can also aggravate the meltdown of the Himalayan glaciers which currently supply 85 per cent of water to the rivers of the Northern Indian Plain. This could be reduced to nearly 30 per cent of its current contribution over the next 50 years, if forecasts of climate change and glacial retreat are realized resulting in serious consequences on water management and irrigated crop productions (Stern, 2007). This would mean that the impact is felt mostly in agriculture.

> "Crop productivity is projected to increase slightly at mid to high latitudes for local mean temperature increases of 1–3 degree Celsius depending on the crop, and then decrease beyond that in some regions. At lower latitudes, especially seasonally dry and tropical regions, crop productivity is projected to decrease for even small local temperature increases (1–2 degree Celsius), which would increase risk of hunger." (IPCC, 2007, P.6)

> "In higher latitudes, developed countries are likely to benefit from moderate warming but in tropical regions, even small amounts of warming will lead to declines in yield. Here crops are already close to critical temperature threshold[5] and many countries have limited capacity to make economy wise adjustment to farming patterns.....Maize based agriculture is likely to

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[4] *Evaporation (a process whereby liquid water is transformed to water vapour and removes from evaporating surfaces like lakes, rivers, soils, etc.) and transpiration (a process whereby liquid water is vaporized from plant tissue to atmosphere) occurring simultaneously resulting in evapo-transpiration.*

[5] *The optimum temperature for crop growth is around 25-30 degree Celsius, while temperature around 40 degree Celsius is dangerous.*

suffer substantial decline as it is less responsive to the direct effects of rising carbon dioxide. "(Stern, 2007, p. 83)

It has been seen that at the global level the most severe impact of climate change on crops is witnessed by Maize, which showed a reductions of yield by 20 to 31 per cent without carbon fertilization and 15 to 24 per cent with carbon fertilization (Rosenzweig and Iglesias, 1994). Maize is the most popular cereal in terms of world's production and has witness a continuous increase in area under its cultivation since 2001-02. At the same time it is also, one of the most sensitive crops with respect to rise in temperature. It shows a greater decline in yield with rising temperature because of its different physiology, which makes it less responsive to the direct effects of rising carbon dioxide. With the improving of the economy, there has been an increase in demand for poultry, dairy and other cattle products, leading to increase in demand. Maize contributes significantly for supporting these farm sectors. Specialty corns such as sweet corn, baby corn and their products, etc., are catching the fancy of the urban semi-urban and rural sections of society. Besides, the significance of maize is increasing the world over due to its increasing application in diverse user sectors. Therefore the impact of climate on agriculture is examined for maize (a sensitive crop) in India.

II. Climate Change and Agriculture: A Literature Review

Agriculture will particularly be sensitive to climate change since crop yield in large parts of the world depend on temperature and rainfall patterns. According to a popular peasant saying - "Abundance of water destroys life; paucity of water destroys life", reflects the link between agriculture and monsoon. In India, Agriculture mostly depends on the mercy of monsoons and the environment. Change in the variation in rainfall has its impact on agriculture. Studies undertaken to analyzed the relationship between Indian Summer Monsoon[6] rainfall and food grain production in India revealed that there is a close

[6] *June-September, the wet season which provides the bulk of rainfall for most of India.*

relationship between the variation of monsoon and the total food grain production (Selvaraju, 2003). Further, studies on crop-climate relationship, using historic production of statistics for major crops[7] showed that the annul total production (except sorghum and sugarcane), production in the monsoon (except sorghum) and post-monsoon seasons (except sorghum and rice) were significantly correlated to all India summer rainfall (Kumar et al., 2004). It can also be inferred that the dependency on environment conditions is significantly high, in India, since the percentage of gross cropped area under irrigation is less than 25 per cent (Bapnal et al., 1981; Jodha, 1985). Another study which was based on the western Vidharbha, Maharastra (2004), reveals that one of the major reasons behind crop failure of is due to excessive or untimely or delays in rain.

Change in average temperature can reduce crop duration, increase crop respiration rate, effects the survival and distributions of pest populations (developing a new equilibrium between crops and pests), decrease fertilizers use, etc. For example, a small change in the growing season temperature over the years appeared to be the key aspect of weather affecting yearly wheat yield fluctuations (Mall and Singh, 2000). Negative trends in solar radiation and an increase in minimum temperature can further result in declining the trend of potential yields of rice and wheat in the Indo-Gangetic plains of India (Pathak et al., 2003).

Further, Achanta (1993) predicts that despite substantial increase in national food grain production, productivity of some important crops such as rice and wheat could decrease considerably with climate change. Kaiser et al. (1995, 1993) and Mount Li (1994) reveals that individual farmers might adjust the output choices and production practices as climate change over time. Adam et al (1995) points out that climate change affect both the input and output choices and that specified climate change might shift national patterns of comparative advantage

[7] *Rice, wheat, sorghum, groundnut, and sugarcane.*

in the production of many crops and lives focus products. Kumar and Parikh (2001), estimated the functional relationship between farm level net revenue and climate variables, introduced through linear, quadratic, and interaction terms, to understand the climatic sensitivity of Indian agriculture. They found that the overall impacts due to the climate change scenario for a 2 degree Celsius rise in temperature and a 7 per cent increase in precipitation are negative and about 8.4 per cent of the total farm level net-revenue for India. The overall negative impact of change in temperature will shadow the positive change in precipitation and that with the higher change the loss caused due to such change will be greater.

Apart from rainfall and temperature, other factors like rising atmosphere concentration of carbon dioxide, change in climate variation and extreme event, etc., have their direct and indirect effects on crops, soils, livestock and pests. For example, increase in atmospheric carbon dioxide has fertilization effect on crops with C_3 photosynthetic pathway and thus promotes their growth and productivity. There have been a few studies in India which aimed at understanding the nature and magnitude of yield gains or losses of crops at selected sites under elevated atmospheric Carbon dioxide and associated climatic change (Sinha and Swaminathan, 1991; Aggarwal and Sinha, 1993; Aggarwal and Kalra, 1994; Rao and Sinha, 1994; Mathauda and Mavi, 1994; Rao et al., 1995; Mohandass et al., 1995; Lal et al., 1998,1999; Saseendran et al., 1999; Mall and Aggarwal, 2002; Aggarwal and Mall, 2002; Aggarwal, 2003; Mall et al., 2004). On the other hand, indirect effects like land use, availability of irrigation, frequency and intensity of inter and intra seasonal droughts and floods, soil erosion, change in pest profiles, etc. have their impact on the agriculture productivity.

III. Research Methodology

There are basically three approaches that have been used to assess the likely economic effects of climate change on agriculture: agro-economic models, agro-ecological zone models and Ricardian cross-sectional models.

III.a. Agro-economic models

This analytical technique make use of well-regulated crop models from carefully controlled experiments in which crops are grown in field or laboratory settings that simulate different climates and levels of carbon dioxide (Adams et al., 1989, 1990, 1993, 1999; Kaiser et al., 1993; Kumar & Parikh, 2001). To ensure that all different outcomes across experimental conditions can be assigned to the variables that are being investigated (temperature, precipitation or carbon dioxide); no variability is allowed in farming methods. In addition, farmer adaptation to changing climate is not included in the estimates from these models. Economic models are then used to predict aggregate crop outputs, prices and net revenue using the yields from the agronomic models (Mendelsohn & Dinar, 1999).

In the Indian context, Kumar and Parikh (2001a) have estimated the macro level impact of climate change using such an approach. They have showed that under doubled carbon dioxide concentration levels, in the latter half of 21st century, the gross domestic product (GDP) would decline by 1.4 to 3 percentage points due to climate change. More significantly, they have also estimated an increase in the proportion of population in the bottom income groups of the society in both rural and urban India under climate change conditions.

III.b. Agro-ecological zone models

This approach assigns crops to agro-ecological zones and yields are then predicted (FAO, 1996). The agro-ecological models examine changes in agro-ecological zones and crops as the climate changes. This analytical technique make use of well-calibrated crop models from carefully controlled experiments in which crops are grown in field or laboratory settings that simulate different climates and levels of carbon dioxide (Adams et al., 1989, 1990, 1993, 1999; Kaiser et al., 1993; Kumar & Parikh, 2001). To ensure that all different outcomes across experimental conditions can be assigned to the variables that are being investigated (temperature, precipitation or carbon dioxide), no variability is allowed in farming methods. In addition, farmer adaptation to changing climate is not included in the estimates from these models.

Economic models are then used to predict aggregate crop outputs, prices and net revenue using the yields from the agronomic models (Mendelsohn & Dinar, 1999). The agro-ecological models, examines changes in agro-ecological zones and crops as climate changes and predict the effect of alternative climate scenarios on crop yields. Economic models then use the yields changes to predict the overall supply and market effects (Darwin et al., 1995). According to Mendelsohn and Dinar (1999), the climate scenarios can be relatively simple stories of uniform changes across a country, or they can involve complex geographic distributions of changes. As a result most impact studies examine multiple climate scenarios.

III.c. The Ricardian cross-sectional models

Since the scope for incorporating adaptation into the agronomic-economic approach is rather limited, an alternative approach was proposed by Mendeloshn, Nordhaus and Shaw in their 1994 paper. The Ricardian approach is the common cross-sectional method that has been used to measure the impact of climate change on agriculture. The method was named after David Ricardo (1772-1823) because of his original observation that land rents would reflect the net productivity of farmland (Mendelsohn & Dinar 2003). It is similar to the Hedonic pricing approach of environmental valuation. It is based on the argument that, "by examining two agricultural areas that are same in all respects except that one has a climate on average 3 degree Celsius warmer than the other, one would be able to infer the willingness to pay in agriculture in order to avoid a 3 degree Celsius temperature rise" (Kolstad, 2000). The Ricardian approach regresses farm performance (land value or net income) on a set of environmental factors, traditional inputs (land and labor) and support systems (infrastructure) to measure the contribution of each factor to the outcome and detect the effects of long-term climate change on farm values (Mendelsohn et al. 1994, 1996; Mendelsohn & Dinar 1999). In a well-functioning market system, the value of a parcel of land should reflect its potential profitability, implying that spatial variations in climate derive spatial variations in land uses and in turn land values (Polsky 2004).

The Ricardian approach is considered better because it takes into account the various adaptations undertaken by the farmers and treats her as though she has perfect foresight. In the Ricardian approach, farmers are assumed to identify instantaneously and perfectly any change in climate, evaluate all associated changes in market conditions, and then, modify their actions to maximize profits. These assumptions also imply that the agricultural system is ergodic, i. e., space and time are substitutable.

It also provides a framework for making a comparative assessment of 'with' and 'without' adaptation scenarios that can show how adaptation measures may help reduce this impact. Farmers will use available information to their maximum economic benefit in adapting to climatic shocks in any economy at equilibrium. For instance, a standard Ricardian model would imply that if growing citrus crops is more profitable than growing wheat, and if the climate becomes more suitable for citrus than wheat, then those farmers will adapt to the changed climate by drawing on the experiences of citrus farmers elsewhere and switching from wheat to citrus (Polsky 2004). The Ricardian approach has been applied in the United States (Mendelsohn et al., 1994, 1996; Seo & Mendelsohn, 2007) and in some developing countries - Brazil (Sanghi, 1998), India (Sanghi et al., 1998; Kumar & Parikh, 1998), Zimbabwe (Mano & Nhemachena, 2007) and South Africa (Gbetibouo & Hassan, 2005) - to examine the sensitivity of agriculture to changes in climate. For India, Kumar and Parikh (2001b) have used a variant of this approach and that a 2 degree Celsius temperature rise and 7 per cent increase in rainfall would lead to an almost 8 per cent loss in farm level net revenue. This study has taken annual farm-level net revenues since there is an absence of the availability of data regarding the land markets. The result shows that the regional differences are significantly large with northern and central Indian districts along with coastal districts bearing a relatively large impact. Kumar (2003) has extended the analysis to include climate variation terms in the Ricardian approach and estimated that a 5 per cent increase in climate variation along with the above-mentioned climate change scenario would result in an almost 10 per cent drop in the farm level net revenue

A criticism of the Ricardian approach is that it fails to fully control the impact of variables that could also explain the variation in farm incomes. For example, incomplete specification can result in underestimating the damages and overestimating the benefits of climate change (Mendelsohn 2000; Kurukulasuriya & Rosenthal 2003). Variability in farms is a result of many factors besides the effects of climate change. Efforts in the Ricardian studies to control for this problem through including other variables, such as soil quality, market access and solar radiation, are hampered by the difficulty of obtaining perfect measures of these variables (Mendelsohn 2000). The result is that many of these factors may not be taken into account when assessing the impacts on farm revenues.

Assuming that prices will remain constant is another limitation of the Ricardian approach (Kurukulasuriya and Rosenthal, 2003; Cline, 1996; Mendelsohn et al., 1994). Existing cross-sectional studies rely on a cross section within a country where there is little price variation across farms, with the result that the studies have not been able to estimate the effects of prices. The assumption in the Ricardian studies that prices are constant leads to bias in the welfare calculations (Cline 1996). The cross-sectional approach only measures the loss as producer surplus from the climate change and ignores the price change that would occur if supply changed, and as a result omits consumer surplus from the analysis.

The result is that damages are underestimated (omit lost consumer surplus) and benefits are overestimated (overstate value of increased supply) (Mendelsohn 2000). The argument however, is that this also applies to all agro-economic models that are confronted with the same difficulty of predicting domestic price changes when changes in agricultural prices due to climate change are determined at the global level (Kurukulasuriya & Rosenthal 2003). Despite the failure to address this problem, Mendelsohn et al. (1994) contend that the bias is less than 7 per cent (Kurukulasuriya & Rosenthal 2003). Another limitation of this approach is that measuring impact in a static spatial model would only be valid if technology, policy or any other temporally varying factor that would affect land use and farmers' production management decisions does not change, or if the value of alternative uses of the land does not change (Antle 1995). For instance, technological changes would alter the relationship between environmental characteristics and land values and thus the approach would give inaccurate effects of climate change on land values (Antle 1995). Failure to take account of water supply is another important criticism that has been raised concerning existing cross-sectional models (Darwin 1999; Kurukulasuriya & Mendelsohn 2006). In examining the effect of country climate on country production the existing models do not take into account water that might come from distant countries through rivers and other water supplies. According to Mendelsohn (2000), there has not been data available predicting the magnitude of these water supplies and how they in turn would be affected by climate change. In addition, the cross-sectional models have not considered the effects from flooding. Integrating water systems into agricultural analysis will be important to all approaches and Mendelsohn and Dinar, (2003) have made a significant contribution by testing the sensitivity of net farm revenues to other sources of water. Research has shown that agronomic-economic and agro-ecological zone models produce reliable results relating agricultural yield and climate variables. However, these methodologies are complex and have high requirements and they do not incorporate farmers' adaptation strategies to changing climate in their analysis.

All the above models here have examined the impact in "time domain" only. The "frequency domain" of time series is hardly examined in the literature. This technique is used here in our study to understand the impact of climate change on yield and in turn determine the supply of food. The long-run-short-run impact can be captured only by using this method that is the spectral method.

IV. Climate change in India

Since the change in the climate is a worldwide phenomenon, India is also witnessing a part of such a change. According to the Indian Meteorological Annual Climate Survey, 2008, India has witnessed thirteen warmest years[8] in the past century and it is also worth mentioning that the latter part of the century has witness the most number of warmest years. In Delhi the minimum and maximum temperature shows a rising trend both in summer (June-October) as well as winter season which start after summer monsoon. There was also a small declining trend in solar radiation during summer and winter season after 1980. A few studies described below predict the future change in climate in both the "business as usual situation" and not.

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[8] *The thirteen warmest years recorded since 1901 are 1941, 1958, 1987, 1998, 1999, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008. 2008 was the warmest year so far.*

According to Lal et. al. (1995), there will be an increase in annual mean maximum and minimum surface air temperatures of 0.7 and 1 degree Celsius over land in the 2040s with respect to the 1980s. The study has taken into account the projected emissions of greenhouse gases and sulphate aerosols[9] for the Indian sub-continent. Kumar et al. (2003) concluded that under future scenarios of increased greenhouse gas concentrations indicates a marked increase in both rainfall and temperature into the 21st century, particularly becoming evident after the 2040s in India. Over the region south of 25 degree North (south of cities such as Udaipur, Khajuraho and Varanasi) the maximum temperature will increase by 2-4 degree Celsius during 2050s. In the northern region the increase in maximum temperature may exceed 4 degree Celsius. This study also indicates a general increase in minimum temperature up to 4 degree Celsius all over the country, which may however exceed over the southern peninsula, northeast India and some parts of Punjab, Haryana and Bihar. There is an overall decrease in number of rainy days over a major part of the country. This decrease is more in western and central part (by more than 15 days) while near the foothills of Himalayas (Uttaranchal state) and in northeast India the number of rainy days may increase by 5-10 days. However, increase in GHG may lead to overall increase in the rainy days intensity by 1-4 mm/day except for small areas in the northwest India, where the rainfall intensities decrease by 1 mm/day.

Further, Kothawale and Rupakumar (2005) reported that while all-India mean annual temperature has shown significant warming trend of 0.05 degree Celsius/10yr during the period1901-2003, the recent period 1971- 2003 has seen a relatively accelerated warming of 0.22 degree Celsius/10yr, which is largely due to unprecedented warming during the last decade. A Study by Arora et al. (2005) reported that annual mean temperature, mean maximum and minimum temperatures have increased at the rate of 0.42, 0.92 and 0.09 degree

[9] *A gaseous suspension of fine solid or liquid particles that can remain suspended in air for a few minutes to many months depending on its size and weight.*

Celsius/100yr, respectively. With the above mentioned study on India, let us now examine the impact of climate change on agriculture in India.

V. Agriculture and Climate in India

An agrarian economy likes ours mostly depend on the onset of monsoon. Nearly 43 per cent of India's geographical area is used for agricultural activity. Agriculture accounts for approximately 33 per cent of India's GDP and employs nearly 62 per cent of the population. It accounts for 8.56 per cent of India's exports (CRIDA, 2008). About one third of the cropland in India is irrigated, but rain-fed agriculture is central to the Indian economy. Despite technological advances such as improved crop varieties and irrigation systems, weather and climate are still playing key role in Indian agricultural productivity thereby national prosperity. The year 2002 can be best given as an example to show how Indian food grains production depends on rainfall of July. The year was declared as the all-India drought[10], as the rainfall deficiency was 19 per cent against the long period average of the country and 29 per cent of area was affected due to drought. This caused a whopping fall of 19.1 per cent in the *kharif* food grains production and the story was nearly the same during the all-India drought in 1979 and 1987. Similarly, the cold wave during 2002-03 over the northern States of India, particularly in Himachal Pradesh, led to the estimated crop loss up to 100 per cent, depending upon the type of crops (CRIDA, 2008). A very common notion is that, the developing countries are more vulnerable to climate change because of their reliance on low-capital agriculture, which have difficulties in adapting to climate changes is also valid in the case of India. Agronomic studies of crop yield reductions support this wisdom implying large potential agricultural damages in India from climate change.

[10] *It is defined as the drought year when the rainfall deficiency for the Country as a whole is more than 10 per cent of normal and more than 20 per cent of the Country's area is affected by drought conditions.*

The climate sensitivity of agriculture is uncertain, as there is regional variation of rainfall, temperature, crops and cropping system, soils and management practices. Different crops respond differently with different climatic conditions. According to Rosenzweig and Parry (1994), the net estimated effect of climate change on global cereal production would be up to 5 per cent. They further indicated that production in the developed world would increase while it can decline in developing countries. Increasing temperature in future is likely to reduce fertilizer use efficiency. This could lead to increased fertilizer requirement for meeting future food production demands, leads to higher emissions of greenhouse gases (GHG). This could become a cause for concern, in case of reducing GHG emissions in future. Increased temperature can also reduce the profit from wheat cultivation and will compel farmers of lower latitudes to opt for maize and sorghum which are better adapted to higher temperature. As per the United Nations Report of FAO, 2008, India stands to lose 125 million tonnes, equivalent to 18 per cent of its rain-fed cereal production from climate change by 2015. The likely changes need careful empirical analysis. Our study aims at understanding the impacts in the case of a crop, maize, which is very sensitive to climate change.

V.a. Maize and Climate

Nearly, 80 per cent of maize in India is grown during monsoon season, where over 80 per cent of the total annual precipitation is received. It thus is very important for the soil to have an adequate water- holding capacity and proper drainage to minimize damage due to water- logging and seed and seedling diseases. About 80 per cent of the maize belt being rain dependent remains exposed to vagaries of weather, either floods or droughts. It is also important that the average temperature during the growing season should stay above 12 degree Celsius and that there should not be any frost, since frost can damage the crop at all the stages of growth period, particularly during the *rabi* season. The threats posed by the change in the climate needs to be addressed in case of maize since most of its production depends on rainfall. More frequent and severe drought will worsen the situation, as it is more vulnerable to droughts. It is been seen that its annual yields fluctuate more widely than is the case for rice and wheat, which are more commonly irrigated (CIMMYT, 2010). Truly, in India, the total irrigation coverage for maize is around 20 per cent (Chand and Raju, 2008). And as irrigation costs are increasing and land gets scarcer, many farmers in Asia are switching from irrigated wheat and rice to maize, growing it with reduced irrigation or under rain-fed conditions. This could lead to fluctuations in Production giving rise to hike in prices and food shortages.

VI. Objectives of the Study

In a broader picture the study intends to understand the impact of climate change on the yield of maize. More specifically we can narrow down to the following objectives.

- To examine whether there is any change in climate in the past fifty years.
- To analyse the major components (trends, cycles, etc) of the time series in temperature and precipitation using spectral method.
- To understand the relationship between the change in temperature and regional dimensions.
- To examine how climate change affects the productivity of maize regionally using coherence spectrum.

VII. Sources of Data

The study is based on the secondary data collected from various sources. Different issues of Agricultural Statistics of India Vol. I, Estimates of Area and Production of principal crops in India and CMIE Economics Intelligence Service Agriculture, are used. The meteorological data like precipitation, wet day frequency, average temperature, maximum and minimum temperature and diurnal temperature are taken from the website-*www.indiawaterportal.org/metdata*. Since the above mentioned meteorological variables are available in this website, therefore we have opted for it.

VIII. Methodology

In our Study we are concerned with the long-run phenomenon and we have used the frequency domain to analyse the data. We have taken spectral analysis to understand the relationship between temperature, precipitation and yield. In Spectrum analysis we decompose a complex time series into a few underlying sinusoidal (sine and cosine) functions of particular wavelengths (Warner, 1998). Both univariate and bivariate analysis is considered in our study. The very first step of our study is to make the series stationary by removing the trend and the cyclical fluctuations (Warner, 1998). The first order differencing is used to remove the linear trends from the series. For non-linear series (which can be concluded from the R^2) we have detrended the series by subtracting the predicted values from the original series, giving us the residual which is free from trend.

After the adjustment done, the series will then be subjected to periodogram analysis for the cyclical behavior. We have used the Fisher test (Warner, 1998) to conclude whether there are any significant peaks or not. Or in other words the test helps us to learn whether a series has any significant cyclical fluctuations or not. In order to make the series cycle free we use the harmonic analysis (Warner, 1998). Thus, by identifying the important underlying cyclical components, we can learn something about the phenomenon of interest. It also helps us to identify the wave lengths and the importance of underlying cyclical components. The series adjusted for trend and cycles are then used for estimation spectral density by smoothing techniques (window). We have used the Daniel window (with width = 5) for its simplicity and that it uses equal-weight window. Apart from the univariate analysis, our study also focuses on the bivariate relationship between the series by using cross-spectral analysis.

Cross spectral analysis/bivariate analysis examine the relationship between maize productivity and metrological variables such as temperature and precipitation in the frequency domain. In this case we develop a methodology for analyzing the relationship using coherence spectrum and phase spectrum of cross spectral analysis. The coherence spectrum is the linear relationship between the two variables and is correlated if the coherency spectrum is significant that is more than 0.3 (Koopmans, 1974).

The phase spectrum are the positional estimates. They are known for the lead-lag relationship between variables. We have taken the summary statistics of the phase estimates for all the frequencies. The average phase value is then confirmed, only if the coherence value of the frequency corresponding to the average phase taken in the summary statistics is significant (more than 0.3), otherwise no lead- lag relationship. After the confirmation we check for the sign of the phase value. Here the sign of the phase matters that is whether the phase value is positive or negative. If the phase value is positive then the first factor is leading and the second is lagging and vice-versa. Based on this methodology we try to answer our objectives of the study.

IX. Plan of the Thesis

The study consists of six chapters including the introduction chapter. We begin with the story of climate change, a historical review in chapter 2. This chapter helps us to hone our understanding about the very issue of climate change and its implications. In the third chapter we have undertaken a State wise spectral analysis as well as the traditional analysis of the climatic variables. This chapter helps us to understand the various components of climatic factors in a time series basis and also helped us to see the change in the climate in the last fifty years.

The fourth chapter deals with the State wise spectral and traditional analysis of maize yield in India. In the fifth chapter, we take up the cross spectral analysis to understand the relationship between temperature, precipitation and yield. Finally, we conclude in the sixth chapter along with some suggestions for policies implications.

2

The Story of Climate Change: Historical Review

"If we can conquer climate, the whole world will become stronger and nobler"

Ellsworth Huntington

Civilisation and Climate (1915)

This chapter reviews how the idea of anthropogenic climate change first emerged and when and how the idea achieved wider prominence. It also includes individuals both physical and social scientists, who played the key roles in contributing to the science of climate change. The story of climate change is not a simple one of science progressing purposefully in a straight line from ignorance to a state of knowledge. It meant different to different places at different time in the past, undergoing many changes in its adaptability. The story of climate change will help us to hone our understanding about the dangers ahead and how the issue is important in the present context.

I. The Genesis of Climate Change

The genealogy of climate change can be traced back with the Greeks. Parmenides (a Pythagoras's disciple) was the first to use the word κλίμα or *klima,* meaning inclination, in the sixth century BC to differentiate between the five zones on the surface of the supposed spherical world. Aristotle, in the fourth century BC, in his treatise on Meteorology describes his theories about earth science. He divided earth into five different types of climatic zones, which was based on their distance from the equator. In the later periods, Greeks further extended the idea of physical climates and Ptolemy's seven *klimata* from the second century AD persisted as the conventional framework for explaining different climates well into the early Renaissance period. The Greek notion of *klimata* or climate as a stable property of the natural world lasted for 2000 years. Ptolemy's system of seven climes was popular in Arab and Persia, while in Europe, Aristotle's system of five climatic zones was more successful. A Russian geographer Wladimir Köppen, originated the Köppen classification[11] of world climates in the twentieth century, which brought an end to the Greek classification of climate which was based on latitudes.

II. Climate Change and Civilization

In the fourth century BC Hippocrates, in his treatise on *Airs, Waters, Places,* became one of the pioneers to develop an association between the climate and human being. According to him, the physicality of climate acts as a constraint on human action and helps to hone/destroy human fortunes. Further in the third century BC, Aristotle's student Theopharstus, was the first to observe and document the local changes in climate induced by human agency: the draining of marshes cooled the climate around Thessaly in Greece, while the clearing of forest in Philippi warmed the climate.

Changes in climate have been invoked to (help) explain the decline of civilization more often then they have been interrogated to explain their rise. One of the first systematic attempts to relate climatic factors to the decline in fortunes of a civilization was done by the historian Edward Gibbon in 1776. He associated the decline in agriculture due to change in climate to the decline in Rome. Further studies undertaken conclude that a favorable climate is an essential condition of high civilization (Huntington, 1915; Brooks, 1926; Singh, 1997, Misra, 2007). Eduard Brückner, a prominent Austrian geographer, was another of this small band of climate change believer in the late nineteenth/ early twentieth century, demonstrated that changes in climate would have severe implications for rivers, lakes and agriculture. He insisted that such changes were real and were related

[11] *In Köppen's classification the geographical complexities of regional climates are mapped by grouping together those climates whose statistical propertied yield similar natural vegetation types.*

to deforestation led him to advocate in the Prussian House of Representatives what was probably the first climate change policy: a proposal law to preserve the forests of Prussian to protect the rainfall and river levels of the state. Change in climate also stimulated mass migration and other social and geopolitical movements due to the change in ecology and desertification (Issar, 1995).

III. The Dawning of a New Era

The scientific inquiry of climate change started from the early part of nineteen century when changes were suspected and the greenhouse gasses (GHGs) were first quantified. The quantification of climate through its physical attributes were gaining grounds due to which various meteorological measurement were extended to various parts of the world and was vigorously promoted by scientific entrepreneurs like Alexandra Von Humboldt and Mathew Maurya, which resulted in the first systematic quantitative large scale climatologist. In the latter part of the century, scientists argued that human activities can change the climate on a timescale of decades but were not sure about the impact of such a change.

The Prussian physicist Heinrich Dove (1848) published the first global map of monthly mean temperature followed by the Austrian meteorologist, Julius Hann's monumental Handbüch der Klimatologie[12] (1883). A crucial part of the story of climate change begins with the realization of the multiple glaciations which the Earth has experienced over its history. Jean de Charpentier, a German Swiss geologist hypothesized that Swiss glaciers had once been much more extensive. He contradicted the idea of the Biblical Flood, causing deposition and believed that boulders were brought by the glaciers, which no longer existed. His idea was further taken up by Agassiz (1837), who was the first to present a

[12] *Its three volumes covered general, regional and local climates, and albeit Hann captured these climates through the growing number of instrumental measurements, his third volume on local climate continue to use literary and eye-witness description.*

coherent Ice Age theory which proposes that our planet has been subject to ice age, in the Swiss Society of Natural Sciences meeting in Neuchâtel. Studies like that of Monsieur Arago (1834), based on the evidence of grape-ripening dates further added that the summers in several parts of France were "colder than they had been formerly".

IV. The Discovery of Anthropogenic Climate Change

The story of anthropogenic gasses started with the French mathematician and physicist, Joseph Fourier, who discovered the basic mechanism underlying climate change in 1827. He found out that the Earth's atmosphere kept the planet warmer and that the atmosphere is asymmetrical with respect to the transmission of incoming solar energy and outgoing terrestrial energy. It is the atmosphere that lets light through very effectively, but not thermal radiation, which is transformed into light on the ground. This phenomenon was latter named as the "greenhouse effect". He was also the first to calculate the warming effects and suspected that human activities could influence climate, albeit he focused on land use change only.

In May, 1859, John Tyndall, a British physicist experimented with different gasses present in the atmosphere to study there absorptive properties to various short-wave and long wave radiations. He was the first to discover that the molecules of water vapour, carbon dioxide, nitrous oxide, methane and ozone each exhibit unique absorptive properties when radiant (infra-red) heat is passed through them; thus, for example, water vapour is 16,000 times more effective at absorbing infra-red radiation, molecule-for- molecule, than is oxygen. His discoveries became central for understanding the heat budget of the atmosphere. He named this as "greenhouse gasses", which possessed distinctive radiative properties, his work opened up the possibility that, by altering the concentration of these gasses in the atmosphere, human activities could alter the temperature regulation of the planet and he claimed that it must form one of the chief foundation stones of the science of metrology.

A new debate started when a Swedish chemist, Svante August Arrhenius in 1896 proposed a theory on how energy generation-related emissions resulting from the industrial revolution could increase the level of carbon dioxide in the atmosphere and increase the planet's temperature between 4 and 5 degree Celsius. There were many scientists who differed from this finding and tried to argue that the emissions cannot change the climate, which was governed by the "balance of nature". But in the 1930s, the United States and North Atlantic region had warmed significantly during the previous half century. The Scientists supposed this was just a phase of some mild natural cycles with unknown causes but Callendar insisted that greenhouse warming was on the way. He began collecting long series of meteorological observations from stations around the world and also made his own set of calculations about the net absorption effect of carbon dioxide in the atmosphere, following Arrhenius footsteps but using more recent coefficients. He argued in 1938 that the rise in the world's temperature was likely to be a result of the rise in carbon dioxide.

In the 1950s, Callendar's claims resulted in various researches which were undertaken to see that whether carbon dioxide emissions accelerated the greenhouse phenomenon or not. The new studies showed that, contrary to earlier crude estimates, carbon dioxide could indeed build up in the atmosphere and should bring warming. Painstaking measurements undertaken in the 1960s showed that the level of the gas was in fact rising, year by year. Some of the scientists found them believable but were not convinced regarding the need for any policy action, but rather preferred to put more effort into research to find out more appropriate things that was happening. The development of thermal radiation measurement technology further helped to acquire more detailed data on this. Studies by Gilbert Plaas, Hans Sues and Roger Revelle (the three

American scientists) proved the mechanism behind the greenhouse effect. Gilbert Plaas showed that with a small increase in carbon dioxide, there would be an acceleration of the greenhouse phenomenon. Hans Suess, from his studies on radiocarbon dating on mummies, identified that the carbon dioxide in the atmosphere is generated by man. In 1957, Roger Revelle proposed a generally accepted theory that the world's oceans absorb carbon dioxide so slowly that the molecules resulting from emissions could remain in the atmosphere for as long as 100 years. He further persuaded Charles David Keeling, who was an American scientist to work on the Mauna Loa Observatory.

Keeling started collecting carbon dioxide samples in September 1957 and by 1960, he had established that there are strong seasonal variations in carbon dioxide levels which reached the peak levels during the late northern hemisphere winter and dips low during the spring and early summer each year due to growth in plants in the northern hemisphere. In 1961, Keeling produced data showing that carbon dioxide levels were rising steadily in what became known as the "Keeling Curve"[13]. He concluded that the atmospheric concentration of carbon dioxide has grown from 315 parts per million (ppm) in 1958 to 380 ppm in 2005 and that the increase in fossil fuel emissions has led to increase in carbon dioxide concentration between 0.5 and 1.3 parts ppm per year. This was the first evidence produced for the increase of green house gasses in the atmosphere that Callendar has estimated and Arrhenius had earlier speculated. Further 1960s witnessed a whole range of new technologies for measuring carbon dioxide which showed conclusively that manmade emissions are increasing the levels of carbon dioxide in the atmosphere.

Over the next decade, few scientists devised simple mathematical models of the climate, some tried to regain past temperatures by studying ancient pollens and

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[13] *The data collected at Mauna Loa is so far the longest continuous record of atmospheric carbon dioxide in the world and is considered very much authentic.*

fossil shells and turned up feedbacks that could make the system surprisingly variable. It appeared that severe climate change could happen, and in the past had happened. This finding was reinforced by computer models of the general circulation of the atmosphere, to predict the weather. Initially it was used for short-range weather forecasting of the global climate atmosphere with which climate change could be simulated. Syukuro Manabe along with Richard Wetherald, in 1975, conducted the first model experiment. The model computed a climate sensitivity of 2.9 degree Celsius. Their model also allowed them to determine, for the first time, the vertical and latitudinal inclines of the air temperature response to the doubling of carbon dioxide. Moreover, by the late 1970s global temperatures had begun to rise again and many climate scientists were convinced that the rise was likely to continue as greenhouse gases accumulated more and more.

One unexpected discovery was witnessed in the 1980s; the rise in level of gases which further accelerated the problem of global warming. These gasses degraded the atmosphere's protective ozone layer, and it added worries about the fragility of the atmosphere. The revelation of the hole in the Antarctic ozone layer by the British geophysicist Joe Farmam in 1985 was the beginning of such discoveries. It was the first time that there was a change in the ozone levels since the measurements began in 1926. A new concept of climate change was developed by an American oceanographer Wallace S. Broeker in 1987. As against the general notion that climate change is a slow process, he introduced the concept of abrupt climate change which might be caused due to the rapid changes in the concentration of anthropogenic gasses in the atmosphere. Finally in 1988, James Hansen made one of the first assessments that human-caused warming had already measurably affected global climate.

Earlier scientists had sought a single master-key to climate, but now they were coming to understand that climate is an intricate system responding to a great many influences.

Volcanic eruptions and solar variations were the possible causes of change, and can they swamp any effects of human activities. Even subtle changes in the Earth's orbit could make a difference. Surprisingly, studies of ancient climates showed that astronomical cycles had predicted regarding the time of the ice age. The whole climate system was so delicately balanced that almost any small perturbation might set off a great shift. The new "chaos" theories, predicted that in such delicate systems a shift might even come all by itself and suddenly. The highly sophisticated computer models began to suggest how such jump could possibly happen and the experts started predicting droughts, storms, tsunamis, and other such disasters. However, the modelers had to make many arbitrary assumptions about clouds, etc., and reputable scientists disputed the authenticity of such results.

V. The Aftermath

In the early 1970s, the rise of environmentalism raised public doubts about the benefits of human activity for the planet. Curiosity about climate turned into apprehensions in the summer of 1988, the hottest year record till then. Along with the greenhouse effect, some scientists pointed out that human activity was putting dust and smog particles into the atmosphere, where they could block sunlight and cool the world. Moreover, analysis of Northern Hemisphere weather statistics showed that a cooling trend had begun in the 1940s. This lead further lead to more confusion that is whether there will be floods in the coastal areas due to the melting of ice caps or a new disastrous ice age. The only thing most scientists had general consensus was that much more research was needed to understand the climate system more appropriately. This led to acceleration of research activity on climate which included collection of data.

The very first United Nations Conference on the Environment was held in Stockholm in 1972 which aimed at addressing the international environment issue. This conference provided a fillip to the development of international environment politics. Following which on 1979 the World Climate Conference of the World Meteorological Organization concluded that "it appears plausible that an increased amount of carbon dioxide in the atmosphere can contribute to a gradual warming of the lower atmosphere, especially at the higher latitudes......it is possible that some effects on a regional and global scale may be detectable before the end of this century and become significant before the middle of the next century".

By the mid-to-late 1980s, the dominant scientific opinion had settled firmly on the prediction of the future warming. In 1985 a joint United Nation's Environment Programme/World Meteorological Organisation/ICSU conference on the "Assessment of the Role of Carbon Dioxide and Other Greenhouse Gasses in Climate Variations and Associated Impacts" assessed the role of carbon dioxide and aerosols in the atmosphere, and concluded that greenhouse gasses "are expected" to cause significant warning in the next century and that some warming is inevitable. Meanwhile, in 1988, the World Meteorological Organization along with the support of the United Nation's Environment Programme established the Intergovernmental Panel on Climate Change in order to get the most reliable possible advice, as negotiated among thousands of climate experts and officials. It helped to understand the potential environment and socio-economic consequences of the change in climate and it has so far successfully issued four assessment reports on various dimensions relating to climate change in 1990, 1996, 2001, and 2007.

The First Assessment Report of the IPCC (1990), as well as a supplemental report prepared in 1992, makes it certain that the emissions resulting from human activities are substantially increasing the atmospheric concentrations of the greenhouse gases, which is resulting in an additional warming of the Earth's surface and carbon dioxide is the root cause of the warming. They predict that under business as usual scenario, there will be an increase of global mean temperature during the 21st century of about 0.3 degree Celsius per decade and that that global mean surface air temperature has increased by 0.3 to 0.6 degree Celsius over the last 100 years. It supported the establishment of the United Nations Framework Convention on Climate Change (UNFCCC) at the United Nations Conference on Environment and Development (UNCED, commonly known as "*The Earth Summit*" held in Rio de Janeiro, Brazil, in May, 1992. The UNFCCC treaty, which the United States has signed, serves as the foundation of international political efforts to combat global warming. It aimed to stabilize the atmospheric green houses gases so that the eco-system can adapt naturally to climate change, to ensure that the food production is not threatened and to enable economic development to proceed in a sustainable manner.

In the meanwhile, the first Conference of the Parties (COP) to the Climate Convention, held in Berlin, Germany, in 1995, where the *Berlin Mandate* was produced. Various terms was put forth for a negotiation process that would produce binding commitments by industrial countries to reduce their heat-trapping emissions after the year 2000. The following year witness the release of the Second Assessment Report of IPCC in 1996 which stated that "the balance of evidence suggests that there is a discernible human influence in global climate" and is expected to continue in future. The greenhouse gas concentrations have continued to increase and that anthropogenic aerosols tend to produce negative radiative forcing. This report provided key input to the negotiations that led to the adoption of the Kyoto Protocol by the UNFCCC on 11th December, 1997 but the Kyoto Protocol came into force on 2005, when 55 countries, responsible for over 55% of emissions by the world's industrialized nations, ratified the agreement. It aimed in establishing a binding target for reducing the heat-trapping emissions of developed countries especially for 37 industrialized countries and European community. The targets set for the individual industrial countries during the *first commitment period* that is 2008-12 is 5.2 per cent below their aggregate 1990 emissions. It also sets up a global market for carbon credit and provides mechanisms for the developed countries to acquire greenhouse gas reduction credits from activities outside their own boundaries at relatively lesser costs. The Clean Development Mechanism is one of the flexible arrangements under the Kyoto Protocol. At present there are 161 parties in the Kyoto Protocol.

The Third Assessment Report of IPCC was released in 2001, which concluded that temperature increases over the twenty-first century could be significantly larger than previously thought (by about 0.6 degree Celsius), and that the evidence for human influence on climate change is stronger than ever. While, the Fourth Assessment Report in 2007, states that green house gas emissions resulting in global warming are primarily the result of the use of fossil fuels, changes in land use, and agriculture and further there is a likelihood of "irreversible" impacts (like frequent coral bleaching events and widespread mortality, increase in droughts, heat waves and floods, loss of glaciers or ice sheets from the Antarctic or Greenland, etc.). Thus, there is growing concern that any benefits linked with climate change will be gone after more modest temperature rises.

Apart from the release of the Fourth Assessment Report by the IPCC, the year 2007, also witnessed two important landmarks- the Bali climate change conference and the first commitment period of the Kyoto Protocol was about to begin. The major outcome of the Bali conference was to determine a process the greenhouse gas reduction commitments of industrialized countries under Kyoto Protocol beyond 2012 and to address the four major building blocks of climate change that is GHG mitigation, adaptation to climate change impacts, technology development and co-operation, and finally finance.

The first target period contained in the Kyoto Protocol will end in 2012. Negotiations are now under way on future climate policy, but views are still far apart. Disagreements are likely to center on areas such as how to define obligations, whether they should limit emissions, what measures will be required, and who should be obliged to do what?

VI. Climate Change and India

India's has its own story to say. Starting from the Indus civilization to the present world India has witnessed a plethora of incidents that has destroyed its civilizations due to the change of climate. Much importance was given to the conservation and protection of its natural resources right from the very beginning. The rulers of India rarely intervened in the forests and whenever they did so was mainly to possess valuable animals like elephant (Rangarajan, 2009). The *"Arthashastra" by* Kautilya, is a classical example, written between 321 and 300 BC, contained provisions meant to regulate a number of aspects related to the environment and forests. It was only after the intrusion of the British that disequilibrium of the nature and human being started arising. The British government started to control the forest in the year 1806 when a commission was appointed to enquire about the availability of Teak in Malabar and Travancore. Subsequently, many acts were passed during the colonial rule like the Indian Forest Act of 1865; Elephant Preservation Act of 1879, etc. in order to have an upper hand over the forest in India and to exploit them. Other act like the Bombay Shore Nuisance Act of 1853; the Poison Act of 1908, etc were undertaken to control air and water pollution. These laws had several flaws in them and most of them showed their capability on papers and not in reality.

After the Independence, India was the first country to amend its Constitution to give the state governments the power to protect and improve their environment. The Government of India has formed the National Commission on Environmental Planning (NCEP) in the year 1972 in the Department of Science and Technology which was regarded as an apex body concerning all environmental matters. Its main responsibility was to plan and co-ordinate the activities of various ministries and agencies dealing with environmental matters.

The 42nd Amendment was adopted in 1976, and came into effect in January 1977. The Department of Environment was created in 1980 and became the MoEF (Ministry of Environment and Forests) in 1985.

One of the prominent movements in India was the Chipko Movement which comes from the Hindi word "embrace" and was notably successful during 1973 and 1980. This movement was undertaken to stop the encroachment of land for industrialization and to protect the traditional land uses and cultural practices. This action took place in April 1973 in Mandal village in Uttar Pradesh with the help of a local NGO; the local women went into the forest and formed a human chain around the trees, preventing the men from cutting them down. The success achieved by this act led to similar protests in other parts of the country and due to this, in 1980, a 15-year ban was imposed on tree felling in the Himalayan forests of that state by the order of, the then prime minister Mrs Indira Gandhi.

In India, we saw the first major step taken regarding the cause was when parliament enacted the Wildlife Protection Act in 1972 to combat deforestation. This act was designed to bring several major forests of national importance into an integrated scheme for the protection of the trees and plant life an integrated schemes for the protection of the trees and plant life of the forest as well as the various species of animals inhabiting the forest. There followed a series of legal enactments by Parliament in the next fourteen years relating to pollution of air, water and other environmental resources, ultimately culminating in the more comprehensive Environment (Protection) Act in 1986. India has other acts like the Factories Act of 1948; Motor Vehicles Act of 1988; National Environmental Tribunal Act 1995, etc. to control hazardous pollutants.

The government of India recently launched its National Action Plan on Climate Change, outlining the details of its commitment towards fighting climate change. The Action Plan incorporates eight guiding missions: solar energy development, enhanced energy efficiency, sustainable habitats, water conservation, sustaining the Himalayan ecosystem, developing a 'green' India, sustainable agriculture and building a strategic knowledge platform on climate change.

VII. Summary and Conclusion

Understanding the story of climate change will help us to further inquire about the basic problems connected with it. The various causes associated with the change in climate will give us a platform to mitigate the underlying causes. It will further give us a clear picture regarding its effects on the civilization and mankind. In the following chapter we will discuss about Maize (Zea mays.) and how it is affected due to the change in climate in India. As mentioned in the chapter earlier, there has been strong evidence regarding the decline in agricultural production in the past due to the change in climate. Therefore, it is necessary to investigate further into this area in order to understand its impact and the role of the government in policy making.

3

Change in Climate: A Spectral Analysis

Having read about the historical background of climate change, it will be very interesting to see whether there is any change in the climate in India. In this chapter we will examine various parameters of climate change using two approaches- traditional and modern to understand the behaviour of climate change in all the States of India.

This chapter is divided into four sections. The First section, discusses the two major components of climate that is temperature and precipitation in the traditional framework. The second section contains climatic index of various States and the ranking of States and Union Territories. In the third section we analyze the climate by components using spectral method. This section also deals with the conversion of time series into a stationary series. Finally in fourth we have the chapter's summary and conclusion.

I. Climatic Factors: Temperature and Precipitation

The year 1998 was the warmest year and was declared as the disaster year due to occurrence of various natural disasters. The year witnessed hurricane havoc in Central America and floods in China, India and Bangladesh. U.S.A suffered heavily due to ice-storms in January while Turkey, Argentina and Paraguay with floods in June 1998. In contrast, huge crop losses were noticed in Maharashtra (India) due to poor distribution of rainfall during 1997-98. The 1997/1998 El Nino[14] event was the strongest of the last century which affected 110 million

[14] *It means "the boy" or "the small one. It was named by Roman Catholic Peruvian Fisherman in the nineteenth century to a warm coastal current that appeared sporadically along the shores of Ecuador and Peru. It is an abnormal warming of surface ocean waters which has its own severe impacts like droughts and floods.*

people and it cost nearly US$ 100 billion to the global economy. Due to heavy rainfall over Mumbai on 26th July, 2005[15] and 3rd September, 2005 over Bangalore; severe tropical storms in Andhra Pradesh in September; floods in Kerala, Karnataka, Maharashtra, Gujarat, Orissa and Himachal Pradesh during the Southwest monsoon[16], 2005 in India devastated cropped area to a large extent in addition to losses of thousands of human lives

The southwest monsoon contributes significantly to the annual total amount of rain received by India. Except for Jammu and Kashmir, Bay islands, coastal Andhra Pradesh, Rayalaseema and Tamil Nadu, 60-95 per cent of the annual rainfall over various sub-divisions of the country occurs during the southwest monsoon season (Handbook of Agriculture, 2006). It enters India through the gates of Kerala, around 1st June. A large part of the country receives on an average rainfall less than 1000 mm per annum. The normal annual rainfall over the plains of India is 1170 mm which is not sufficient for a country like India. The least rainfall range of less than 500 mm occurs in western Rajasthan, Saurasthra and Kutch and Ladakh region of Jammu and Kashmir. Theses regions constitute the main arid zones of India. The retreating of southwest monsoon is called the northwest monsoon and it is confined only to Tamil Nadu and Kerala after 15th November.

Both temperature and rainfall plays an important role in the shaping of an economy. India's maximum temperatures are quiet high in March, April and May over northern Deccan and central parts of India. Later in June, the highest values shift northwards and northwestwards. The Southwest monsoon brings some relief in July and August, and there is a decline in the maximum temperature during these months as compared to the summer temperatures. However, parts of Tamil Nadu still experience high maximum temperature. The

[15] *A record of highest single-day rainfall of 944 mm was witnessed in India.*
[16] *Southwest monsoon sets in between June to September.*

climate projections over India indicate that temperature rise is likely to be around 3 degree Celsius and rainfall increase is expected by 10-20 per cent over Central part of India by the end of this century (CRIDA, 2008). The occurrence of extreme climatic hazards like tsunami[17], cyclone Laila, etc are still fresh in our minds and it hardly matters that whether the projections mentioned above would become real or not.

The climatic conditions in India have witnessed very erratic change over the past few decades. Therefore, in order to understand the climatic change, we construct an index and examined the same with spectral method. The former is called traditional and the latter is called modern.

II. The Traditional Approach: Climate Change Index

An index is constructed using six climatic variables namely average temperature, maximum and minimum temperature, diurnal temperature[18], wet-day frequency[19] and precipitation of all the states across India. The monthly data collected from www.indiawaterportal.com is averaged and converted into annually. The standard minimum and maximum index is taken into consideration in order to see whether there is any significant change in the climate system. Let *Max* and *Min* denote the maximum and minimum values of indicator *i* respectively and *X* is the own values for the respective indicator. Then, the index for indicator *i* for the time period t_1, t_2....... t_6 is given by

$$I_i = \frac{Max_i - X_i}{Max_i - Min_i}$$

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[17] *It hit the East and West coasts of India along with Indonesia on 26th December, 2004.*

[18] *It refers to the variation of temperature that is the difference between the maximum temperature during the day and the minimum temperature during night.*

[19] *It refers to the average annual number of wet days.*

The overall index is then simply the average of the various climatic factors of the six indicators and is defined as

$$\frac{1}{6}\sum_{n=1}^{6} I_i$$

The values are expressed in the Table 3.1, illustrates the climate index of Indian States for six time periods 1950s, 1960s, 1970s, 1980s, 1990s and 2000. Though the variation among the States showed not much difference but there is an interesting twist in the story, in the 1960s as indicated by the variation in almost every state. States like Delhi, Gujarat, Haryana, Punjab, Rajasthan, Tripura and Uttar Pradesh showed a dip in the 1960s. The possible reason behind this can be that these years witnessed the occurrences of El Nino and droughts in the year 1965, 1966, and 1968. Whereas, Kerala was stable through out and maintained its position.

The latter period of 1970s showed more or less same variations. Except Tamil Nadu, Rajasthan, Karnataka, Assam and Andhra Pradesh has gradually decreased over time. Further States like Delhi, Gujarat, Haryana, Kerala, Madhya Pradesh, Maharashtra, Orissa and Sikkim had showed a stable variation with respect to 1950s and 2000 (*See* Table 3.1).

Table 3.1: All India Climatic Index

	Levels					
State(s)	1950s	1960s	1970s	1980s	1990s	2000
Andhra Pradesh	0.60	0.50	0.62	0.64	0.63	0.65
Arunachal Pradesh	0.49	0.37	0.41	0.49	0.44	0.42
Assam	0.62	0.75	0.61	0.68	0.64	0.63
Bihar	0.63	0.48	0.63	0.61	0.58	0.57
Delhi	0.55	0.19	0.59	0.57	0.55	0.55
Gujarat	0.60	0.39	0.63	0.62	0.61	0.60
Haryana	0.56	0.33	0.60	0.57	0.54	0.56
Himachal Pradesh	0.43	0.24	0.41	0.43	0.40	0.37
Jammu & Kashmir	0.26	0.19	0.26	0.27	0.26	0.19
Karnataka	0.60	0.51	0.58	0.62	0.56	0.61
Kerala	0.71	0.76	0.65	0.70	0.67	0.71
Madhya Pradesh	0.63	0.47	0.57	0.65	0.67	0.63
Maharashtra	0.66	0.41	0.68	0.69	0.67	0.66
Manipur	0.56	0.50	0.48	0.59	0.52	0.50
Meghyalaya	0.74	0.52	0.63	0.66	0.69	0.71
Mizoram	0.74	0.61	0.63	0.72	0.70	0.67
Nagaland	0.50	0.39	0.34	0.49	0.43	0.42
Orissa	0.61	0.52	0.62	0.65	0.65	0.61
Punjab	0.58	0.29	0.61	0.59	0.55	0.56
Rajasthan	0.58	0.39	0.63	0.59	0.59	0.60
Sikkim	0.47	0.26	0.30	0.45	0.42	0.37
Tamil Nadu	0.57	0.53	0.57	0.57	0.58	0.61
Tripura	0.74	0.56	0.59	0.74	0.70	0.69
Uttar Pradesh	0.63	0.30	0.56	0.66	0.62	0.60
West Bengal	0.67	0.41	0.63	0.64	0.66	0.61

Source: www.indiawaterportal.com.

The ranking of the States according to the index is examined in Table 3.2. It is seen that though Tripura was rank 1st in 1950s, 1980s and 1990s, but it ranked 7th position in 1970s. Kerala was more or less stable, by securing a rank between 1 and 3 in all the six decades. Futher, the Table 3.2 highlights the very nature of climate and that there is a considerable amount of variation in all the states with respect to the environment indicators undertaken. Keeping in mind, the above results, it is interesting to see whether there is any significant change in the past five decades with respect to change in temperature and precipitation.

Table 3.2: Ranks of States by Climatic Index

	Rankings					
State(s)	**1950s**	**1960s**	**1970s**	**1980s**	**1990s**	**2000**
Andhra Pradesh	8	7	4	8	7	5
Arunachal Pradesh	14	12	12	13	16	13
Assam	6	2	5	5	6	6
Bihar	5	8	3	10	11	9
Delhi	12	18	7	12	13	11
Gujarat	8	11	3	9	9	8
Haryana	11	13	6	12	14	10
Himachal Pradesh	16	17	12	15	19	14
Jammu & Kashmir	17	18	15	16	20	15
Karnataka	8	6	8	9	12	7
Kerala	2	1	2	3	3	1
Madhya Pradesh	5	9	9	7	3	6
Maharashtra	4	10	1	4	3	4
Manipur	11	7	11	11	15	12
Meghyalaya	1	5	3	6	2	1
Mizoram	1	3	3	2	1	3
Nagaland	13	11	13	13	17	13
Orissa	7	5	4	7	5	7
Punjab	9	15	5	11	13	10
Rajasthan	9	11	3	11	10	8
Sikkim	15	16	14	14	18	14
Tamil Nadu	10	5	9	12	11	7
Tripura	1	4	7	1	1	2
Uttar Pradesh	5	14	10	6	8	8
West Bengal	3	10	3	8	4	7

Source: *www.indiawaterportal.com.*

The Table 3.3 is divided into two parts - one shows the percentage change in temperature and the other shows the percentage change in precipitation over the period of fifty years. Jammu and Kashmir has witnessed a maximum change of

12.5 per cent over the last five decades in terms of temperature followed by Himachal Pradesh (7 per cent), Rajasthan (5.2 per cent), Punjab (4.1 percent) and Haryana (4 per cent). These are the top five states which have seen a high increase of per cent change in terms of temperature. Tripura on the other hand shows a negative change, which means that there has been a decline in the temperature with respect to 1950s. Interestingly, almost all the states have showed an increase in the percentage change of temperature over the years except for Tripura.

The results of precipitation in India shows quiet an interesting result. States like Tamil Nadu and Andhra Pradesh observes quiet high percentage change in precipitation over the years with 34.85 per cent and 30.47 per cent respectively. Apart from these States there has been a negative change in almost all the States except for Kerala (16.24 per cent), Orissa (15 per cent), Assam (4.30 per cent) and Arunachal Pradesh (2.68 per cent). Interestingly, States like Tripura shows a negative percentage change as compared to 1950s. Whereas, Jammu and Kashmir shows a very bad state, it has observed the maximum change in temperature and a minimum change in precipitation (-54.42 per cent). There has been a decline in the precipitation to the tune of 54.42 per cent in Jammu and Kashmir which is not a very ideal situation. In other words we can say that Jammu and Kashmir has the potential to be affected more due to the change in climate. Let us now examine the climate using spectral analysis.

Table 3.3: Percentage Change of Temperature and Precipitation by States and Union Territories

States	%change in 60s over 50s		%change in 70s over 60s		%change in 80s over 70s		%change in 90s over 80s		%change in 2000s over 90s		%change in 2000s over 50s	
	T	P	T	P	T	P	T	P	T	P	T	P
A.P	2.35	3.5	-1.06	18.2	3.16	-13.2	-1.87	1.16	24.1	3.71	-1	30.5
Ar P	3.53	-14.6	-3.98	30.5	1.87	-3.5	-0.05	0.78	5.3	2.01	-9.3	2.7
Asm	3.86	-3.1	-3.88	24.9	1.27	-18.2	-0.26	0.95	14.3	1.79	-7.9	4.3
Bhr	2.84	-10.4	-1.76	23.9	0.56	-13.9	-0.59	1.8	7.8	2.81	-35.7	-33.7
Dli	3.45	-22.9	0.28	-3.8	1.24	7.6	-2.02	0.8	22.7	3.73	-17.5	-19.3
Guj	1.86	-32.6	0.3	85.2	1.64	-25.6	-1.05	0.88	15.1	3.67	-31.4	-26.6
Hra	3.64	-37.4	0.16	6.4	-0.67	38	-1.25	2.13	-0.5	3.99	-22.4	-29
H.P	5.83	-36.1	0.07	-25.4	-2.65	117.5	-0.1	3.91	-8.2	7.01	-40.9	-43.8
J&K	6.57	-42.4	4.45	-23.7	-3.45	87.6	1.27	3.32	12.3	12.46	-50.8	-54.4
Kta	2.24	-16.3	-0.77	7.2	1.62	5	-0.79	0.73	-21.4	3.03	31.9	-2.4
	-											
Krl	1.89	19.6	1.88	-0.4	0.18	-8	2.83	-0.02	-8.2	2.94	15.6	16.2
M.P	1.93	21.3	-0.08	8.9	1.38	-20.6	-1.51	1.95	46.5	3.68	-43.3	-12.8
Mha	1.26	13.9	-0.29	21.3	2.25	-22.7	-2.73	1.8	24.8	2.23	-28.1	-4.1
Map	2.2	-0.1	-1.6	-2.6	1.66	2.5	-1.12	0.3	0.1	1.4	-6.5	-6.7
Meg	3.03	-3.8	-3.42	51.5	1.23	-56.7	-1.14	2.29	76.8	1.86	-4.9	6.1
	-											
Miz	0.03	-3.6	0.75	21.8	1.23	-21.9	-0.2	-1.57	13.7	0.16	-7.5	-3.6
Nld	4.53	-8.6	-4.5	10.9	2.12	-4.3	-0.46	0.78	5.8	2.27	-12.5	-10.2
Ors	2.16	23.6	-1.16	3.5	1.05	10	-1.39	2.02	22.3	2.65	-33.2	15
Pb	4.14	-56	0.2	7.1	-1.45	118.7	-1.7	2.99	-12.4	4.11	-37	-43.1
Rj	2.58	-19.1	0.44	47.2	0.97	-31.5	-1.09	2.23	41.6	5.19	-35.2	-25.1
Skm	2.11	-10.7	-1.75	8	1.56	11.7	0.76	-0.43	3.6	2.22	-18	-8.4
T. N	0.82	20.9	-0.26	3.2	1.24	-19.3	1.31	-0.23	14.1	2.91	17.4	34.9
Tri	0.42	7.7	-0.47	-12.9	0.61	7.6	0.45	-1.15	-3.6	-0.14	-0.1	-2.8
U.P	2.91	8.6	-1.18	7.3	0.03	11.4	-0.37	1.91	-14.4	3.27	-37	-30
W.B	1.66	-4.2	-1.37	16.2	0.01	-8.7	0.31	0.72	34.1	1.31	-35.1	-11.5

Source: www. indiawaterportal.com.

Note: T= Temperature; P=Precipitation; A.P= Andhra Pradesh; Ar P= Arunachal Pradesh; Asm= Assam; Bhr=Bihar and Jharkhand ; Dli= Delhi; Guj= Gujarat; Hra= Haryana; H.P= Himachal Pradesh; J&K= Jammu and Kashmir; Kta= Karnataka; Krl= Kerala; Map= Manipur; Meg= Meghalaya; Miz= Mizorum; Nld= Nagaland; M.P= Madhya Pradesh and Chattisgarh; Mha= Maharashtra; Pb=Punjab; Rj= Rajasthan; T.N= Tamil Nadu; UP= Uttar Pradesh and Uttarakhand; and W.B= West Benga.l

III. Spectral Analysis

In this section we will use the spectral analysis, a modern approach to understand the issues at hand. Spectral analysis is concerned with the analysis of stationary time series in the frequency domain.

The overall behavior of time series may be decomposed in three main parts: long, medium and short run behavior. These three parts are respectively associated with slowly evolving secular movements (the trend), a faster oscillating part (the cycles) and a rapidly varying, often irregular, component (the seasonality). The study undertakes annual data, of temperature and precipitation for a period of 53 years. Therefore, seasonal fluctuations are not an important component in this study. Three important aspects of our time series is taken into consideration that is - trend, cyclic components, and a set of residuals free from the trends and cycles, for spectral density analysis. To obtain the spectral density, time series should be stationary (Warner, 1998). Meteorological time series are almost never stationary, primarily because of the pronounced diurnal and annual variations of the physical processes generating the variables. Therefore, the meteorological time series data are made stationary, as discussed below.

III. a. Trends in Climatic Factors: Long-run Analysis

Trend is the most common form of non-stationarity. Many economic time series are so dominated by trend that any attempt to detect other regularities like cyclical fluctuations can be more misleading than helpful until we have a safe way of dealing with the trend. A trend line represents the long-term movement in time series data after other components have been accounted for. It tells whether a particular data set have increased or decreased over the period of time.

Table 3.4: Trend Analysis of Temperature by States/Union Territories

State(s)	Temperature			
	No. Of Observations	R Square	F	P Values
Andhra Pradesh	53	.490	48.923	.000
Arunachal Pradesh	53	.129	7.528	.008
Assam	53	.429	12.294	.005
Bihar	53	.274	6.164	.001*
Chattisgarh	53	.087	4.871	.032
Gujarat	53	.203	13.006	.001
Haryana	53	.149	2.863	.046*
Himachal Pradesh	53	.342	8.505	.000*
Jammu and Kashmir	53	.088	4.934	.031
Jharkhand	53	.155	2.986	.040*
Karnataka	53	.523	55.897	.000
Kerala	53	.385	31.977	.000
Madhya Pradesh	53	.140	8.302	.006
Maharashtra	53	.125	7.297	.009
Manipur	53	.213	13.837	.000
Meghalaya	53	.093	5.253	.026
Mizoram	53	.226	14.890	.000
Nagaland	53	.185	11.569	.001
Orissa	53	.009	.448	.506
Punjab	53	.259	5.700	.002*
Rajasthan	53	.148	2.841	.047*
Sikkim	53	.094	5.267	.026
Tamil Nadu	53	.574	68.780	.000
Tripura	53	.142	8.451	.005
Uttar Pradesh	53	.152	9.115	.004
Uttarakhand	53	.128	3.684	.032*
West Bengal	53	.024	1.272	.265
Chandigarh (UT)	53	.321	1.027	.000*
Dadar and Nagar Haveli (UT)	53	.004	.182	.672
Delhi (UT)	53	.001	.070	.792
Puducherry (UT)	53	.578	69.733	.000
All India	53	.156	9.455	.003

Source: www.indiawaterportal.com

Table 3.4, gives us the R^2, F statistic and probability values of temperature for State/ Union Territories, as well as for all India. The R^2 square describes what fraction of the variance of the data is explained by the fitted trend line, the F values and the P values help us to know the significance of the trend. The thumb rule is taken into consideration, that is, if the P value is less than 0.05, then the trend is significant or else it is not. It is quite evident that in all most all the State there is a visible significant linear trend except for Orissa and West Bengal and the Union Territories of Dadar and Nagar Haveli and Delhi. There is a presence of linear trend in case of over all India and the R square in the table shows that the linear trend accounts for 16 per cent variance.

Table 3.5, describes the values of R^2, F statistic and probability values of precipitation with respect to the State/Union Territories as well as the value of whole India. The statistical rule is that if the P value of the regression equation is less than 0.05, then the trend is significant, otherwise not. By this rule, only one-third of the States/Union Territories shows the presence of any significant linear trend. Therefore, the time series of such States are detrended for cyclical analysis. In case of the rest, the original series is used for the cyclical analysis. The all India data also shows a significant linear trend with 10 per cent variance. The trend is detrended by differencing the series, the standard approach of econometricians. The series is differenced and the differenced series is then used for cycle analysis. It may be noted that the series is differenced only if the trend is significant. The differenced series have only 52 observations. Let us examine the trend free series for cyclical behavior.

Table 3.5: Trend Analysis of Precipitation by States/Union Territories

State(s)	Precipitation			
	No. Of Observations	R Square	F	P Values
Andhra Pradesh	53	.005	.258	.614
Arunachal Pradesh	53	.000	.025	.875
Assam	53	.012	.596	.444
Bihar	53	.157	9.475	.003
Chattisgarh	53	.117	3.312	.045*
Gujarat	53	.015	.786	.379
Haryana	53	.000	.014	.906
Himachal Pradesh	53	.001	.043	.837
Jammu and Kashmir	53	.001	.056	.813
Jharkhand	53	.029	1.503	.226
Karnataka	53	.092	5.196	.027
Kerala	53	.003	.156	.694
Madhya Pradesh	53	.072	3.936	.053
Maharashtra	53	.034	1.814	.184
Manipur	53	.186	11.641	.001
Meghalaya	53	.004	.185	.669
Mizoram	53	.117	3.325	.044*
Nagaland	53	.122	7.085	.010
Orissa	53	.002	.079	.780
Punjab	53	.004	.195	.661
Rajasthan	53	.030	1.586	.214
Sikkim	53	.161	3.142	.033*
Tamil Nadu	53	.004	.215	.645
Tripura	53	.139	8.219	.006
Uttar Pradesh	53	.152	9.115	.004
Uttarakhand	53	.128	3.684	.032*
West Bengal	53	.024	1.272	.265
Chandigarh (UT)	53	.000	.014	.905
Dadar and Nagar Haveli (UT)	53	.004	.182	.672
Delhi (UT)	53	.000	.000	.986
Puducherry (UT)	53	.044	2.350	.131
All India	53	.096	5.417	.024

Source: www.indiawaterportal.com.

III. b. Cycle Analysis: Short-run Analysis

After removing the trend from the time series, we have examined the series for cyclic patterns using periodogram analysis. Periodogram is the analysis of variance by frequencies. In other words it gives us the percentage of variance that is explained by the frequencies. It helps us to learn as to what percentage of the remaining variance in the time series is due to cycles, as well as to determine whether there is any other cyclical pattern in the data. The graphs of the periodogram analysis are given in the appendix A3.1 and A3.2 of this chapter.

For N of 52 observations (sine the first order difference is taken, in order to remove trend from the series), the Fourier frequencies consist of the following set of equally spaced frequencies: 1/52, 2/52,3/52........1/2 (these frequencies are expressed in number of cycles per observation). The corresponding cycles (with cycle length expressed as number of observations) would be 52, 26, 17.33...2 observations long. Because there were N=52 observations in the time series, a set of 26 (N/2) frequencies is basis for the periodogram and the spectrum. If the "white noise" null hypothesis were true we would expect each of these 26 periodic components to account for approximately 1/26, or 0.038, of the overall variance of the time series. We then estimate the periodogram intensity which is the percentage of the periodogram component as a percent to the total variance (see appendix A3.1 and A3.2 for the graphs). Thereafter, we assess the statistical significance of the peaks by using Fisher test (Warner, 1998). If the test confirms the presence of cycles in the series then we remove the cycle from the series before applying the cross- spectral analysis.

III. c. Fisher Test for Cyclical Significance

Fisher test is undertaken to see whether any cyclical components in the series are significant or not (Warner, 1998). In order to do the Fisher test, we have to first look for the largest peak in the periodogram and spectrum that corresponds to the frequencies explaining a large proportion of the variance in the time series. Then, each periodogram estimate was divided by the sum total of all the values of periodogram estimates. The peaks are then tested, for there significance[20].On the other hand in the periodogram analysis, if the peaks are non significant, we can directly go for cross-spectral analysis or else we check out the spectral density and if it is significant remove the cyclical fluctuations from the time series data. In some cases linear trend or spikes (outliers) produce the artifactual peaks in the periodogram, and so each of these patterns should be removed from the time series data before doing periodogram analysis.

The largest values of the proportion that is, the proportion of variance that is explained by the first, second, third, fourth and fifth largest periodogram ordinates are selected. These values are then compared with the critical values, that is, if the proportion of variance of the largest peaks mentioned above is more than the critical value at $\alpha=0.05$, then the peak is significant. We have to adjust for cyclic components that were identified by the periodogram analysis and remove the very cyclical components. This is adjusted in the following way. First we estimate the harmonic function and then the estimated harmonic variables are subtracted from the series. It involves the creation of two predictor variables: on time series represents the cosine of the period, and another that represents a sin of the period. Thus, two sinusoidal functions were generated using the periodogram results and plotted against the original time series data. The new variable formed is computed by the following equation

$$C= A \cos (2\pi t/ \text{Peak Period}) + B \sin (2\pi t/\text{Peak Period})$$

Where, A and B are the coefficients that are applied to the cosine and sine function in the discrete Fourier transform or the periodogram analysis. The values of the new component were then added to the mean of the original time

[20] *If the percentage of variance explained by the cyclical components are higher than the tabled value, then we can conclude that the corresponding peak is significant at $\alpha=0.05$ or not.*

series to adjust the level so that it would be the same as the original time series. These new variables are then plotted super imposed on the original time series in order to see that whether there is any cyclic component. Visual inspection will further help us to understand whether the original series contains cycles and whether it is reasonably well defined by the sinusoids. If there is a vivid presence of cycle and it is well defined by the sinusoids then it means the presence of cycle that can affect the series and it has to be removed for further analysis of cross-spectral. This can be done by subtracting the new values of new variable from the original stationary series. As our series is based on annual data the remaining part of the series will only contain the residuals which are white noise and can be used for further analysis (See appendix A3.3 and A3.4 for details).

The Table 3.6 explains the Fisher test undertaken for the study. The Fisher test was used to test the statistical significance (α=.05) of these peaks. The peaks which were judged to be statistically significant are those peaks which have exceeded the critical value and vice-versa. All the graphs with significant peaks, resulting from the test are given in the appendix of this chapter. States like Arunachal Pradesh (1st and 2nd peaks), Assam (3rd and 4th peaks), Himachal Pradesh (3rd peak), Jammu and Kashmir (4th peak), Manipur (1st peak), Mizoram (1st peak), Nagaland (2nd and 3rd peak), Tripura (3rd and 5th), Uttarakhand (2nd, 3rd and 4th peak) and West Bengal (1st peak) shows a significant result in case of temperature, which means that there is a presence of cyclic component which affects the time series. States like Andhra Pradesh (2nd and 3rd peak), Bihar (5th Peak), Karnataka (1st Peak) and Meghalaya (2nd Peak) shows a significant result in case of precipitation.

Table 3.6: Fisher's Significance Test of All the States for Temperature and Precipitation

State(s)	Significance	
	Temperature	Precipitation
Andhra Pradesh	NSig	Sig
Arunachal Pradesh	Sig	NSig
Assam	Sig	Nsig
Bihar	Nsig	Sig
Chattisgarh	Nsig	Nsig
Gujarat	NSig	NSig
Haryana	Nsig	Nsig
Himachal Pradesh	Sig	Nsig
Jammu and Kashmir	Sig	Nsig
Jharkhand	Nsig	Nsig
Karnataka	Nsig	Sig
Kerala	Nsig	Nsig
Madhya Pradesh	Nsig	NSig
Maharashtra	Nsig	NSig
Manipur	Sig	Nsig
Meghalaya	Nsig	Sig
Mizoram	Sig	NSig
Nagaland	Sig	Nsig
Orissa	NSig	NSig
Punjab	Nsig	NSig
Rajasthan	NSig	NSig
Sikkim	Nsig	Nsig
Tamil Nadu	Nsig	Nsig
Tripura	Sig	Nsig
Uttar Pradesh	Nsig	Nsig
Uttarakhand	Sig	NSig
West Bengal	Sig	NSig
Chandigarh (UT)	Nsig	NSig
Dadar and Nagar Haveli (UT)	Nsig	Nsig
Delhi (UT)	Nsig	Nsig
Puducherry (UT)	Nsig	Nsig
All India	**NSig**	**Sig**

Note: Sig= Significant and Nsig= Non-significant
***Source:* www.indiawaterportal.com**

Interestingly, most of the States show a very different picture in both the climatic variables that is both temperature and precipitation associated with States and Union Territories do not show any significant cyclical component in the series. It is well known that there are cyclic fluctuations in the meteorological variables which affect the series in the long run but the table above gives us quiet a different picture. When all the data are combined together to get the all India result, we find that in case of temperature, the series does not show any fluctuation. However, there is a significant fluctuation in case of all India precipitation series (1st peak), this quiet evident in our day-to day life. Thus, we have to remove the cycles from the series by using the harmonic analysis mentioned above. We have plotted both the original as well as the new series (combined mean of time series with the cycle) by superimposing the new series on the original time series[21]. Thus, by visual examination, especially Andhra Pradesh gives an interesting picture; the new series shows a smooth graph. It can be noted here that all the graphs shows the presence of a strong cycle, especially Arunachal Pradesh and Uttarakhand in case of temperature and Karnataka in case of precipitation, which is needed to be deducted from the series so that we will be able to do cross-spectral analysis among the two variables in the further chapters. The adjusted series for cycle became the data for spectral density estimation.

III.d. Spectral Density of Climatic Factors

The spectral density is plotted by smoothening the periodogram of the series. Various smoothing techniques[22] like Tukey-Hamming, Bartlet, Parzen, Tukey and Daniel were developed to convert the periodogram into power spectrum so that the sampling error can be reduced. The periodogram values are generally subjected to substantial random fluctuations, which results in many "chaotic" periodogram spikes. In that case, we want to find the frequencies with the greatest spectral densities, that is, the frequency regions, consisting of many adjacent frequencies that contribute most to the overall periodic behavior of the series. This can be accomplished by smoothing the periodogram values and in our study we have used the Daniel Window in order to smooth the periodogram.

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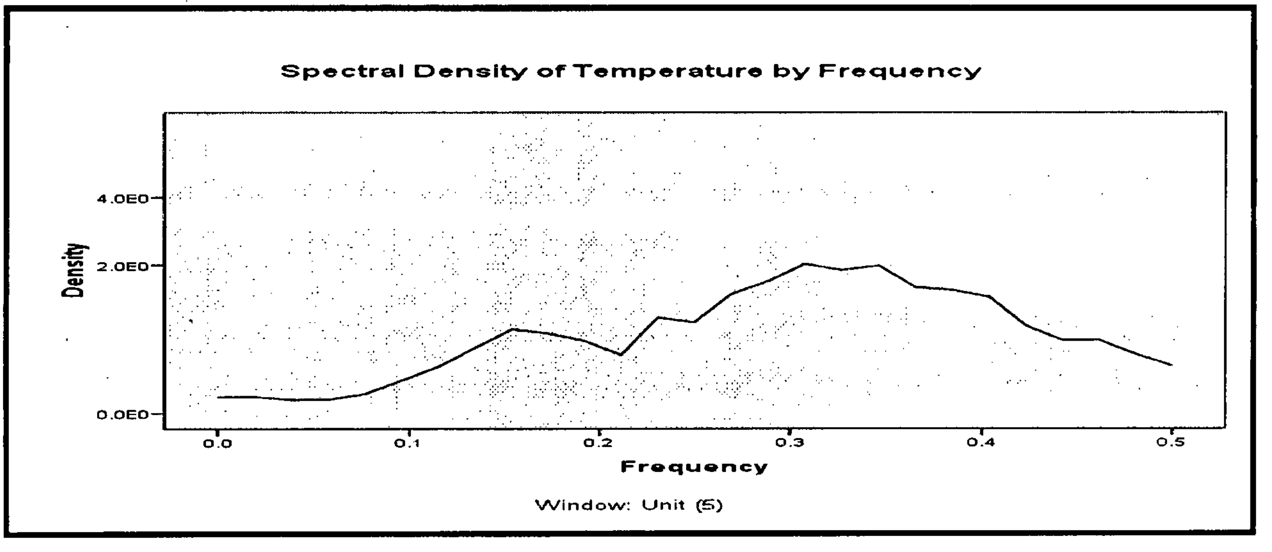
[21] *See the appendix (A 3.3 and A 3.4) of the chapter.*

[22] *This technique is employed both in time and in frequency domain to smoothen all abrupt variation and to minimize the spurious fluctuations generated every time a series is truncated. (Iacobucci, 2003.)*

Because for its simplicity and that it uses equal-weight window, we have used the Daniel Window. Further, if the power spectrum shows any cyclic components then we remove it from the series so that it becomes pre-whitened[23] for cross-spectral analysis.

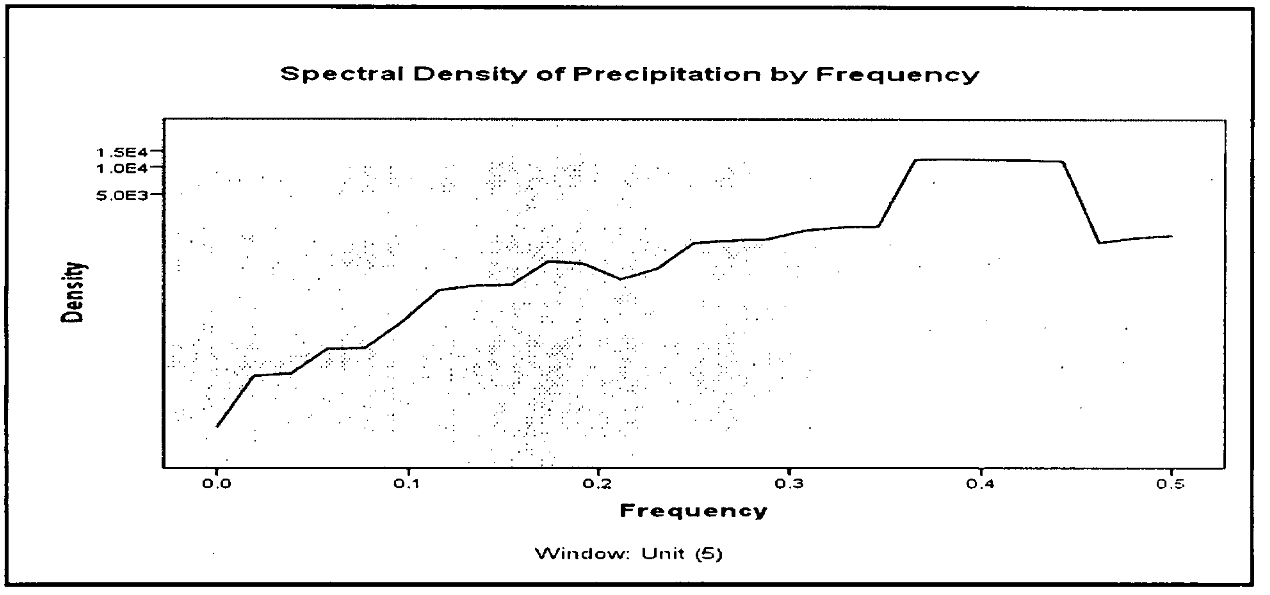
Spectral density graphs are continuous, sloping lines rather than series of vertical lines because they are continuous rather than discrete functions. The periodogram is smoothed in order to make the estimates more reliable. The advantage of using the power spectrum rather than the periodogram is that the spectrum may give a better or more reliable picture of the distribution of power (or variance accounted for) over the set of frequencies. It tells us where the average power is distributed as a function of frequency. It refers to the amount of power per unit (density) of frequency (spectral) as a function of the frequency. In other words it describes how the power (or variance) of a time series is distributed with frequency. All the spectral density figures are given in appendix A3.5 and A3.6. The density for all India is taken for illustrative purpose.

Figure 3.1: Spectral Density of Temperature, All India



[23] Removal of serial dependency from a time series.

Figure 3.2: Spectral Density of Precipitation, All India



We have plotted the spectral density of the all India temperature (Figure 3.1) and precipitation (Figure 3.2) after smoothing using a Daniel window of width 5. In the vertical axis we have the smoothen variance (power) and in the horizontal axis we have the frequencies (cycle per observations). Both the figures show different patterns. Generally, the spectral density graphs are continuous, sloping lines rather than what is seen in the above figures. It describes the composition of the data in the frequency domain by distributing the total variance across the frequencies according to the specific contributions of the components of each individual frequency band. In other words, the shape of the spectrum is determined by the distribution of variance in the data. The power spectrum isolates or peaks on those cycles that display the greatest power or account for the largest amount of variance.

Here, in our case the power spectrum displays relatively high concentrations of power in the middle frequencies for temperature that is the middle frequencies are more prominent and high concentration of power in high frequencies for all India precipitation. These figures are on the all India basis and almost all the

States shows the similar pattern with respect to temperature and precipitation. In case of precipitation a flatten spectral peaks is seen at a frequency of about 0.4 cycles per observations and for temperature, at a frequency of about 0.3 cycles per observation. In both the cases of temperature and precipitation the density is less in the lower frequency. The density of temperature is more in middle group of frequency and for precipitation it is at the higher end. In other words, in the long run the variance is less than the short-run in case of precipitation and in the case of temperature the variance is more in the middle period. It also implies that the peak increases when the density decreases especially in the case of precipitation and for temperature it is quite unpredictable. Such a distribution of power is not common in economic time series and it is interesting to note that further work needed to be done.

Within States also there are some interesting results. States like Harayana, Punjab, Puducherry are showing a converging trend at the extreme ends of the two frequencies, implying that the both the long run and the short run shows a similar kind of variance with respect to temperature. Further, Orissa and the Union Territory Dadar and Haveli show a decline trend, that is the power becomes larger in the low frequency (long run) and smaller in the high frequency (short-run). On the other hand States like Jammu and Kashmir, Meghalaya, Uttarakhand, and Uttar Pradesh are showing an increasing trend, that is the variance is not much in the low frequency (See appendix A3.5 and A3.6).

On a different note, States like Arunachal Pradesh, Jammu and Kashmir, Punjab, Rajasthan, shows some interesting results. There is a dip in the middle frequencies indicating that these are the periods which witnessed major crisis like flood and droughts. States with increasing trend like Bihar, Chattisgarh, Karnataka, Orissa, Uttar Pradesh and Uttarakhand gives us a different picture than what is seen in the economic time series. Thus, further analysis needed to be done in order to understand the nature of these time series. The significant finding is that the spectral density does not follow the density of economic time series (Granger, 1964).

IV. Summary and Conclusion

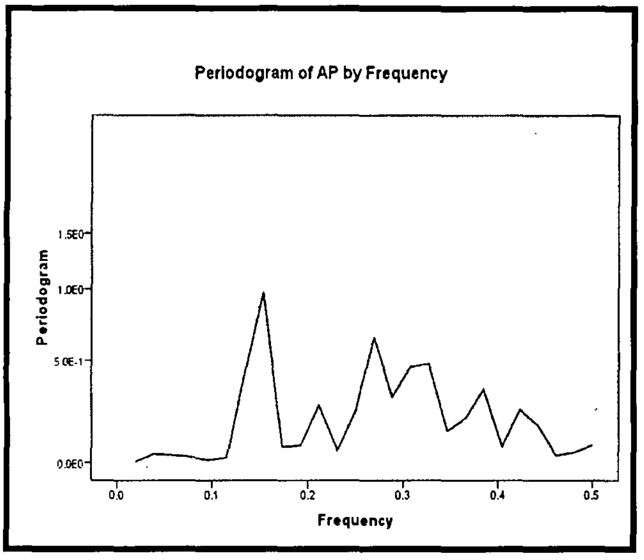
Many interesting outcomes have resulted in this chapter. We have undertaken both the modern as well as the traditional approach to understand the nature climate change in India. As far as the traditional approach is taken into consideration, only Kerala shows a more or less stable climatic condition through out the fifty years whereas all the other States have shown a varying position in the past five decades. Apart from the climatic index, we have also calculated the percentage change in the temperature and precipitation, which has opened up new windows for better understanding of the issue at hand. Jammu and Kashmir has shown a highest change and Tripura has shown a negative change with respect to temperature. Most of the States showed a negative change with respect to precipitation and we can conclude that the worst change has been occurred with Jammu and Kashmir with respect to an increase in temperature and a decrease in precipitation.

We have undertaken Spectral analysis particularly periodogram for the modern analysis of the time series data with respect to the climatic factors, temperature and precipitation. In order to apply the spectral methods, the series has to be trend and cycle free. We have used the trend as well as the fisher test to identify the trend and cyclical fluctuations in the series. Significant cyclical fluctuations in all India precipitation according to the Fisher test. This explains that there are variables which affect the series due to the presence of such cyclical phenomenon. Therefore, we need to remove the cyclical components in order to go for the cross- spectral analysis.

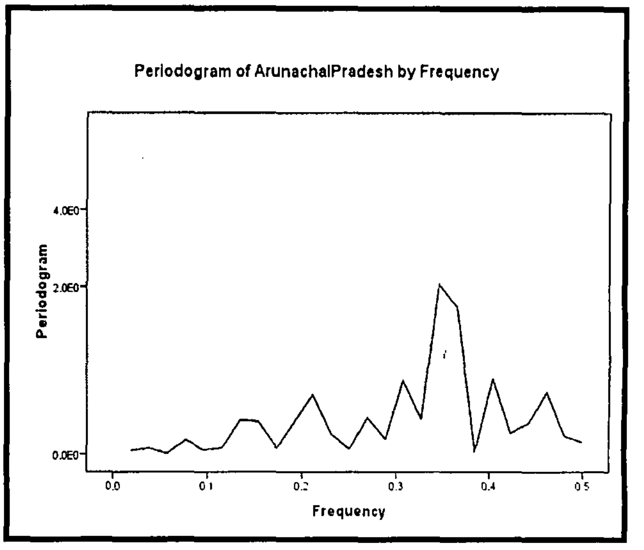
The spectral density of both (temperature and precipitation) time series have shown an interesting phenomenon. In case of all India temperature and precipitation, there is a Instead of downward sloping, both the graphs show some different movements. It can be seen that with the increase in the period the density or the power spectrum falls implying that in the long run the variance is less as compared to the short run. Since these series are not economic variables rather than meteorological, we can conclude that these series shows such different patterns but there is a scope for further detailed analysis of all these data. In the next chapter we are further going to do a univariate analysis on yield of maize by using spectral as well as the traditional approach, so that we can proceed further to do the cross spectral analysis.

APPENDIX 1
A3.1Periodogram (Temperature)

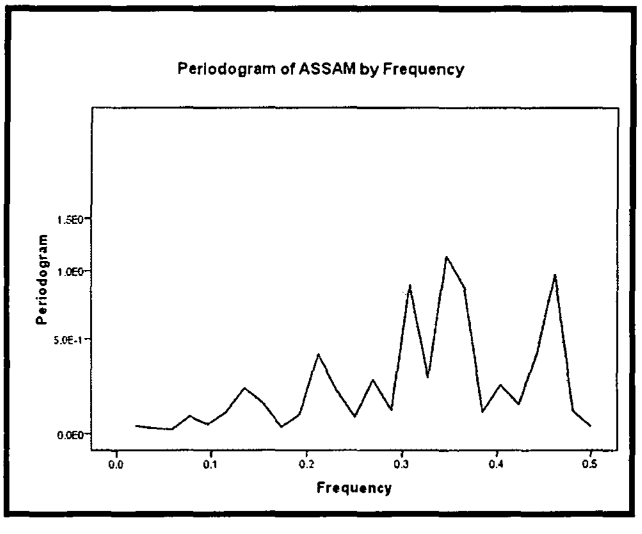
Andhra Pradesh



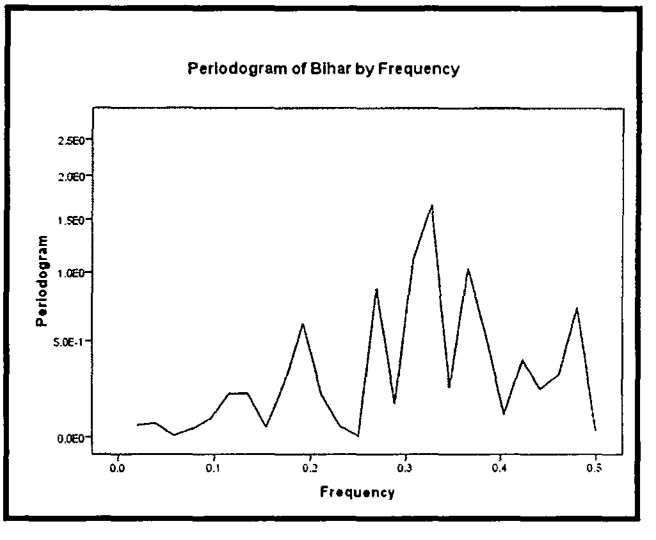
Arunachal Pradesh



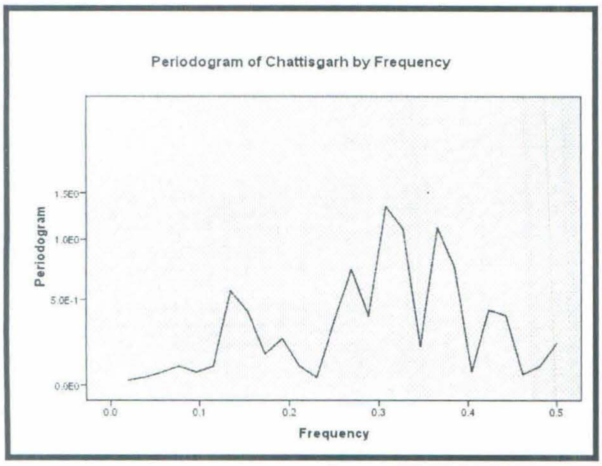
Assam



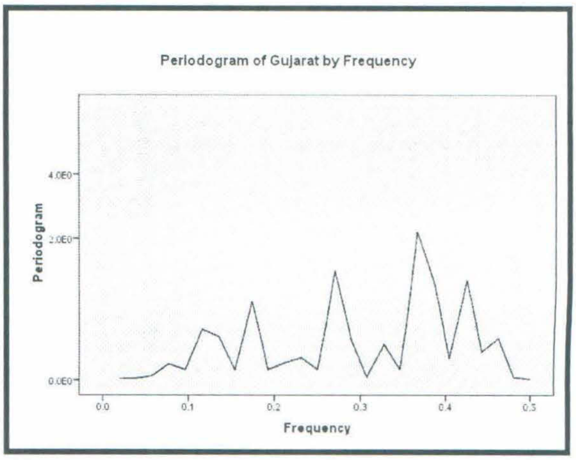
Bihar



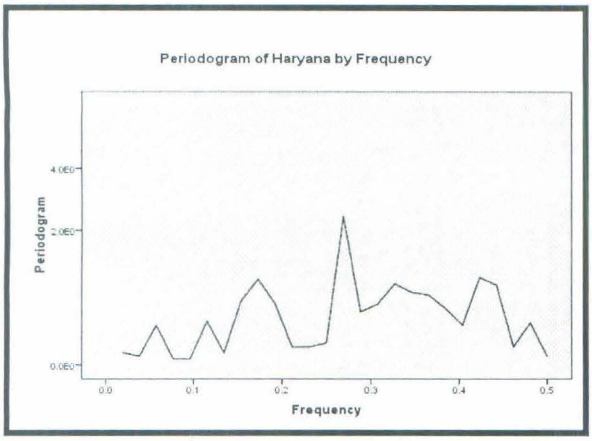
Chattisgarh



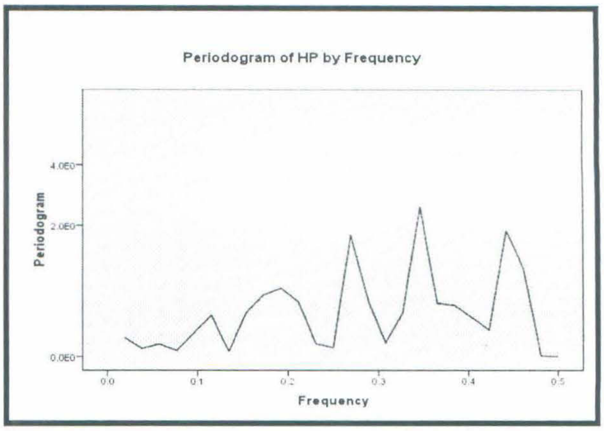
Gujarat



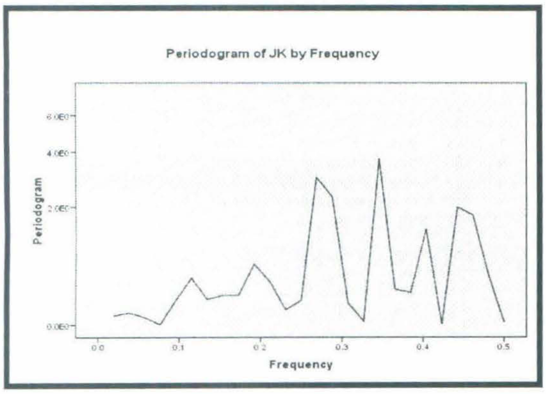
Haryana



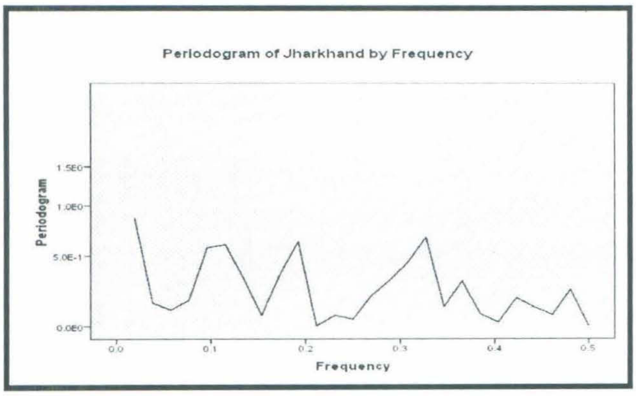
Himachal Pradesh



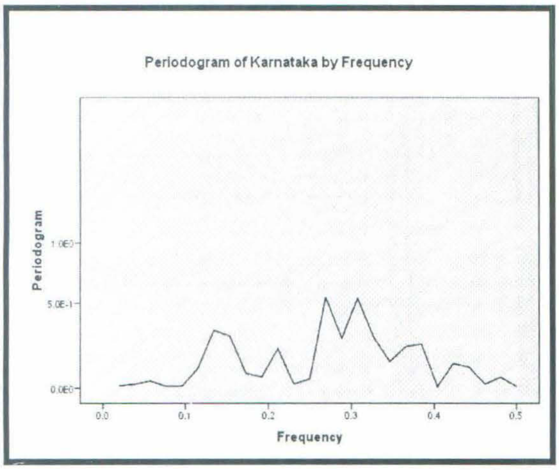
Jammu and Kashmir



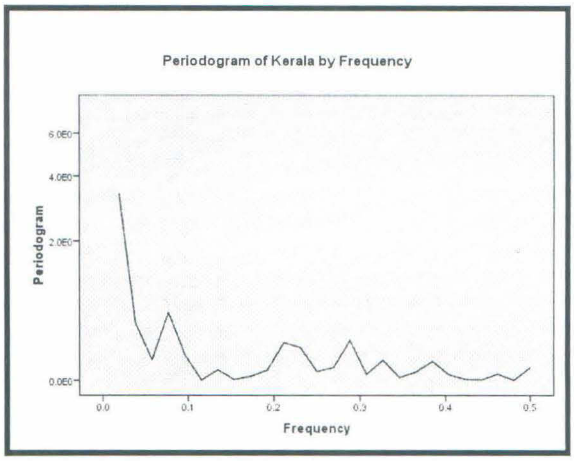
Jharkhand



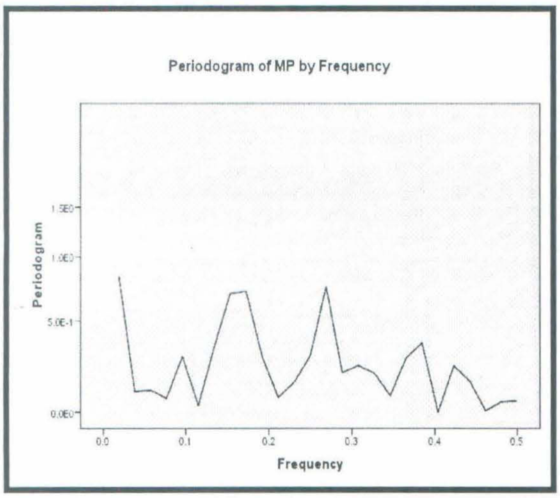
Karnataka



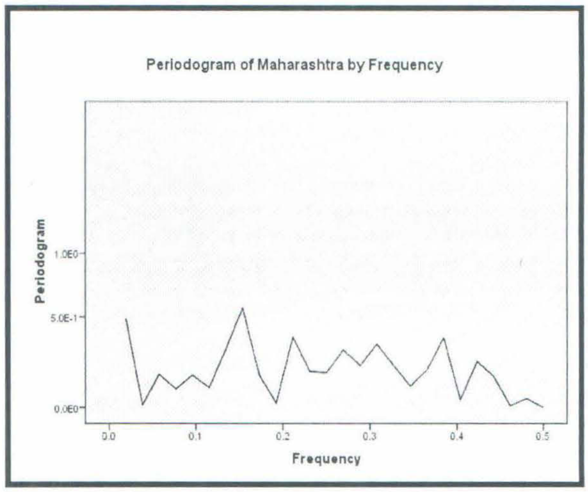
Kerala



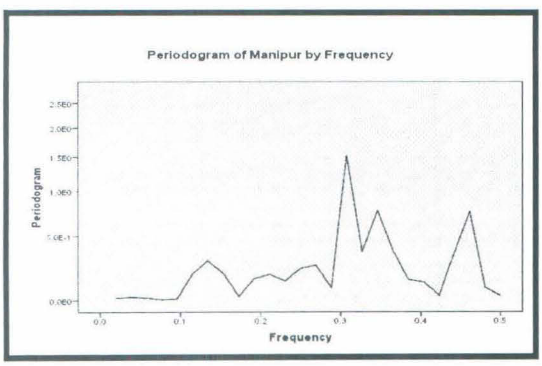
Madhya Pradesh



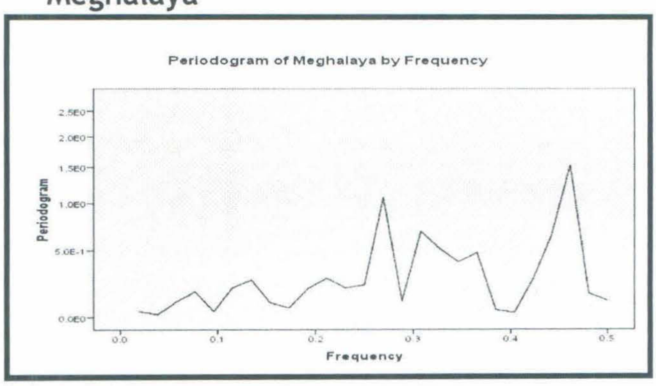
Maharashtra



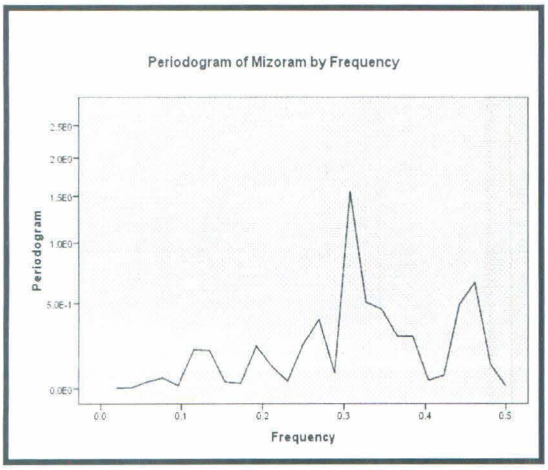
Manipur



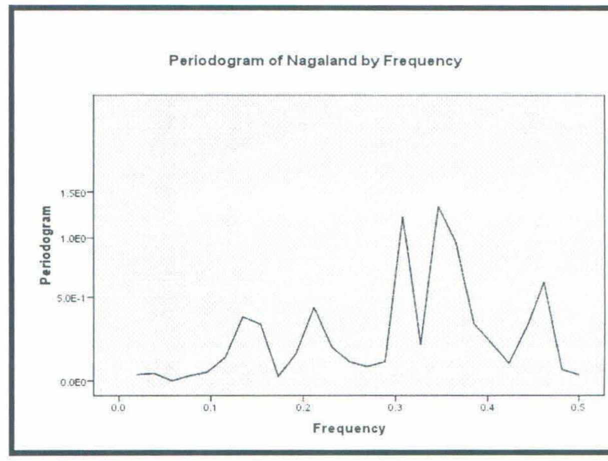
Meghalaya



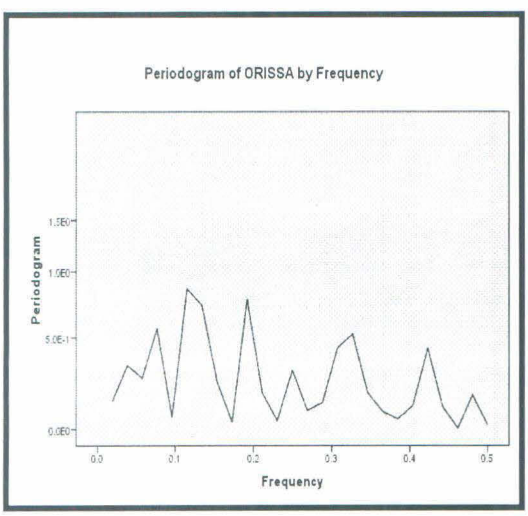
Mizoram



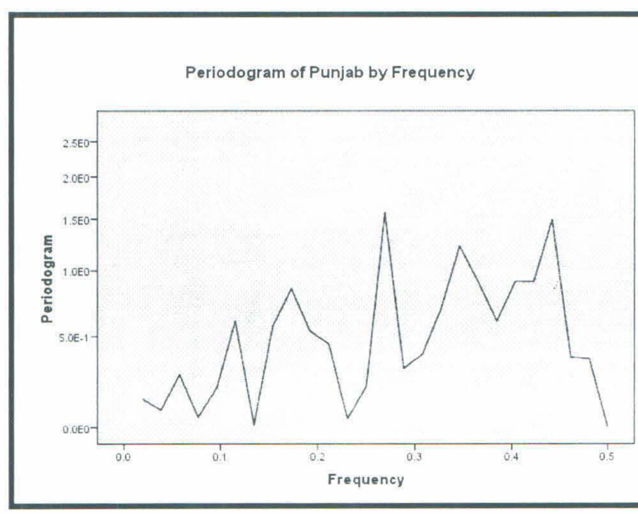
Nagaland



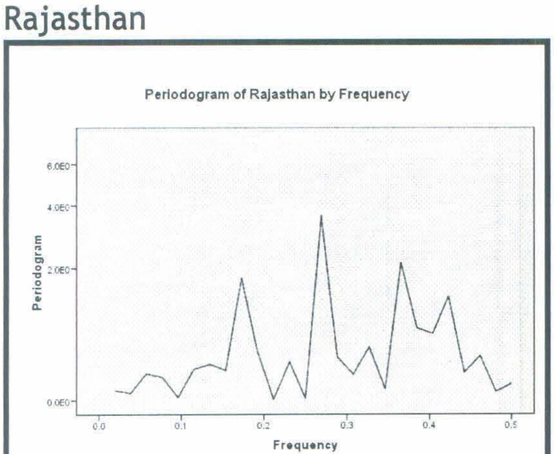
Orissa



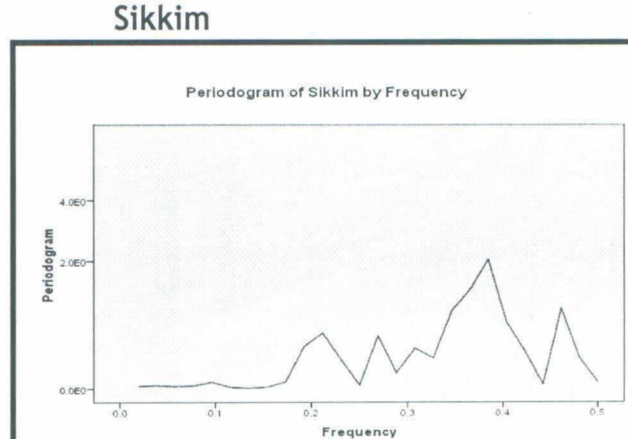
Punjab



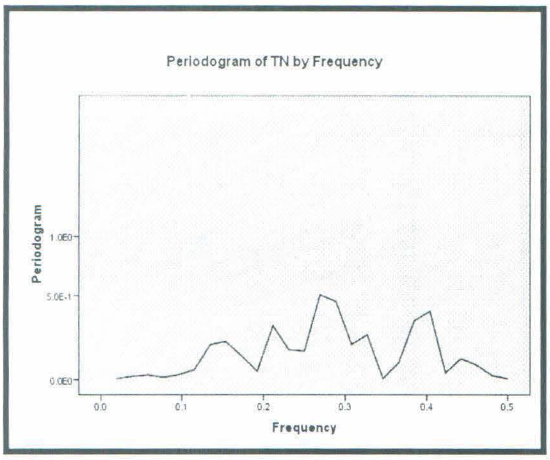
Rajasthan



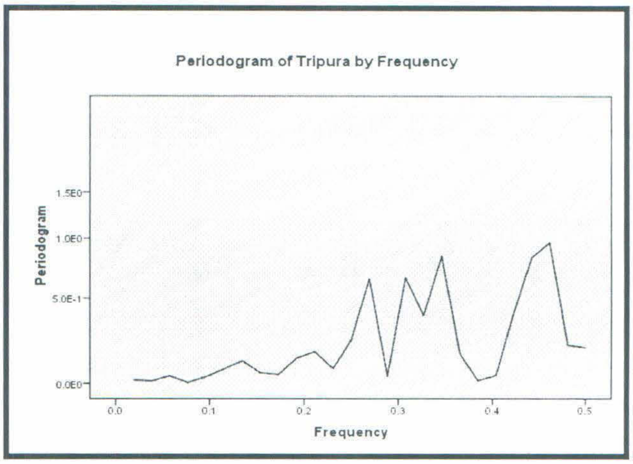
Sikkim



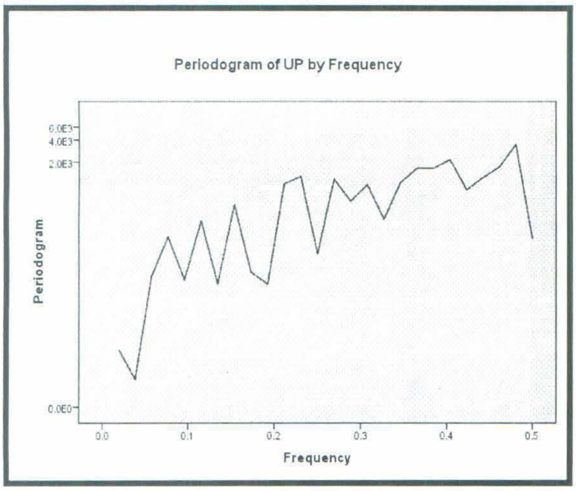
Tamil Nadu



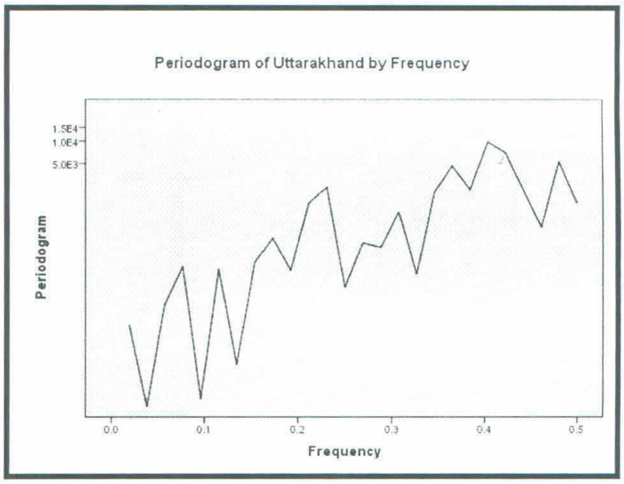
Tripura



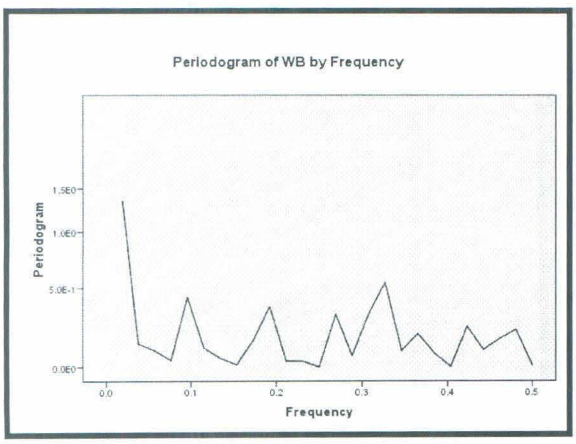
Uttar Pradesh



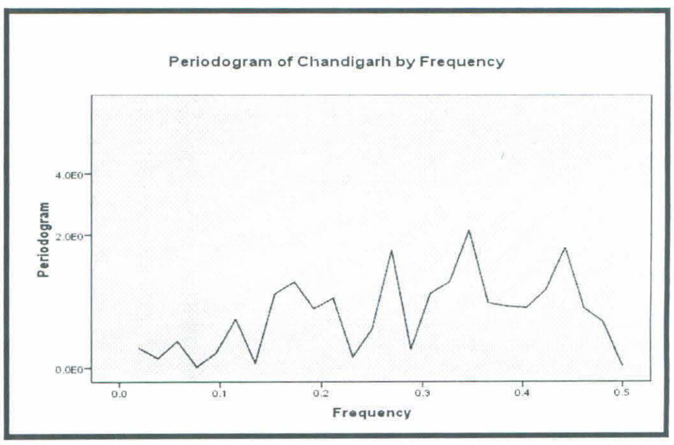
Uttarakhand



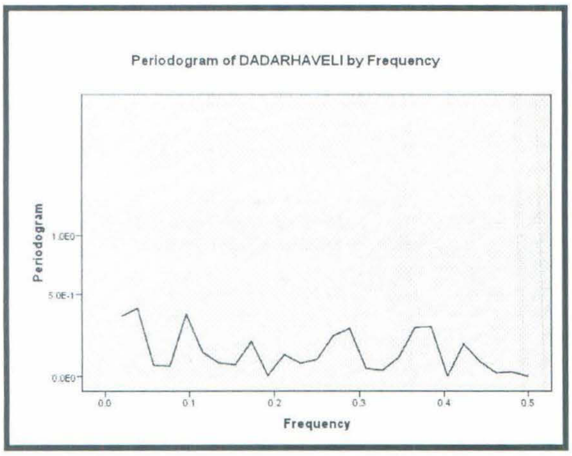
West Bengal



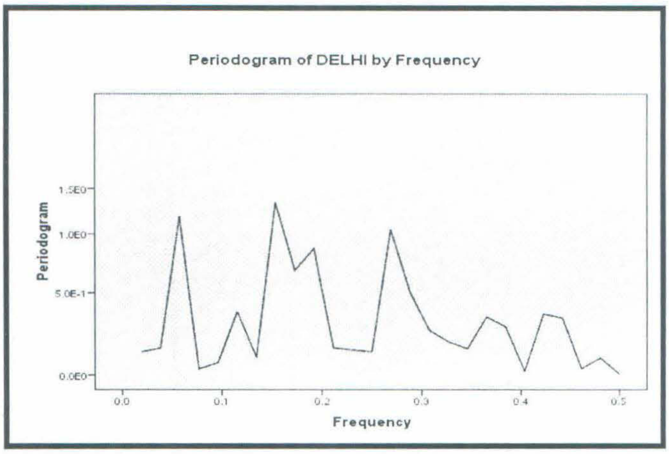
Chandigarh



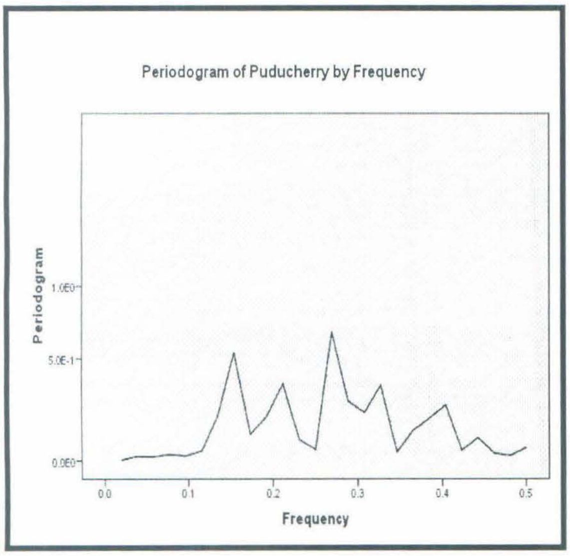
Dadar and Nagar Haveli



Delhi

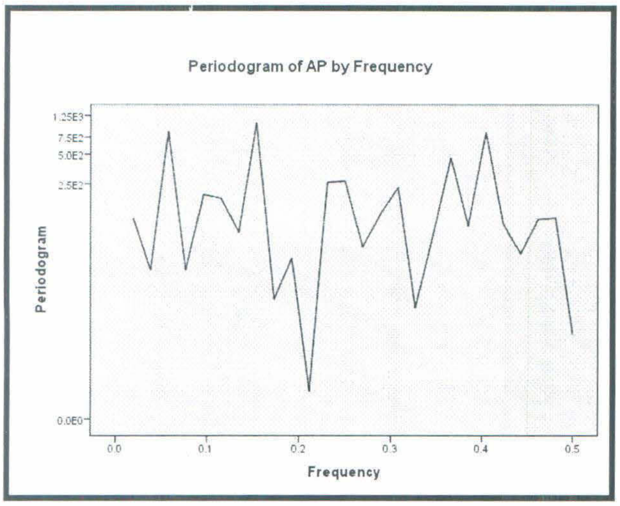


Puducherry

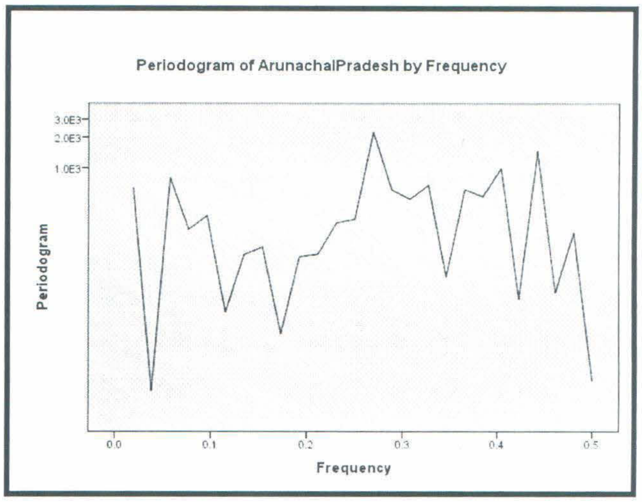


A3.2 Periodogram (Precipitation)

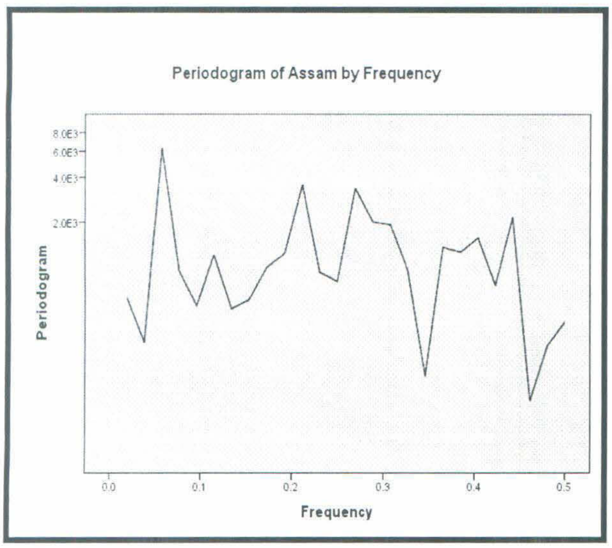
Andhra Pradesh



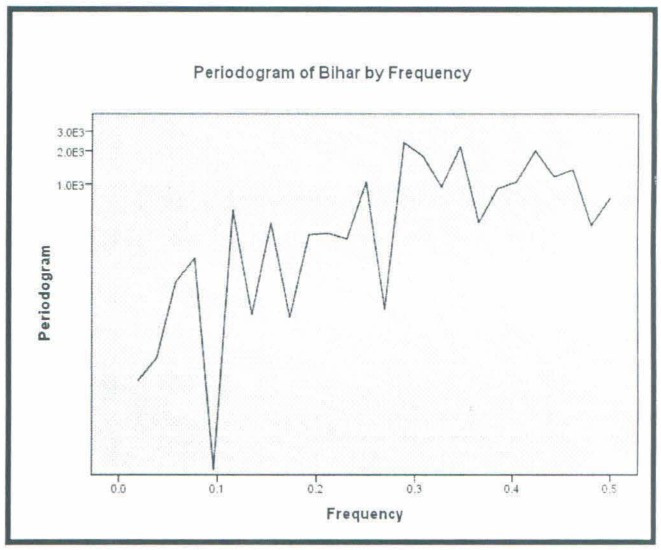
Arunachal Pradesh



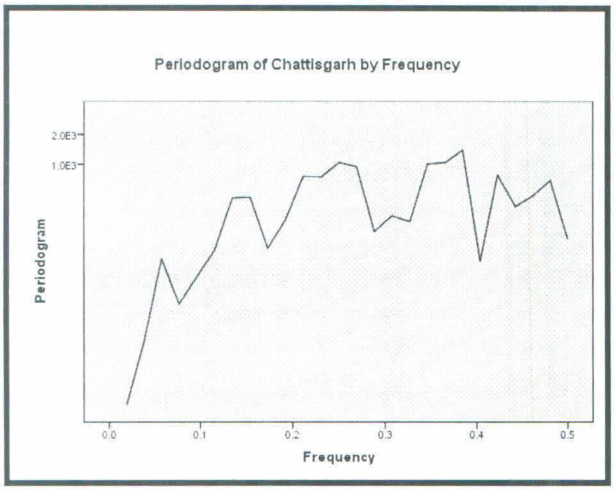
Assam



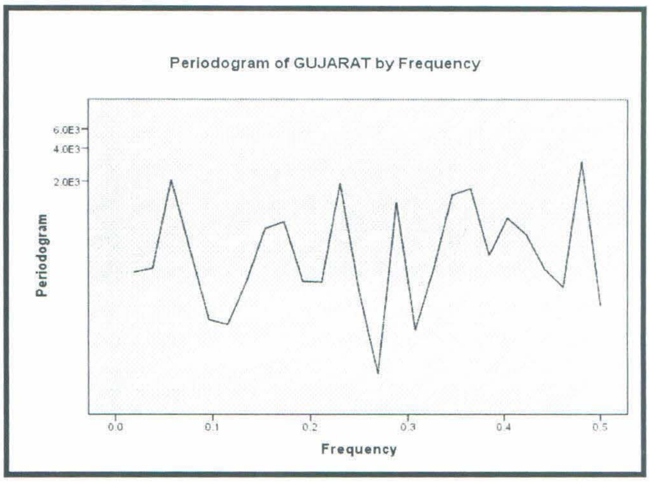
Bihar



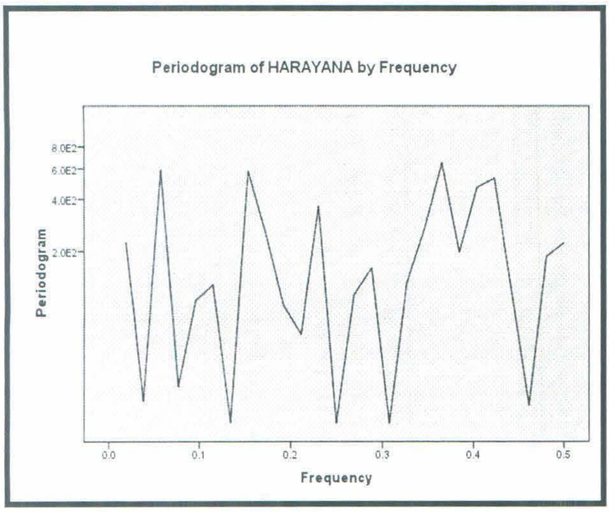
Chattisgarh



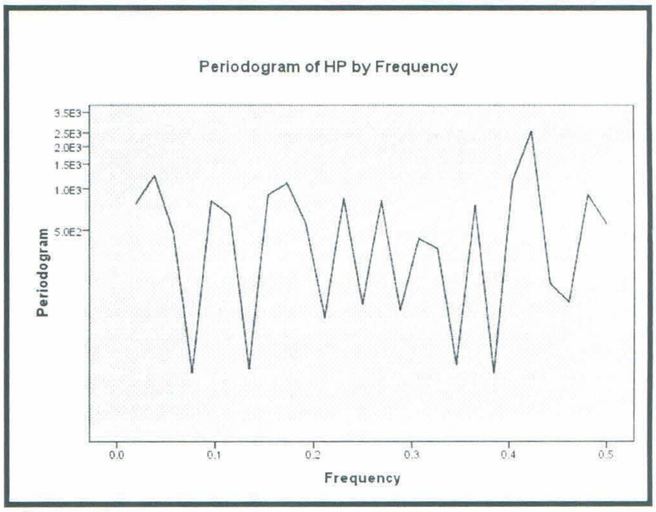
Gujarat



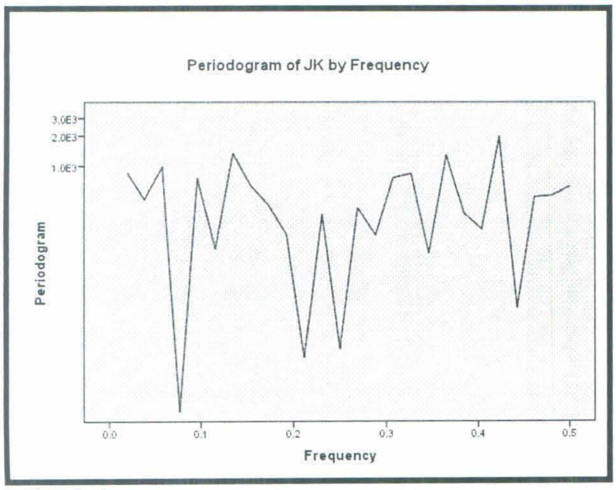
Haryana



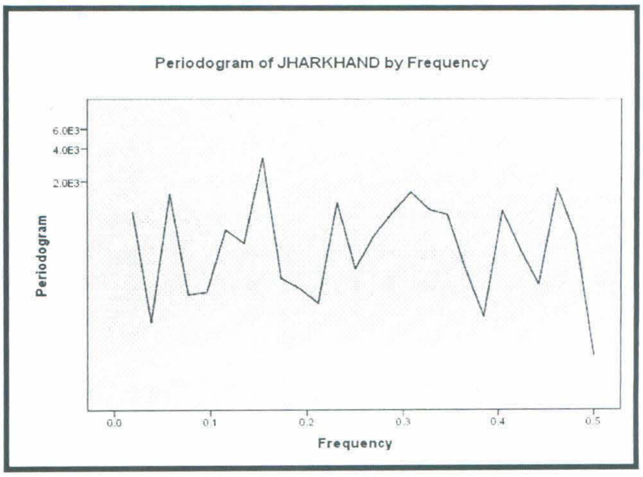
Himachal Pradesh



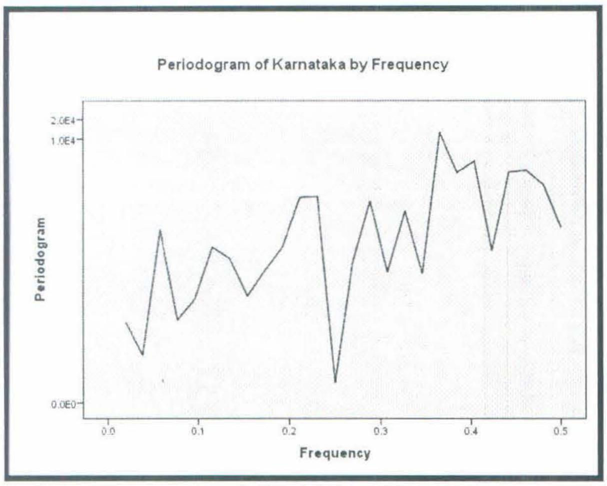
Jammu and Kashmir



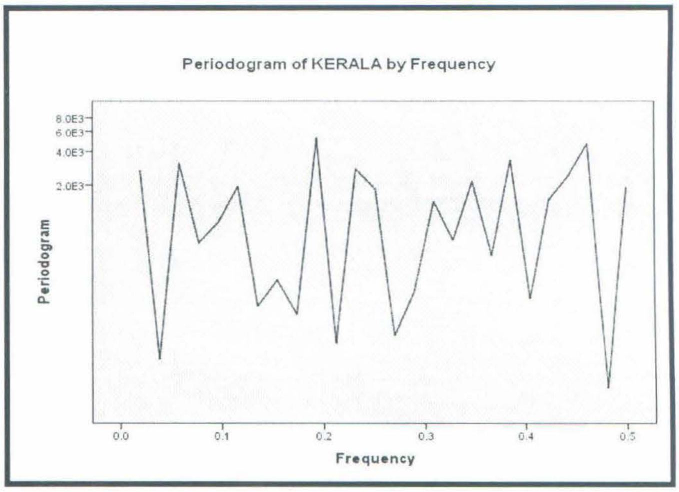
Jharkhand



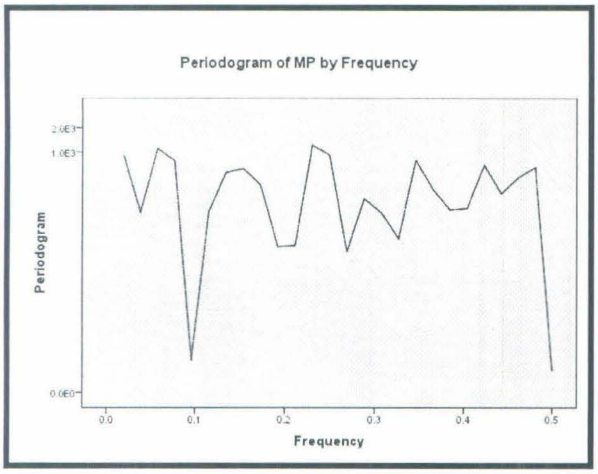
Karnataka



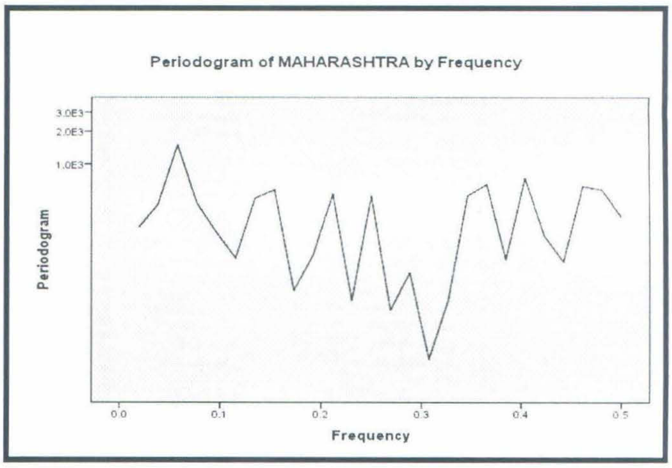
Kerala



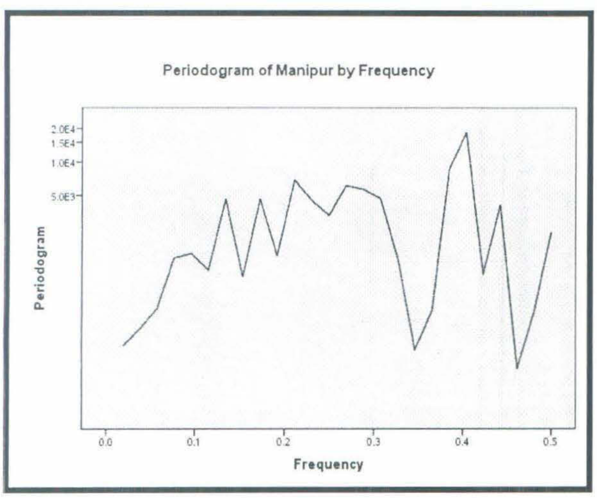
Madhya Pradesh



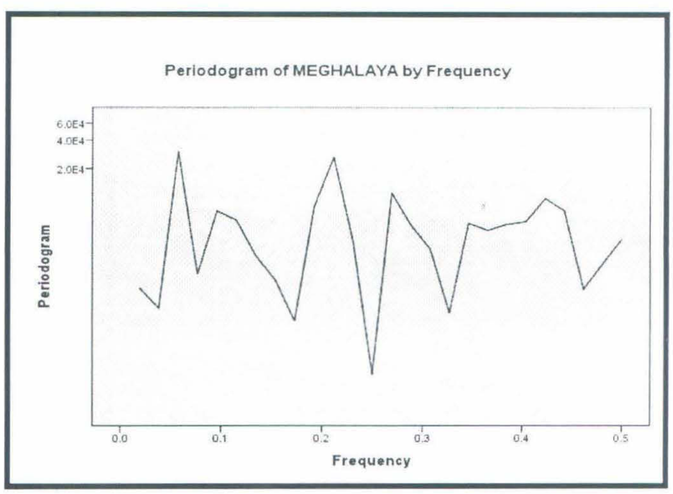
Maharashtra



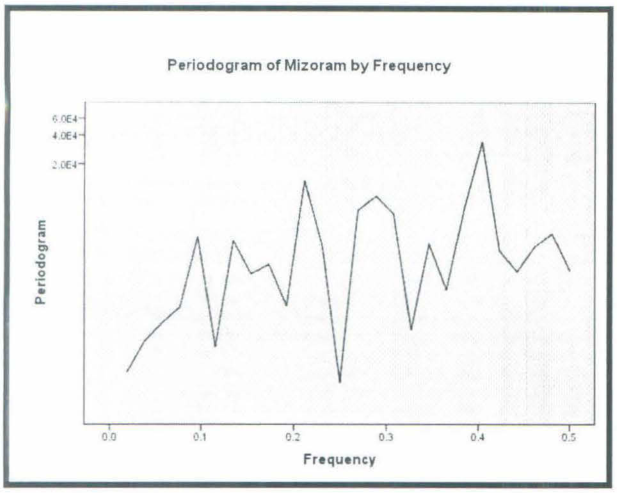
Manipur



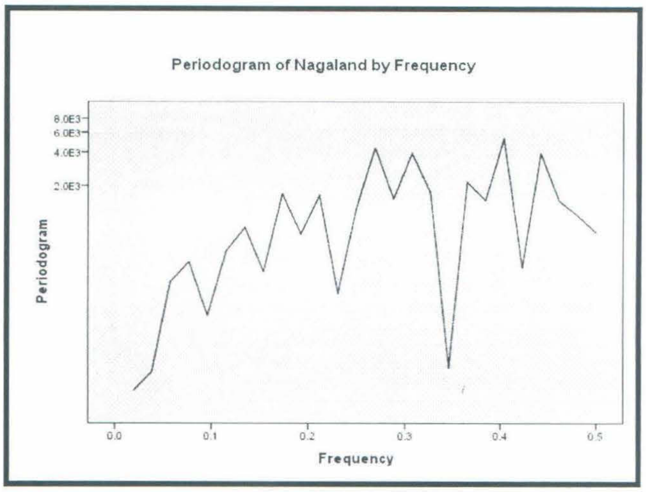
Meghalaya



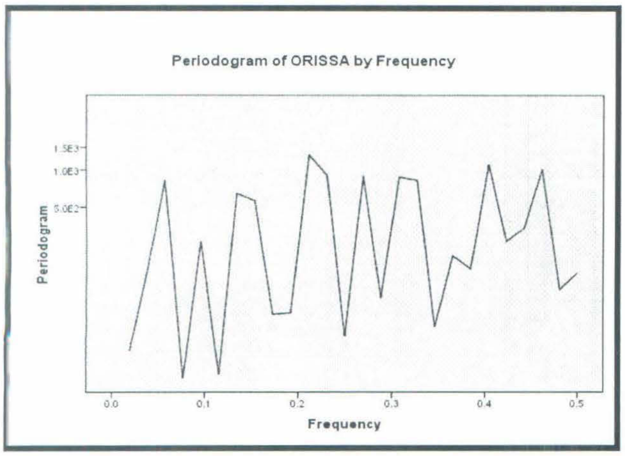
Mizoram



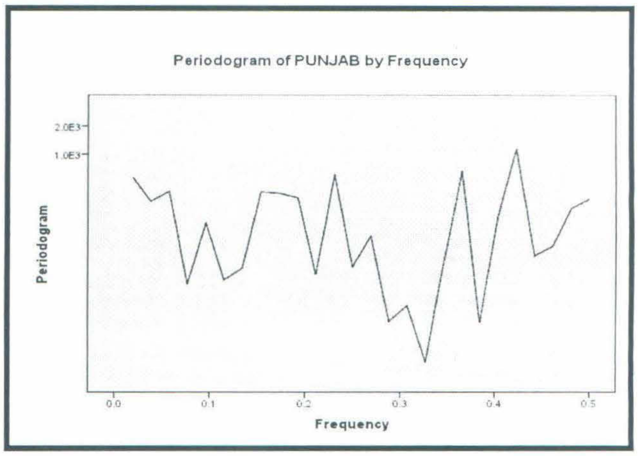
Nagaland



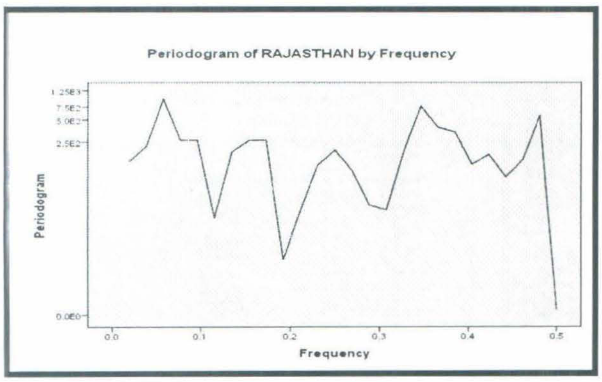
Orissa



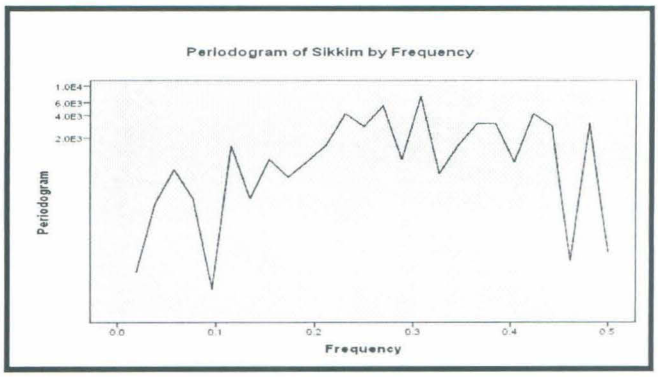
Punjab



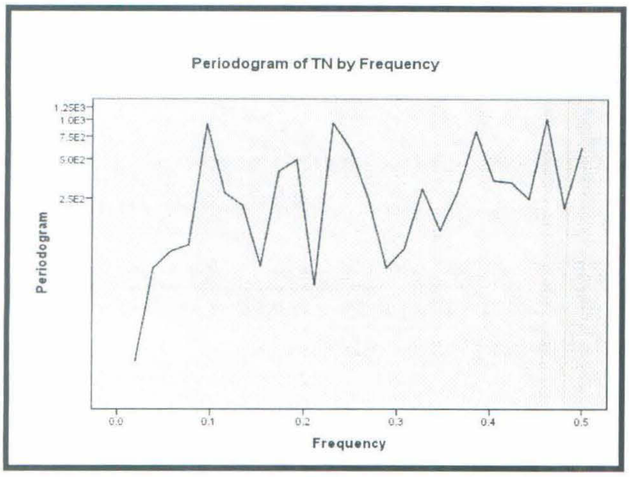
Rajasthan



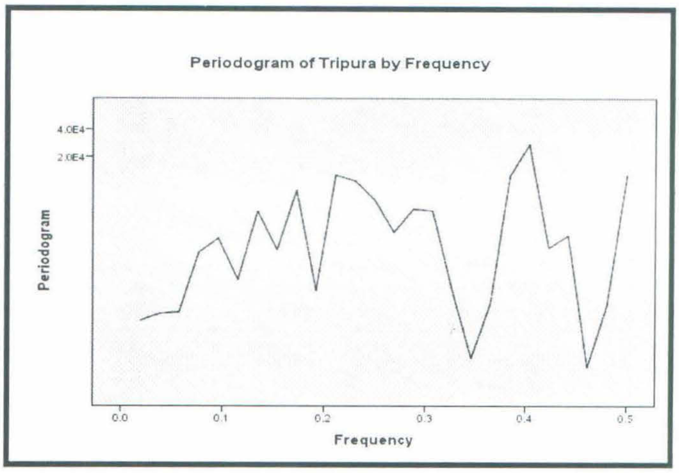
Sikkim



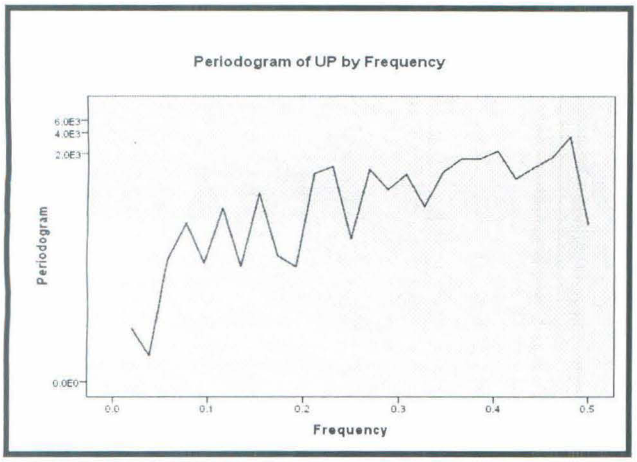
Tamil Nadu



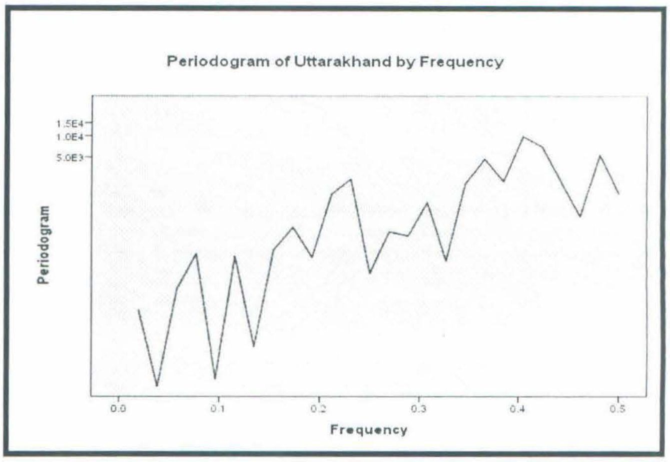
Tripura



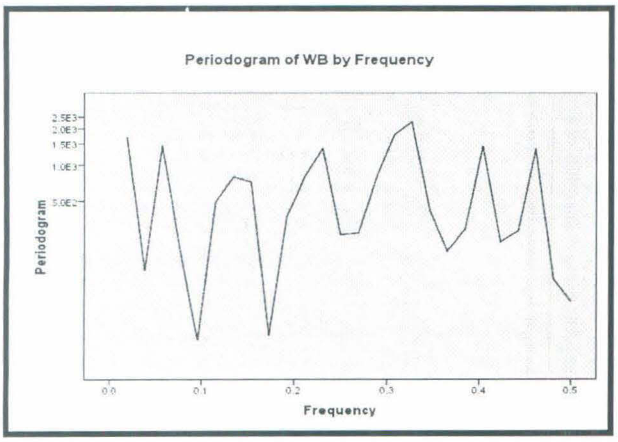
Uttar Pradesh



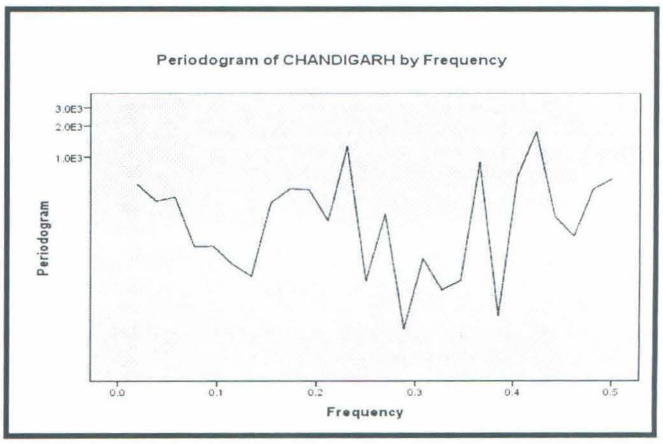
Uttarakhand



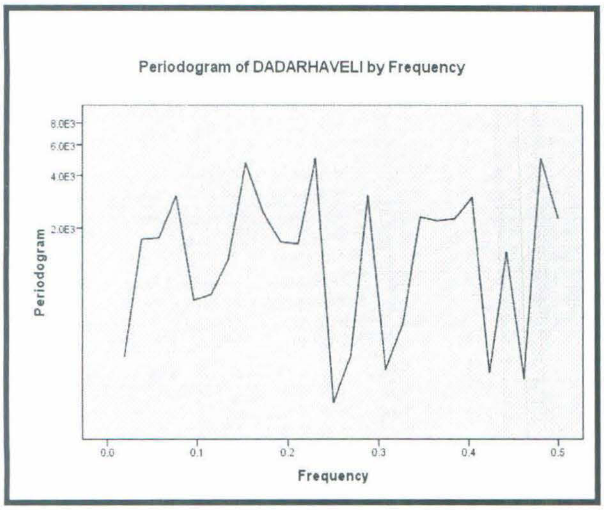
West Bengal



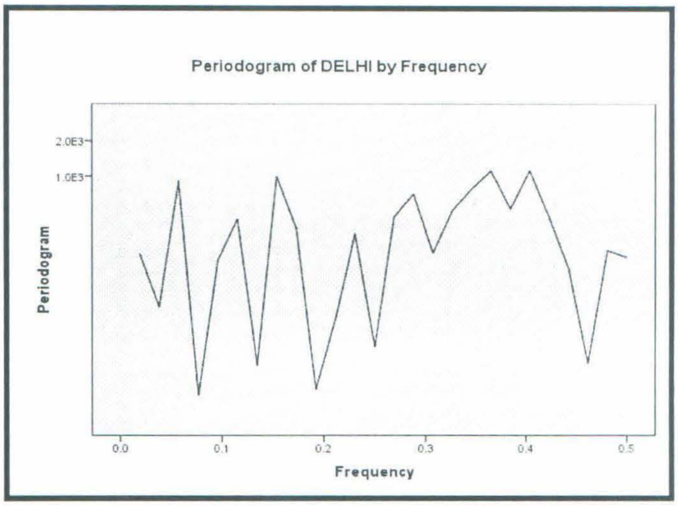
Chandigarh



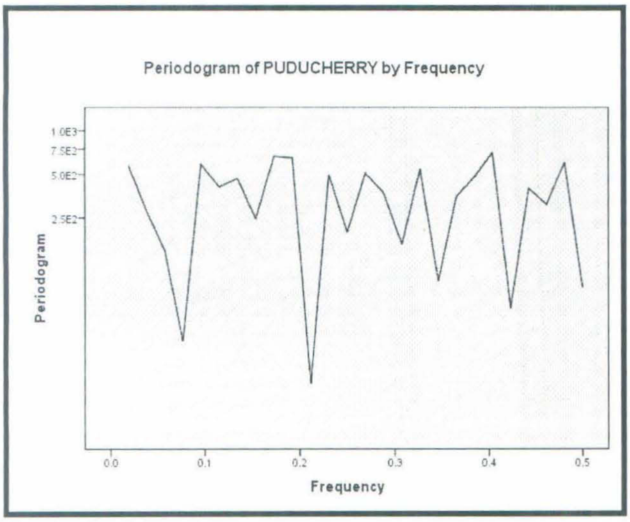
Dadar and Nagar Haveli



Delhi

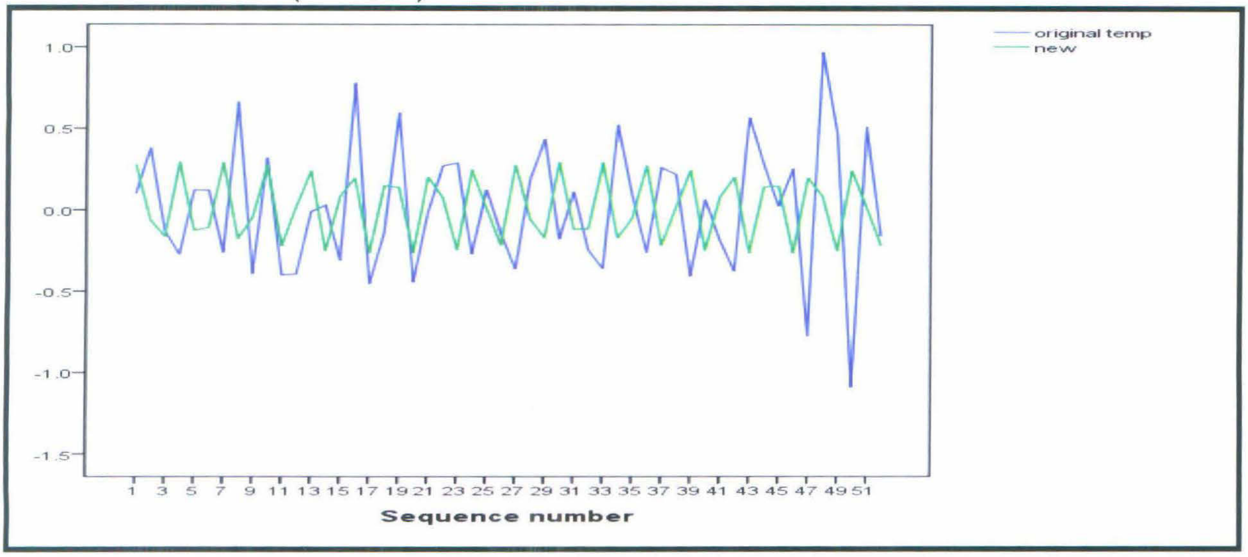


Puducherry

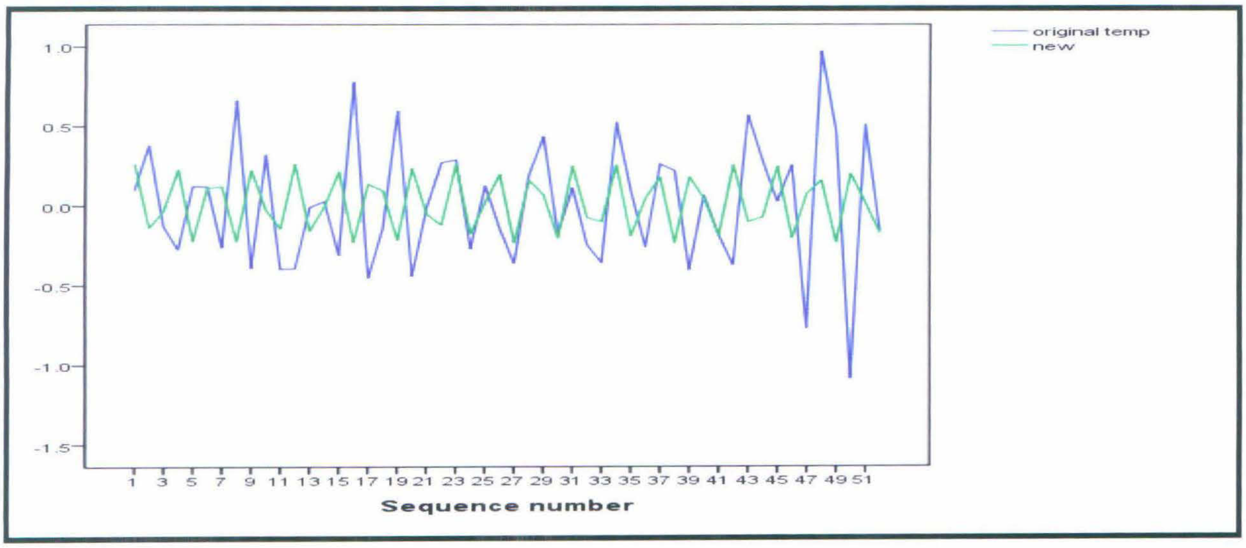


A3.3 Fisher Cycle Test (Temperature)

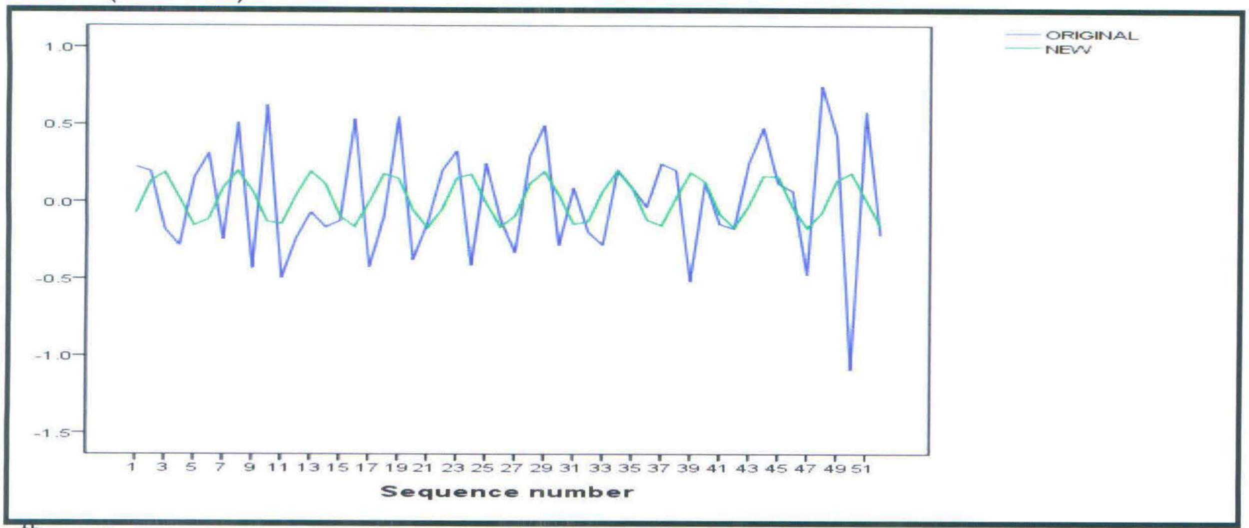
Arunachal Pradesh (1st Peak)



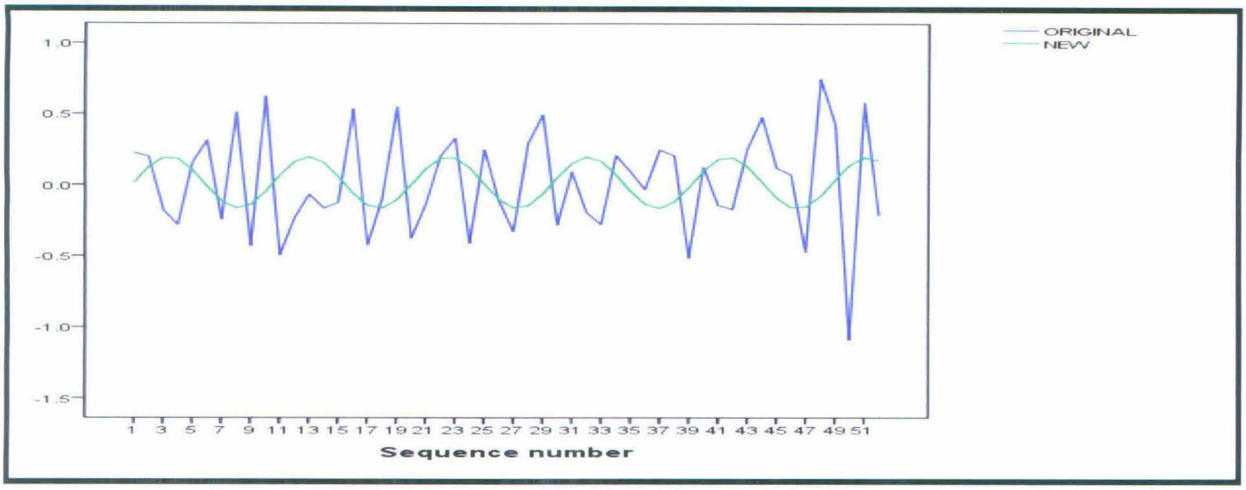
2nd Peak



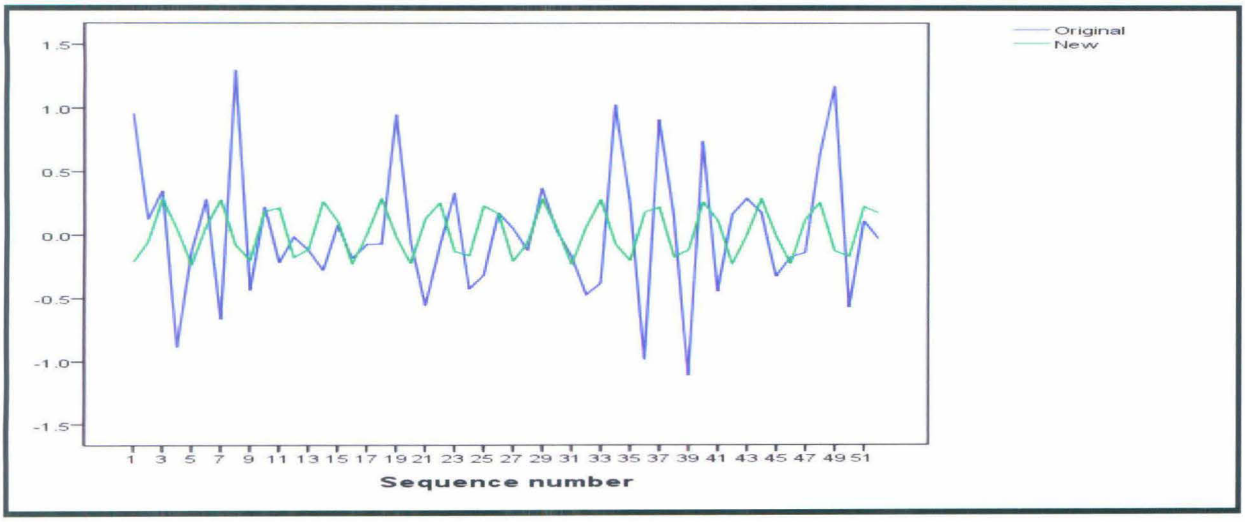
Assam (3rd Peak)



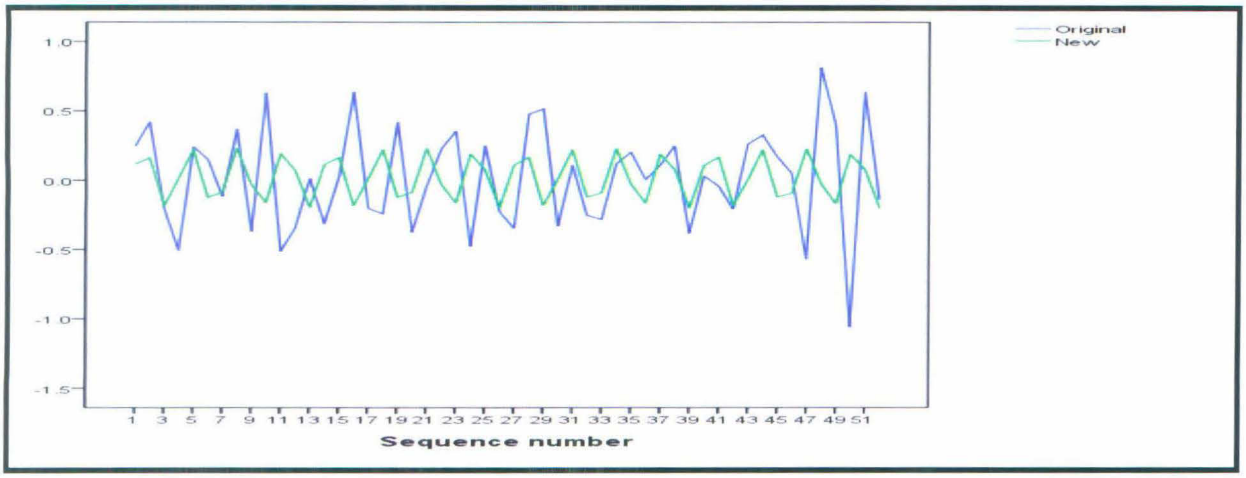
4th Peak



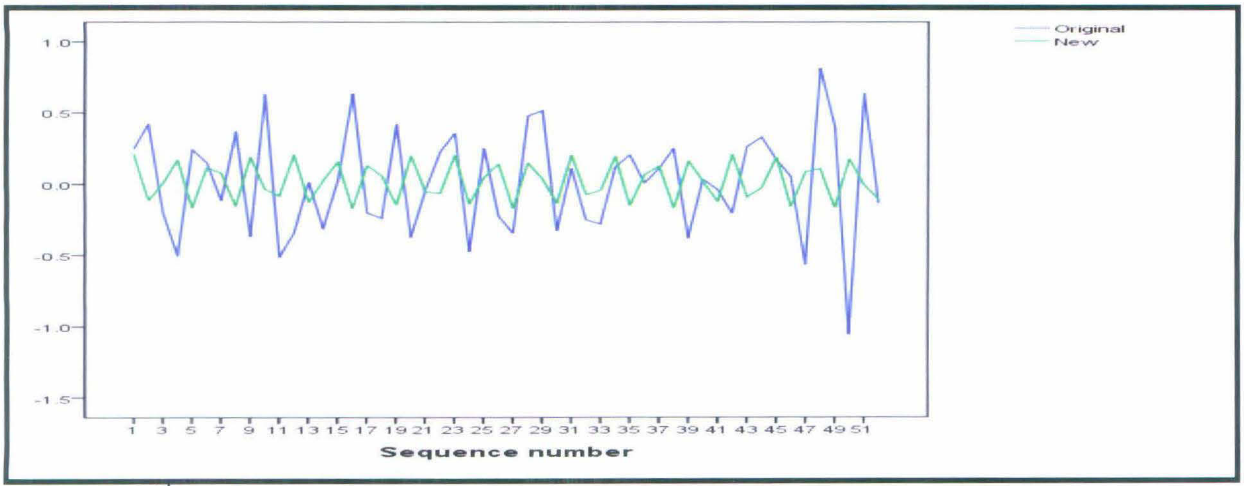
Himachal Pradesh (3rd Peak)



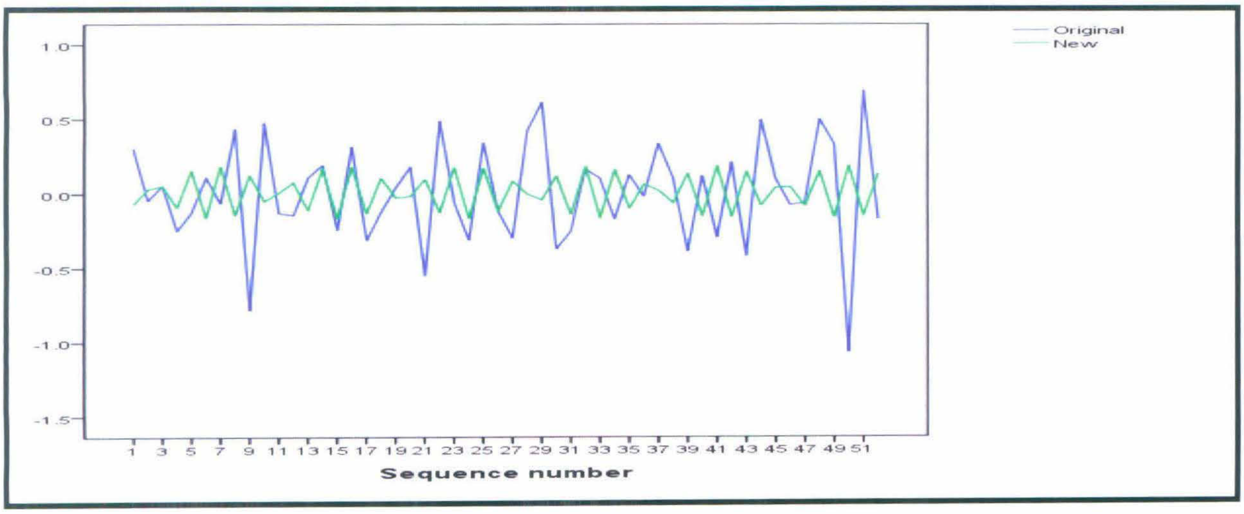
Nagaland (2nd Peak)



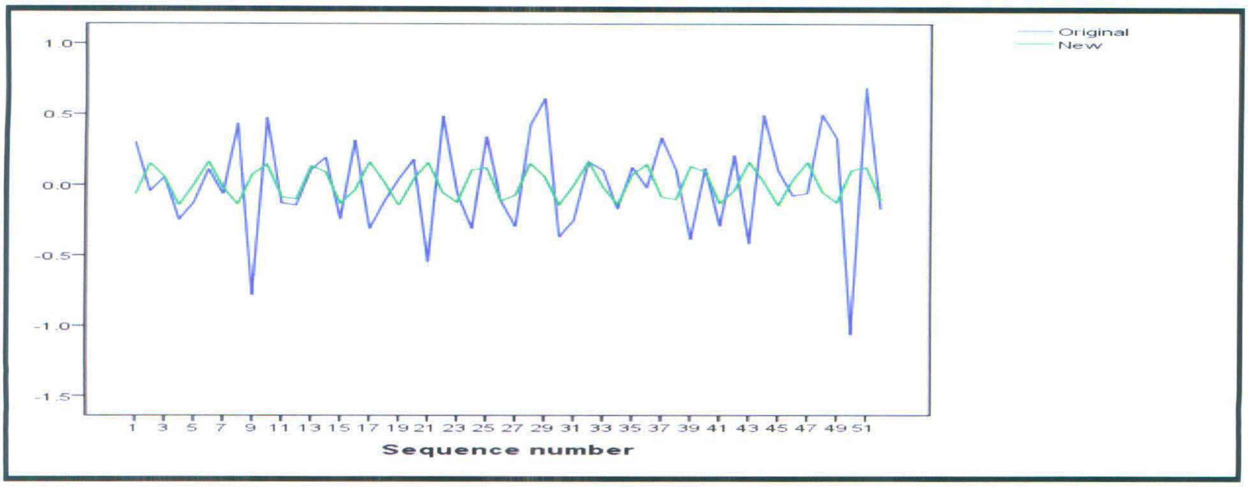
3rd Peak



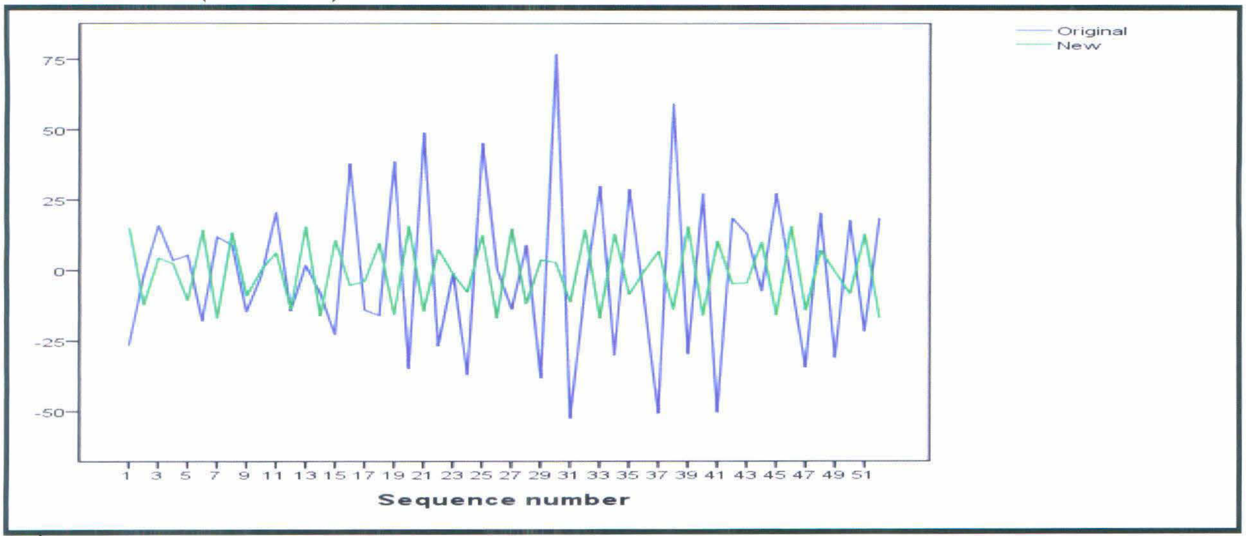
Tripura (3rd Peak)



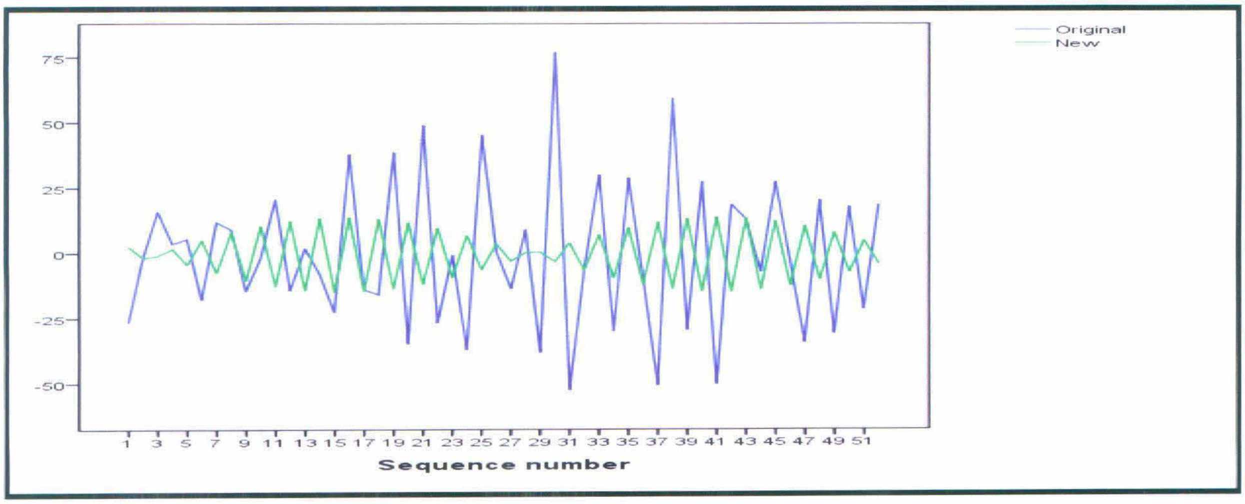
5th Peak



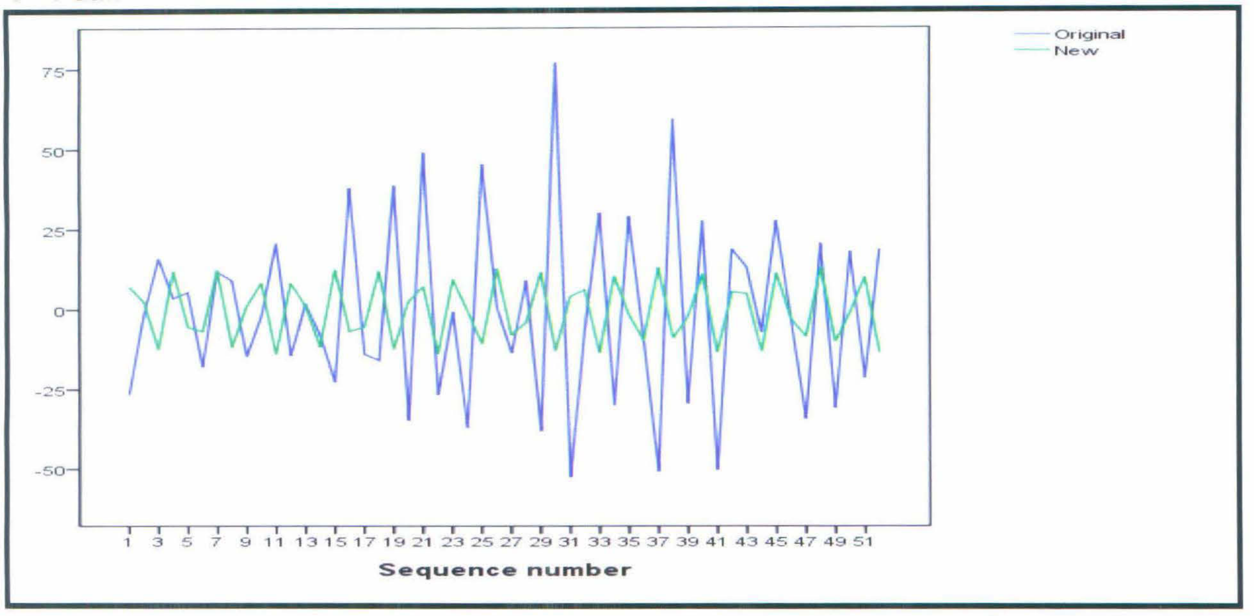
Uttarakhand (2nd Peak)



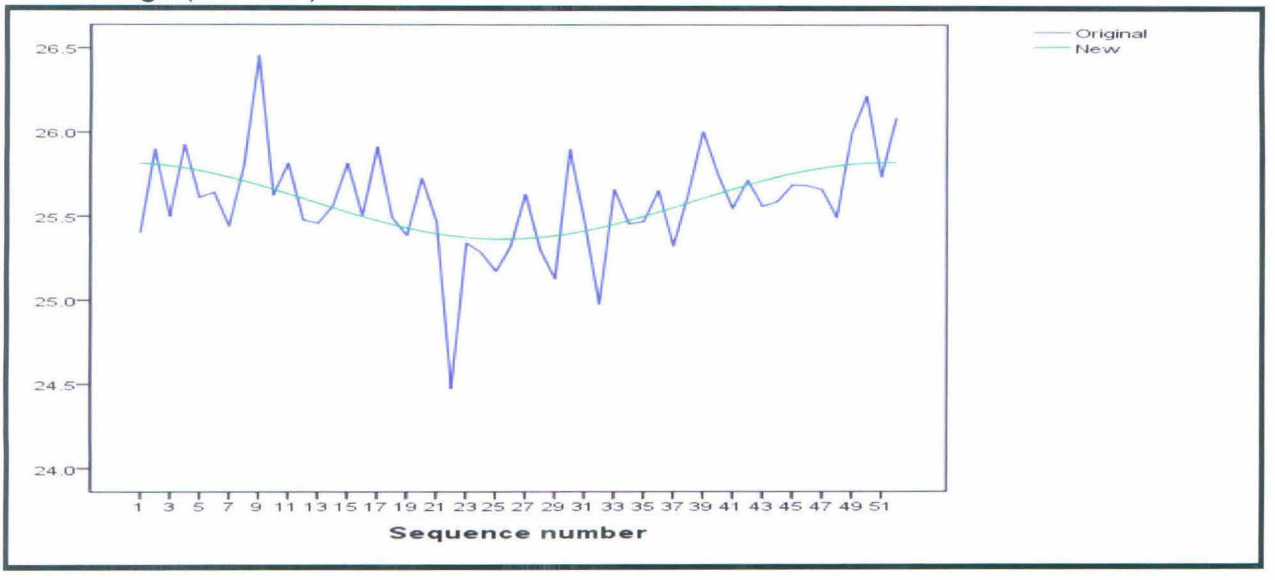
3rd Peak



4th Peak

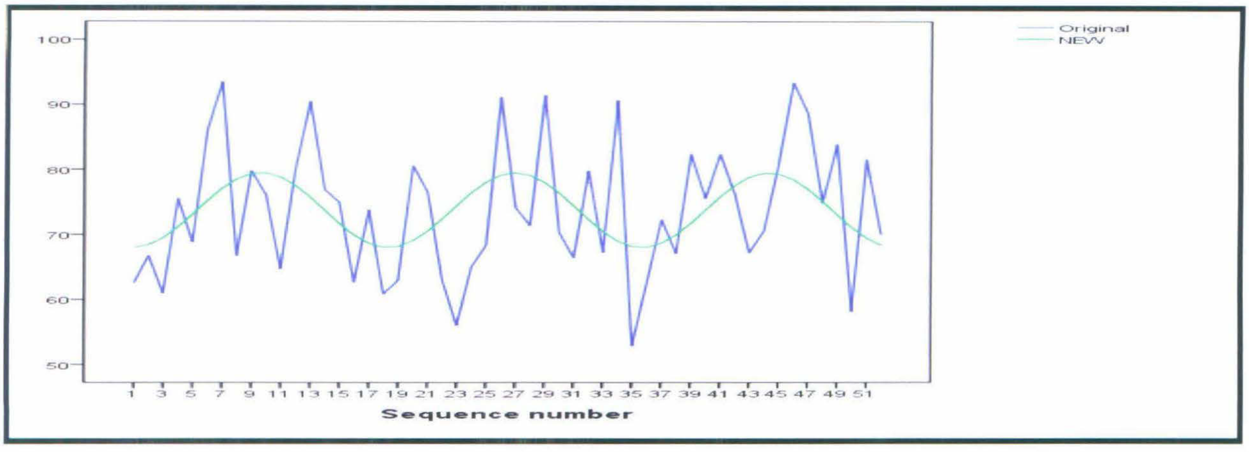


West Bengal(1st Peak)

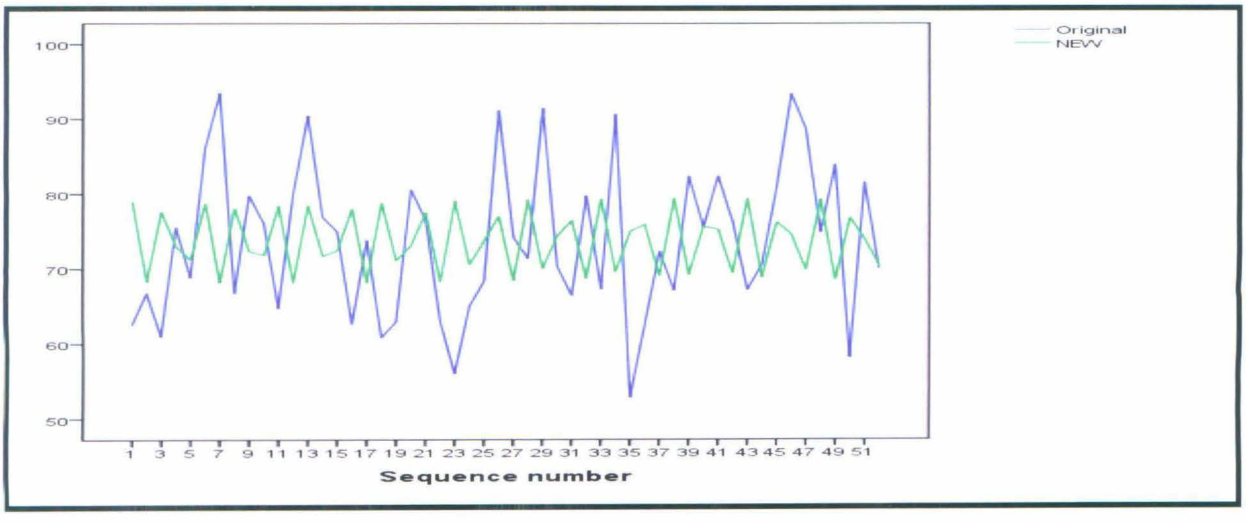


A3.4 Fisher Cycle Test (Precipitation)

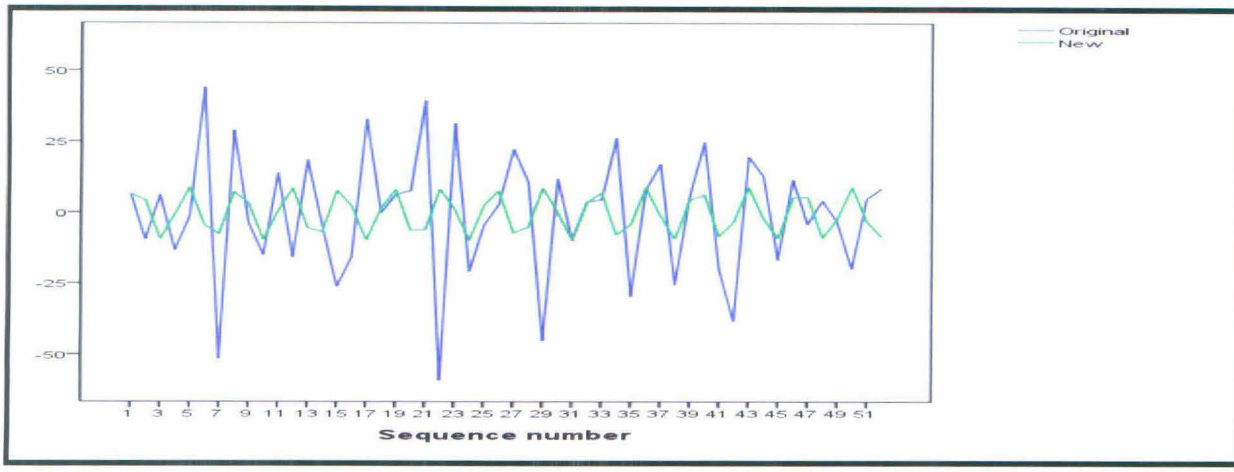
Andhra Pradesh (2nd Peak)



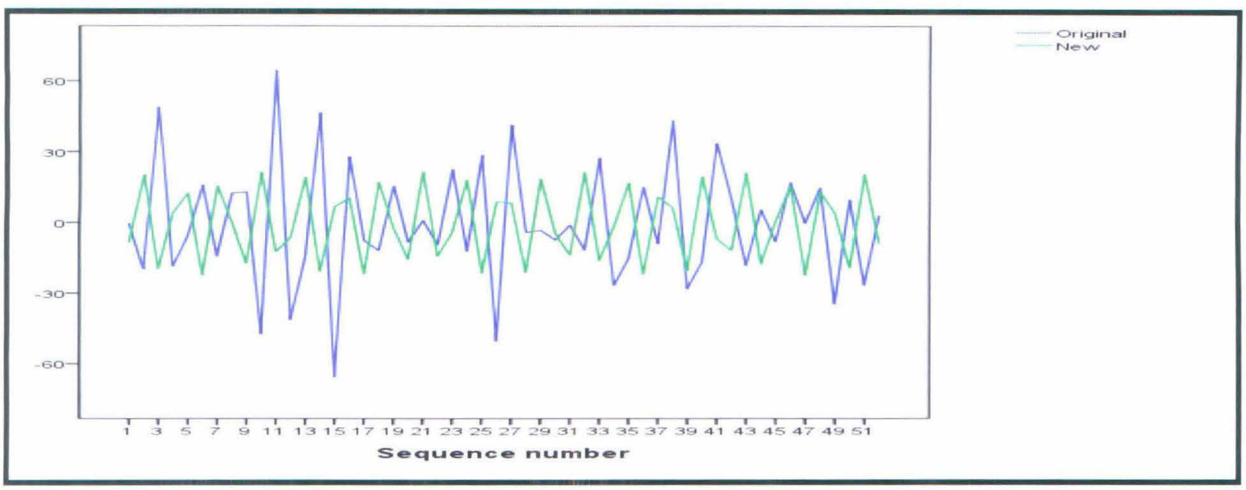
3rd Peak



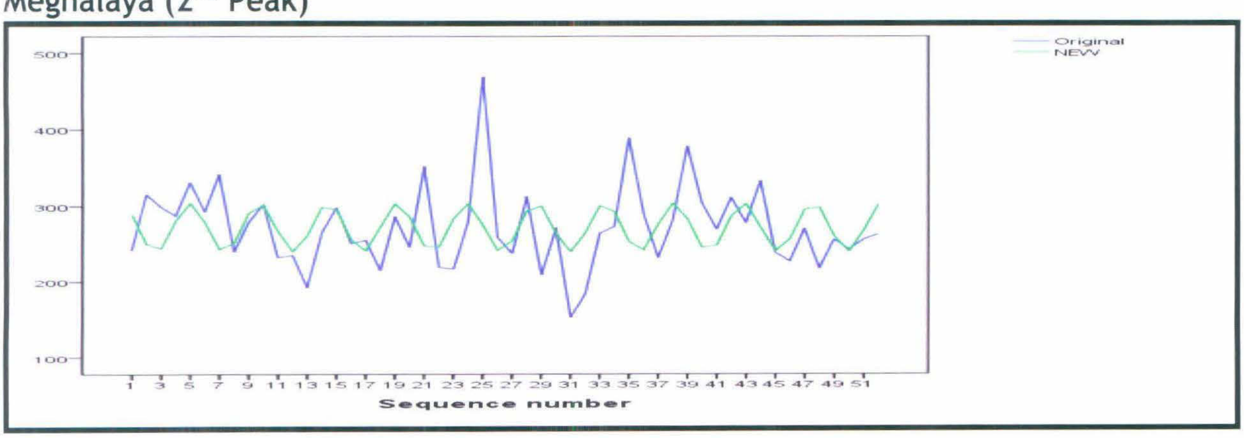
Bihar (5th Peak)



Karnataka (1st Peak)

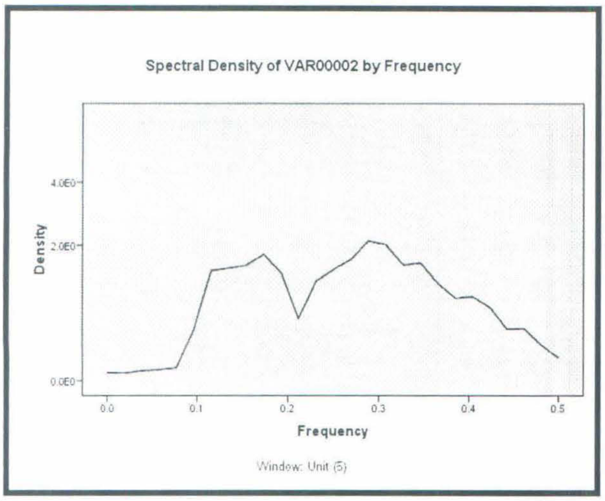


Meghalaya (2nd Peak)

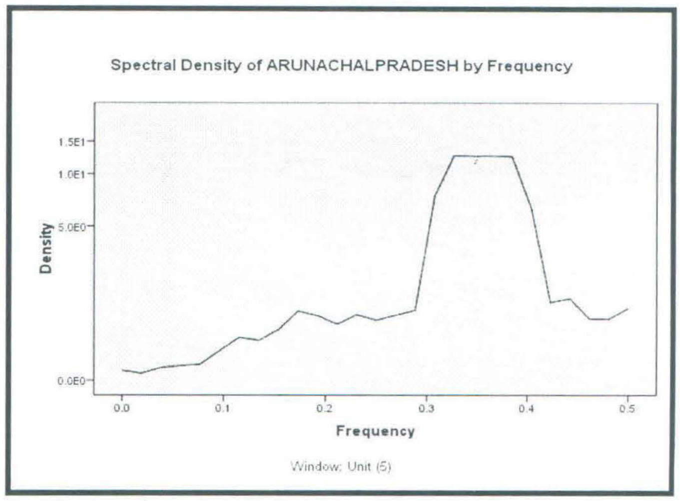


A3.5 Spectral Density (Temperature)

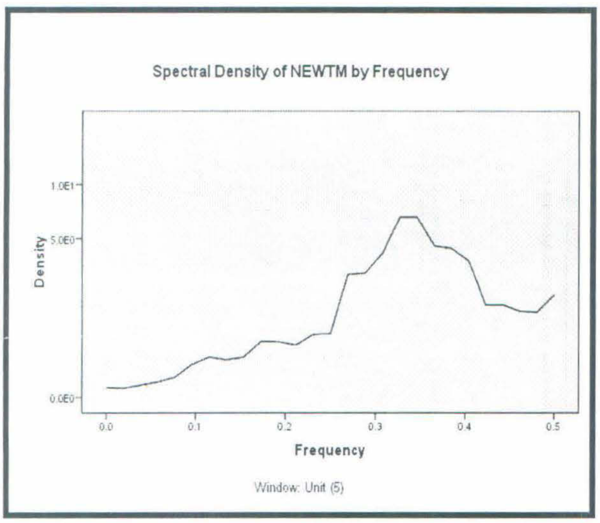
Andhra Pradesh



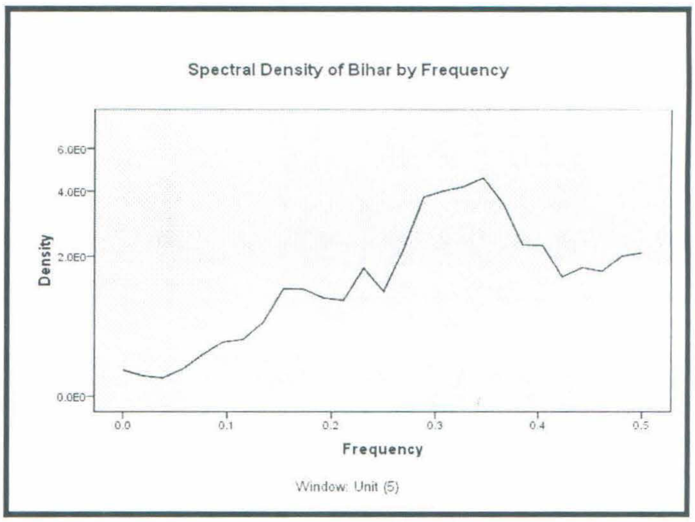
Arunachal Pradesh



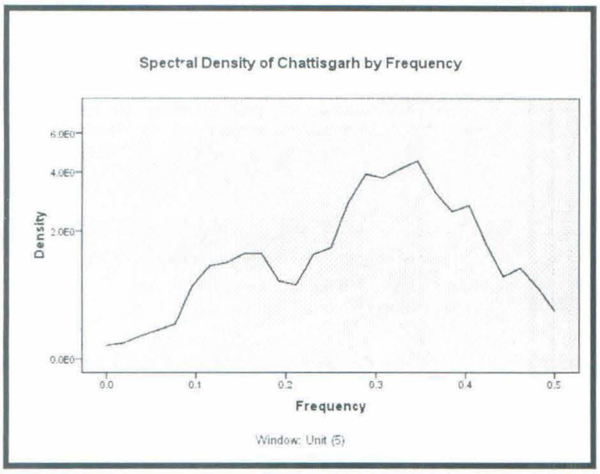
Assam



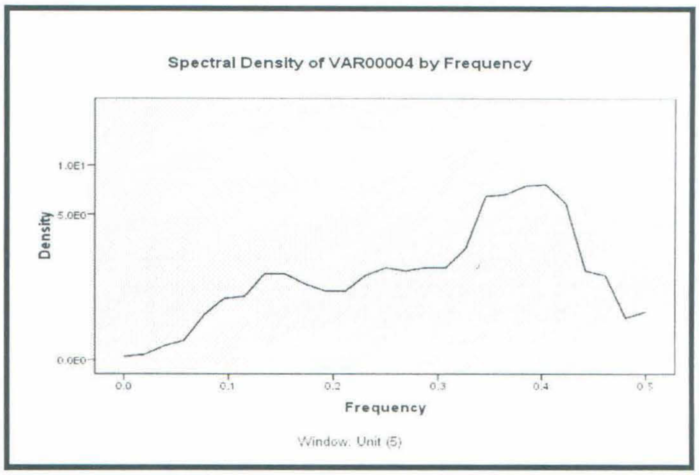
Bihar



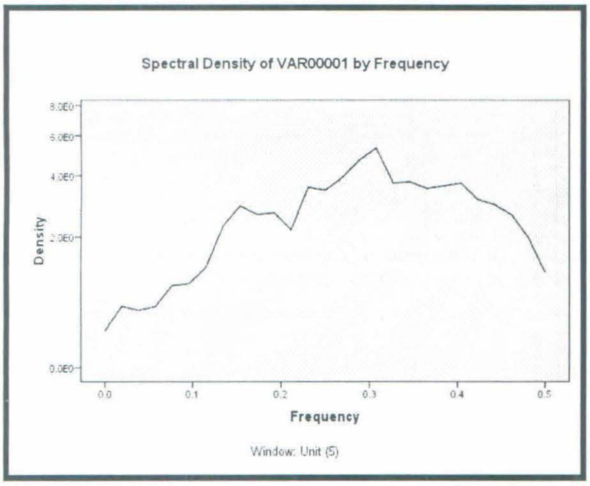
Chattisgarh



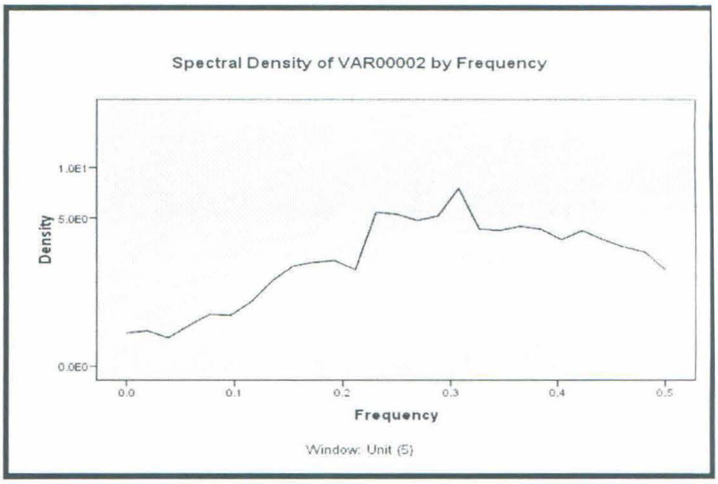
Gujarat



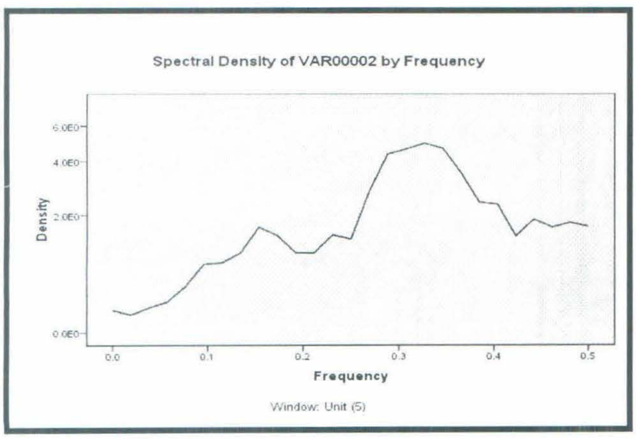
Haryana



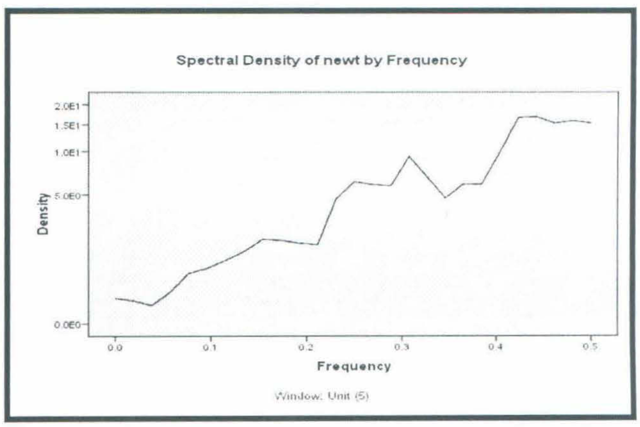
Himachal Pradesh



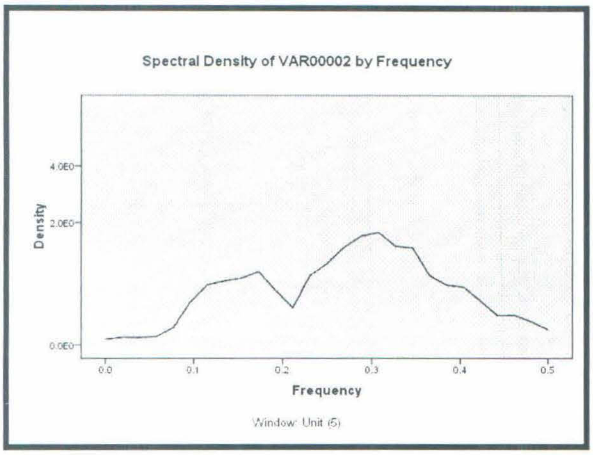
Jammu and Kashmir



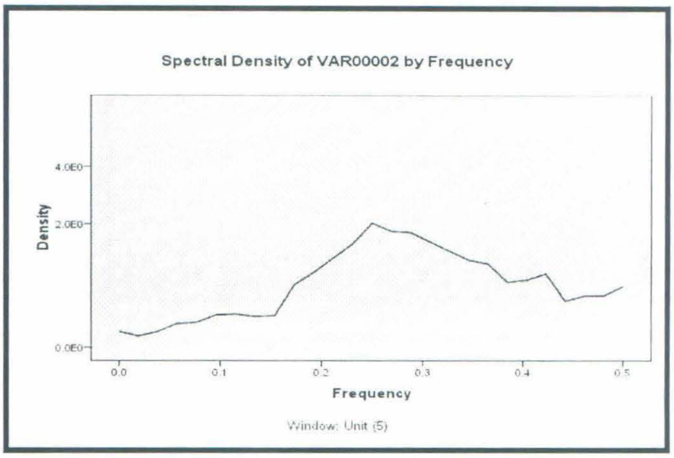
Jharkhand



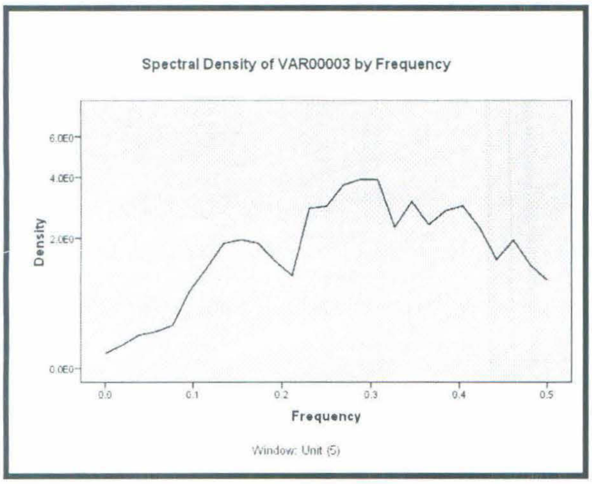
Karnataka



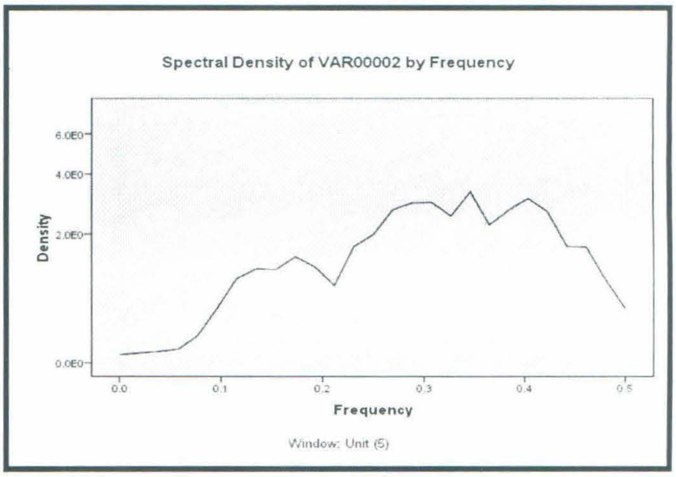
Kerala



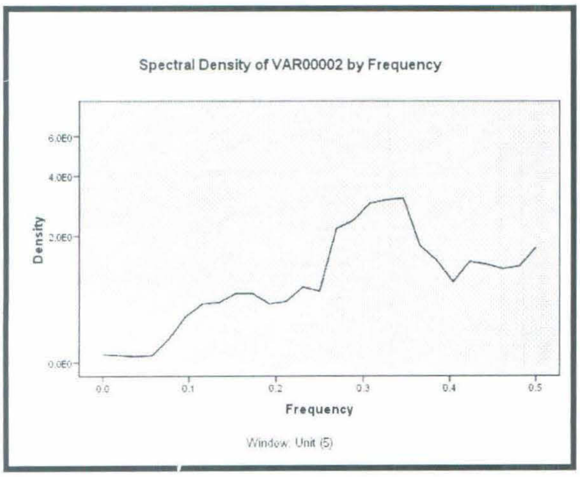
Madhya Pradesh



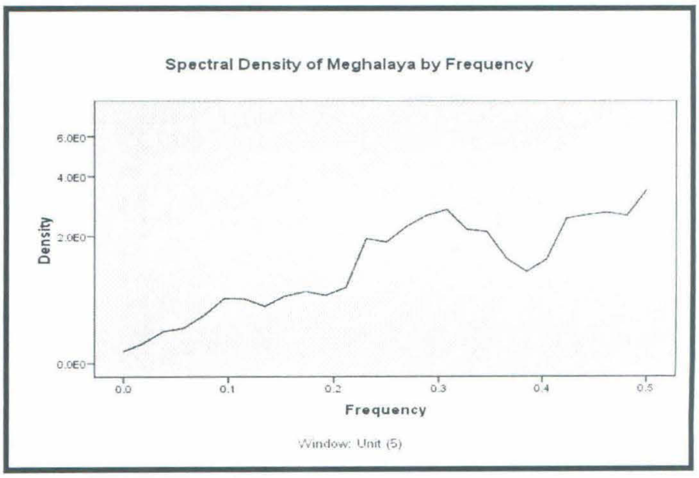
Maharashtra



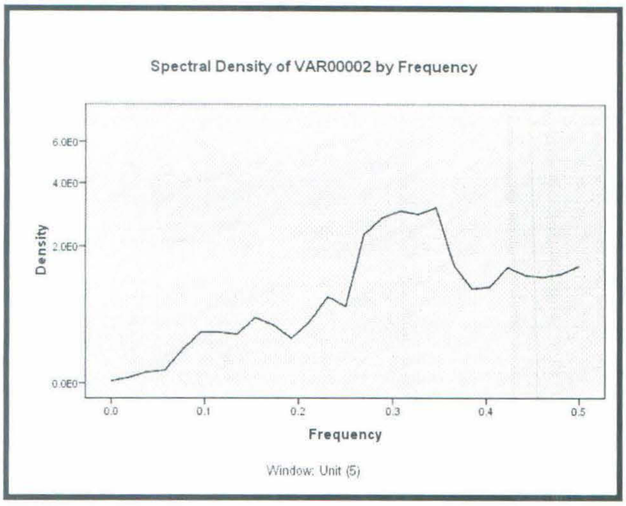
Manipur



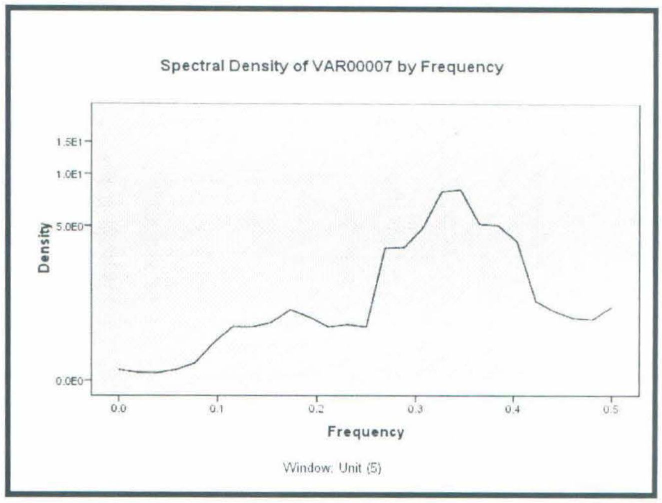
Meghalaya



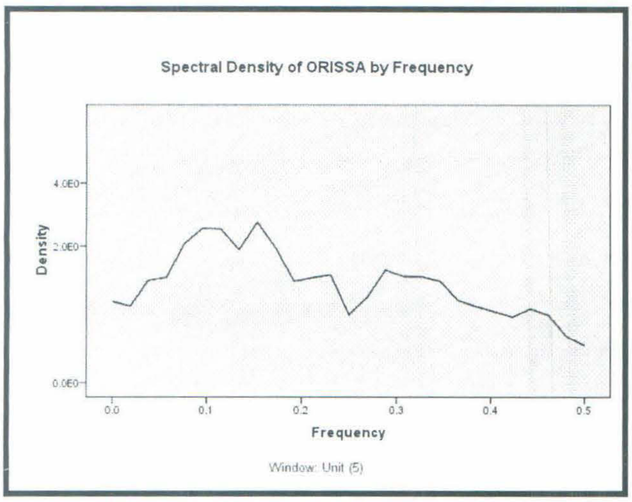
Mizoram



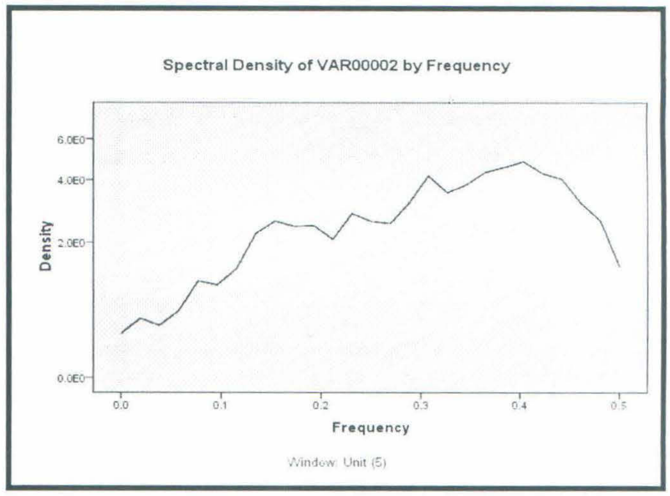
Nagaland



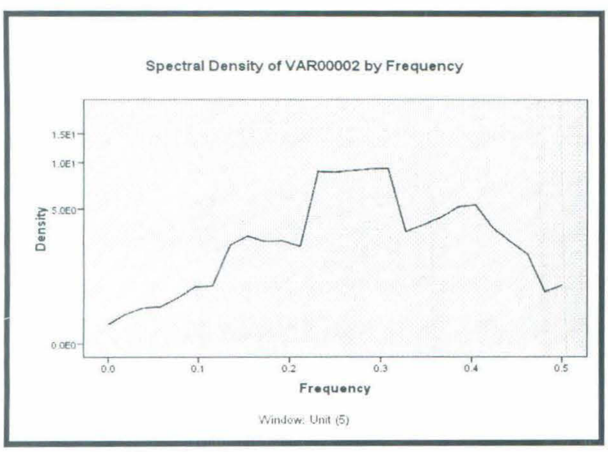
Orissa



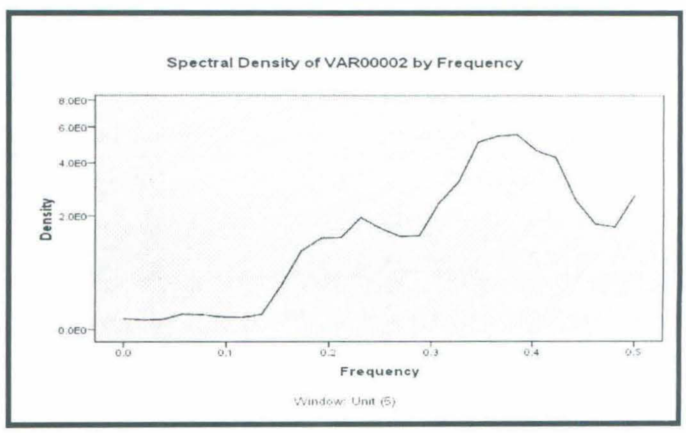
Punjab



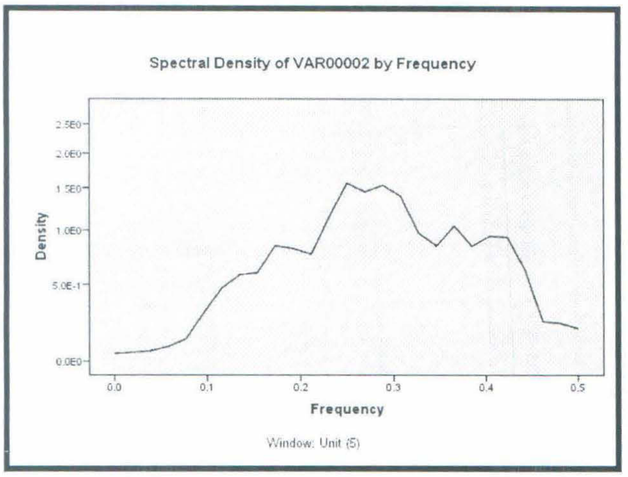
Rajasthan



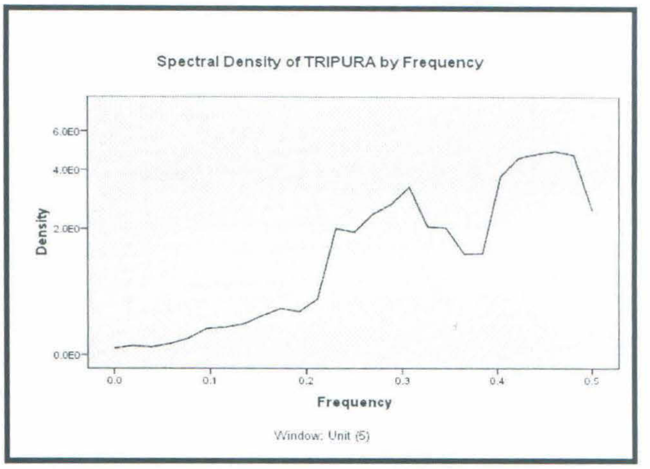
Sikkim



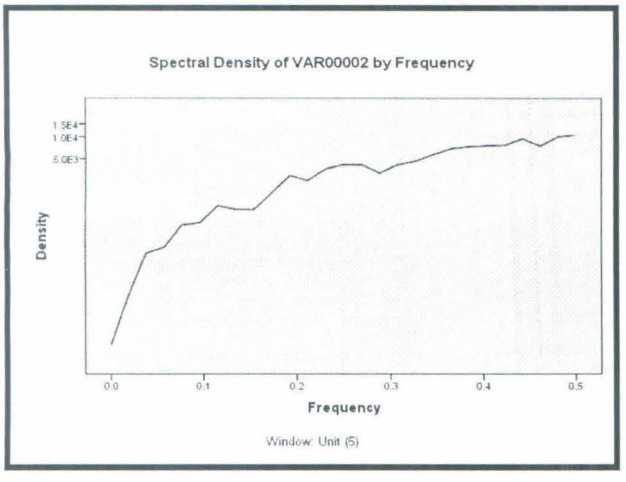
Tamil Nadu



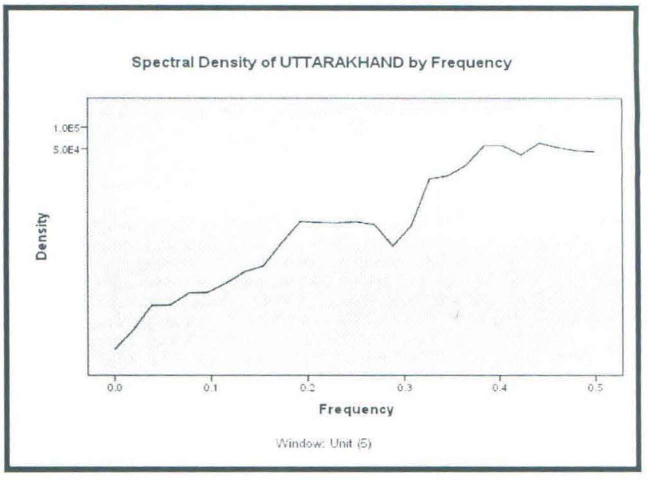
Tripura



Uttar Pradesh



Uttarkhand



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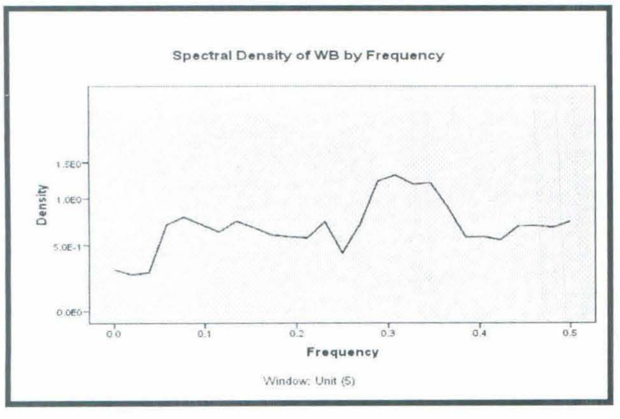
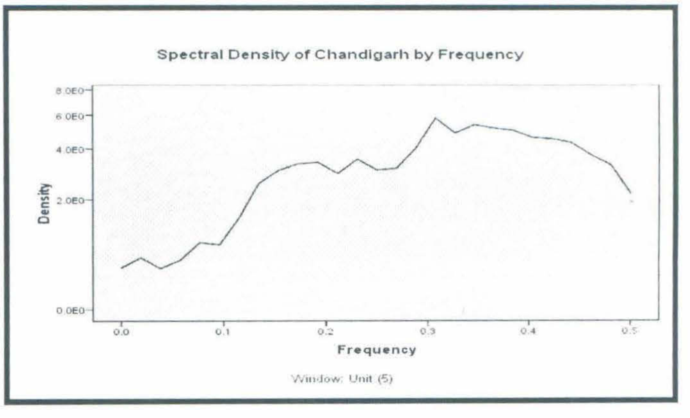
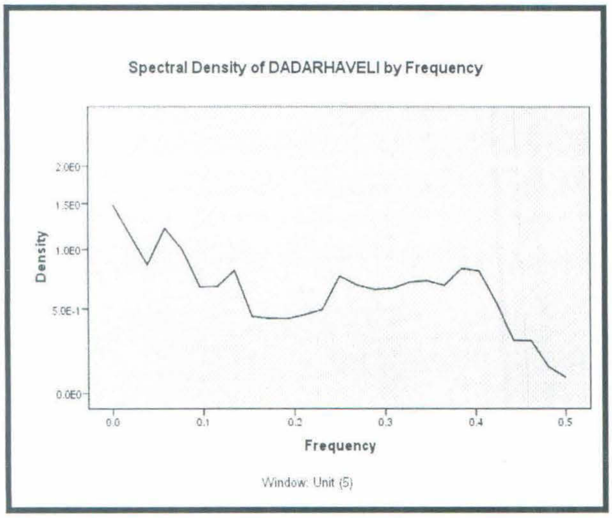


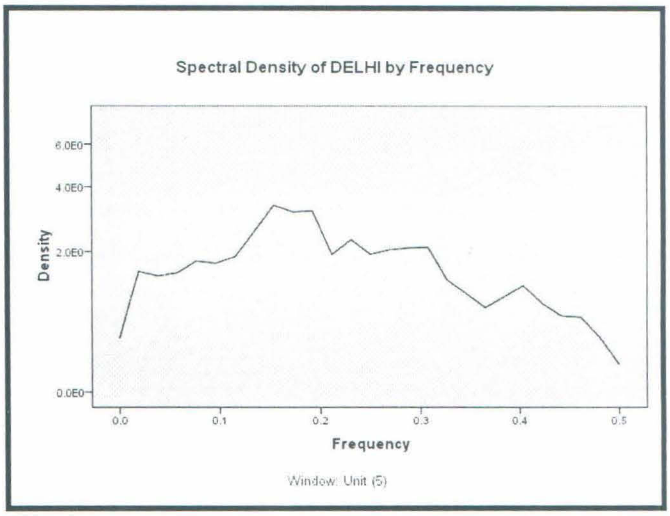
Chandigarh



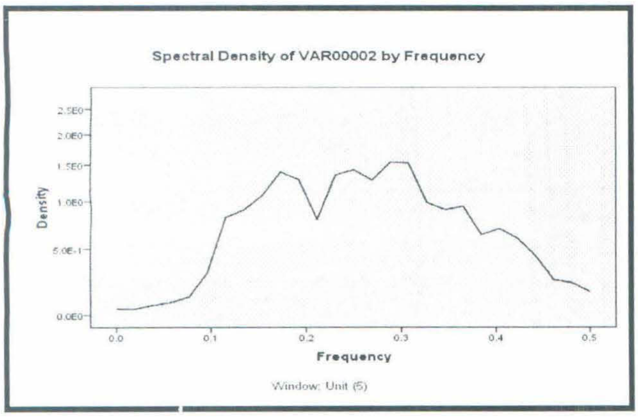
Dadar and Nagar Haveli



Delhi

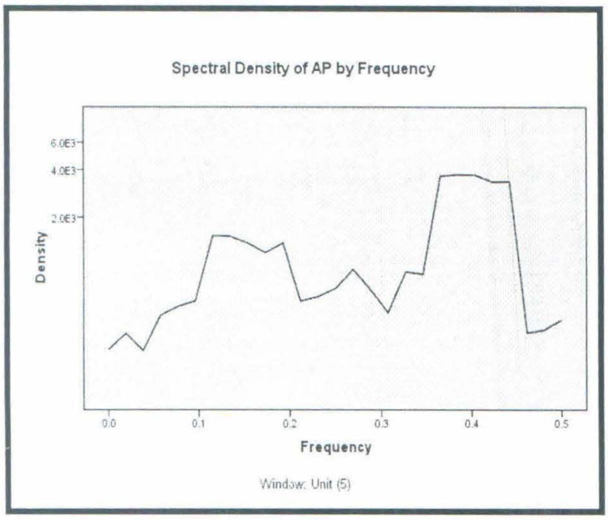


Puducherry

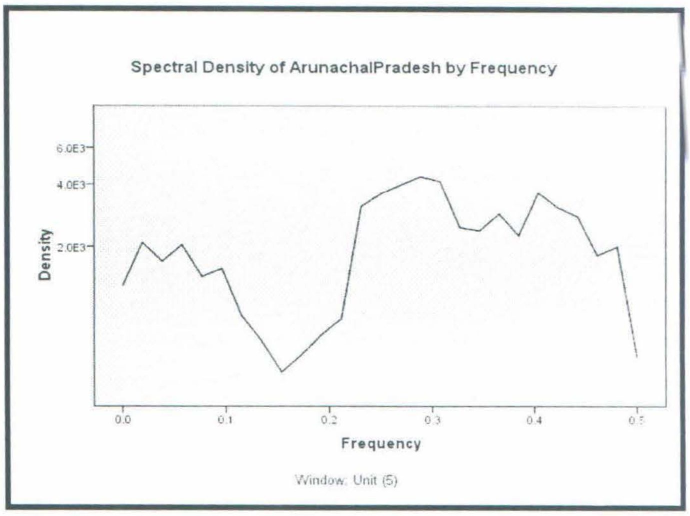


A3.6 Spectral Density (Precipitation)

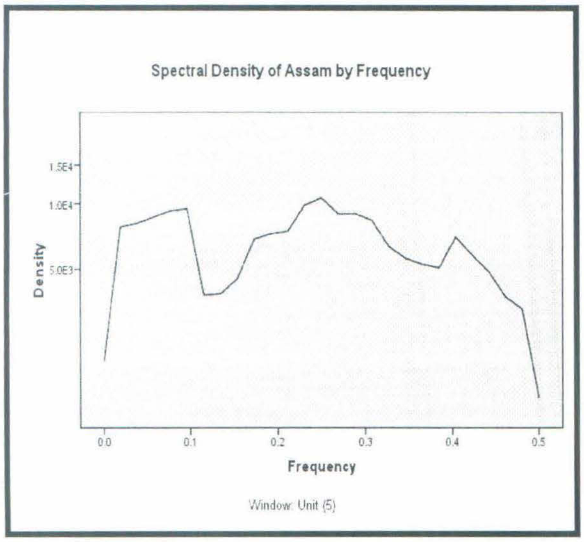
Andhra Pradesh



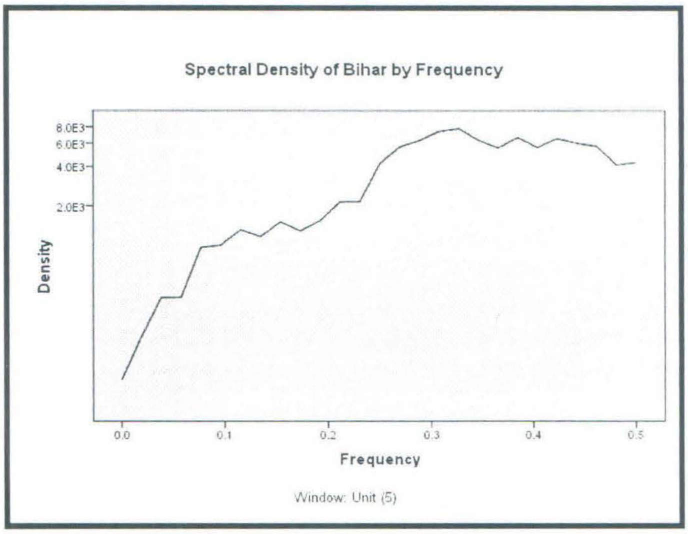
Arunachal Pradesh



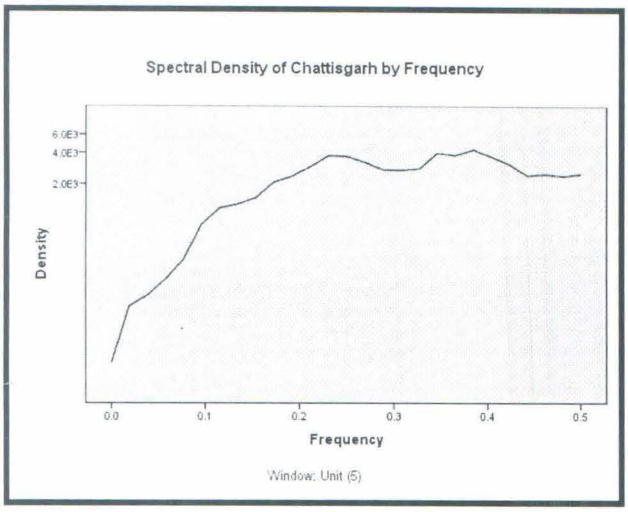
Assam



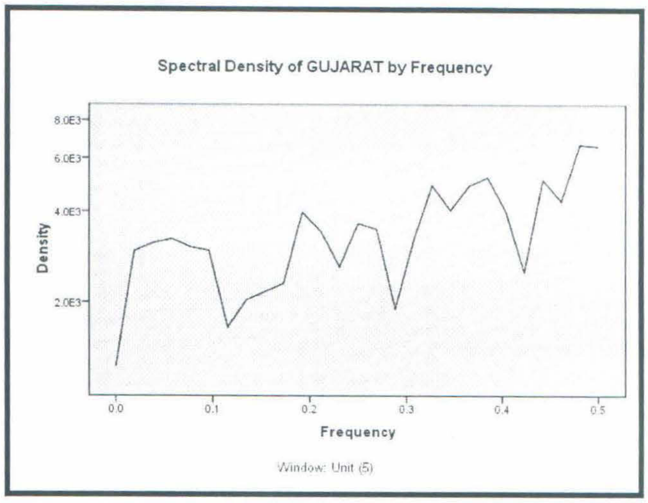
Bihar



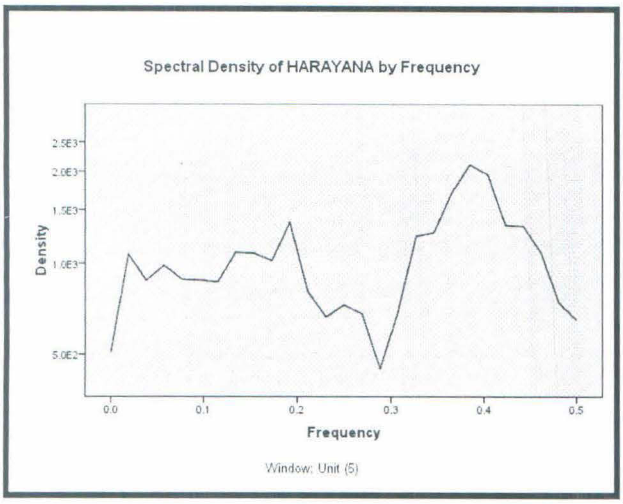
Chattisgarh



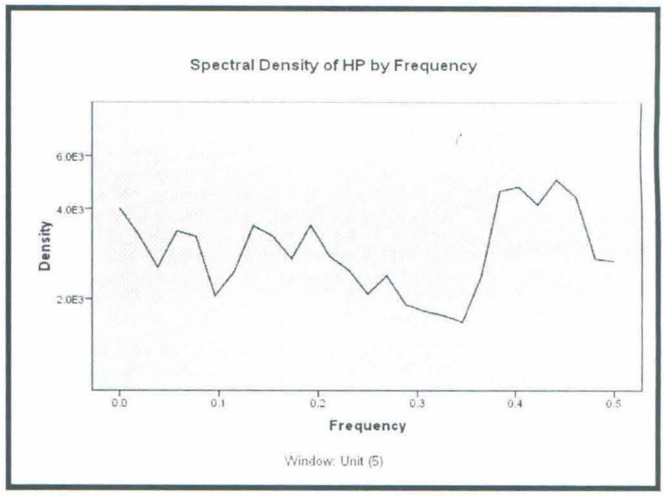
Gujarat



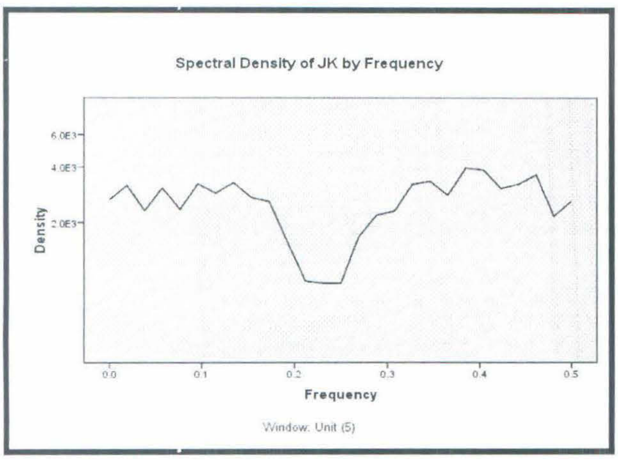
Haryana



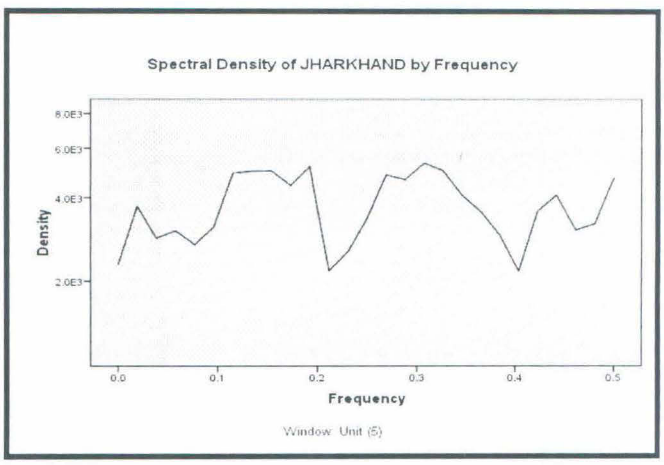
Himachal Pradesh



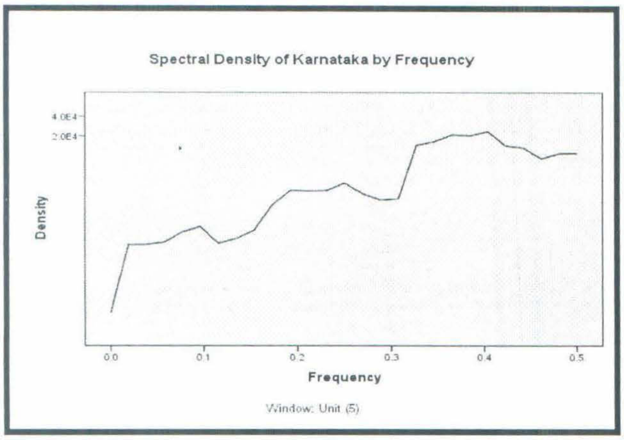
Jammu and Kashmir



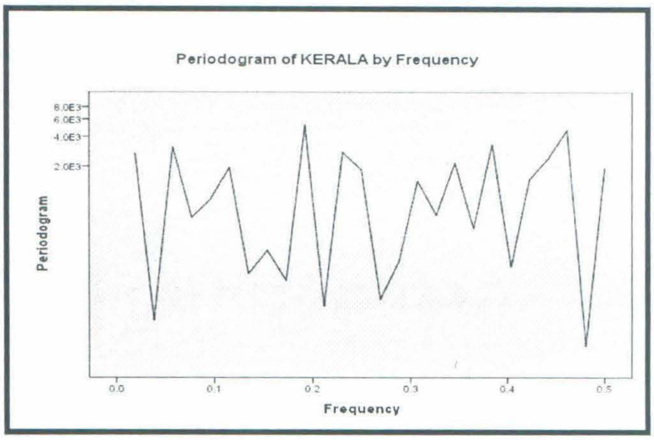
Jharakhand



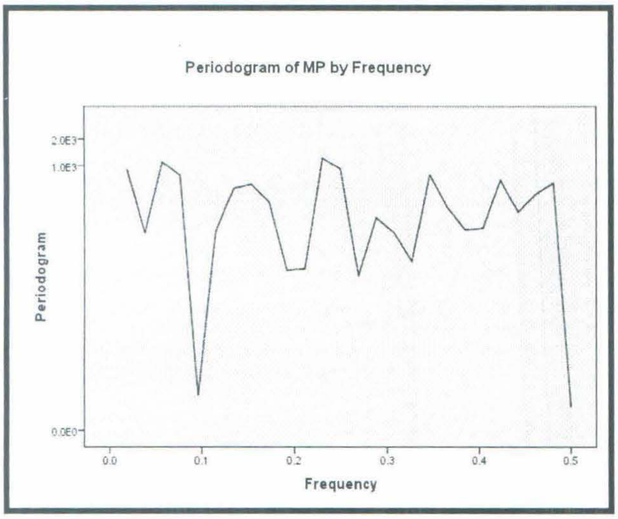
Karnataka



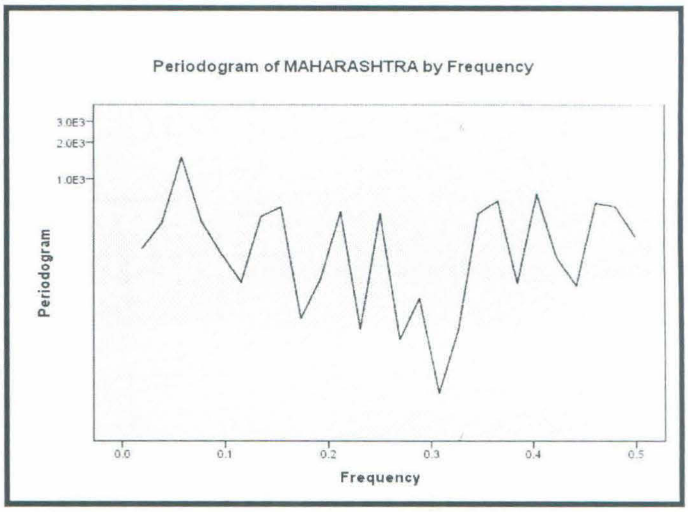
Kerala



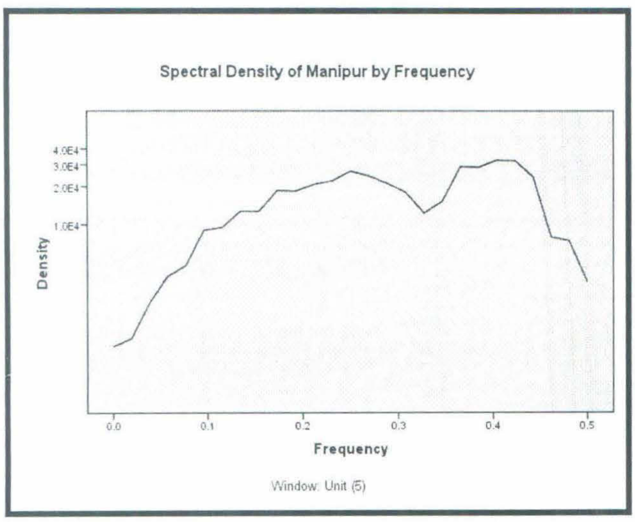
Madhya Pradesh



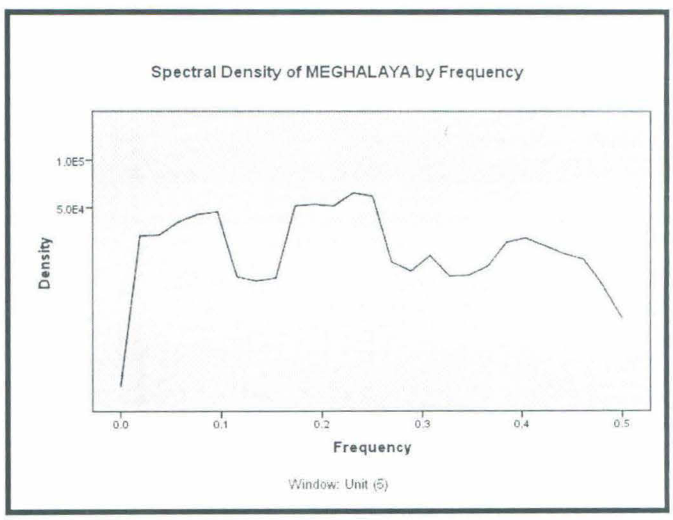
Maharashtra



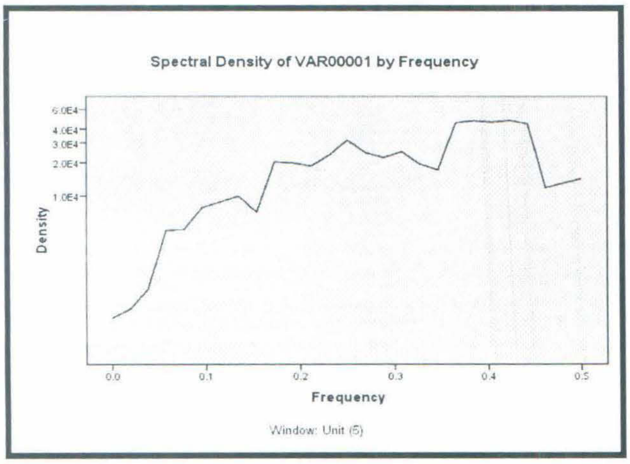
Manipur



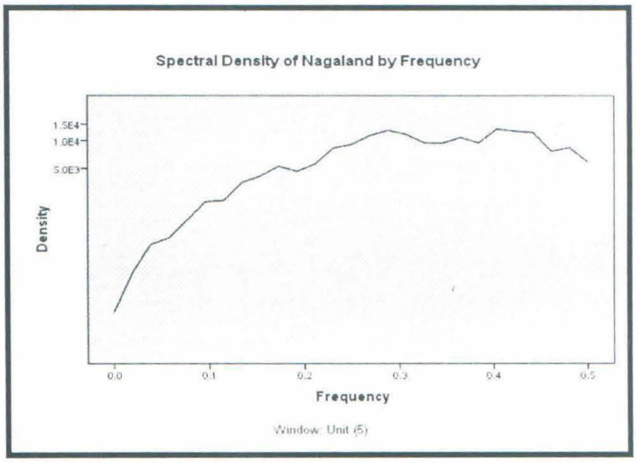
Meghalaya



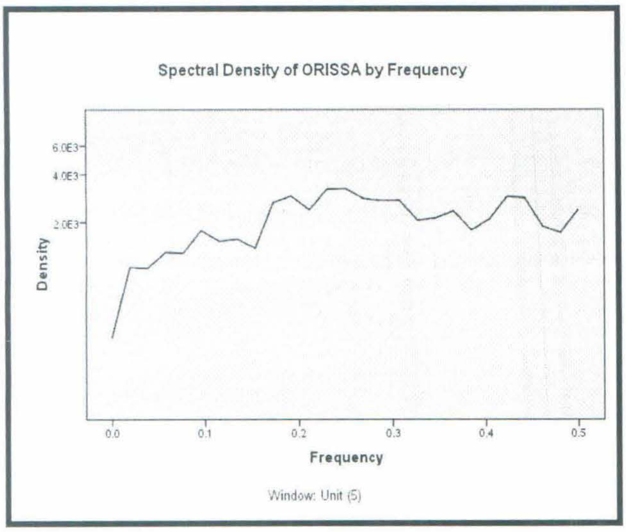
Mizoram



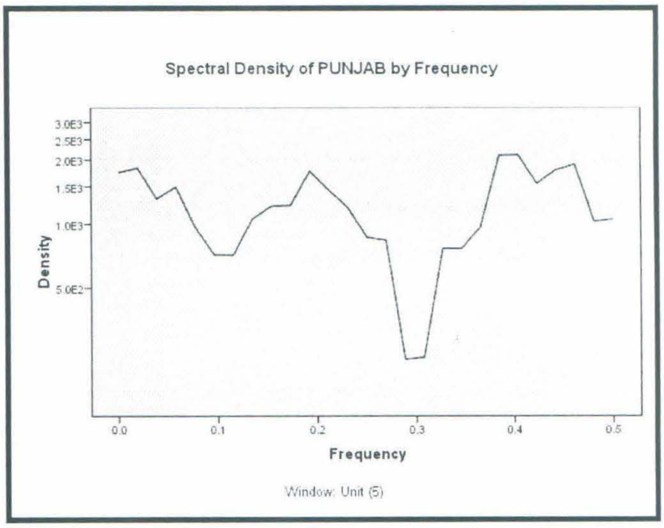
Nagaland



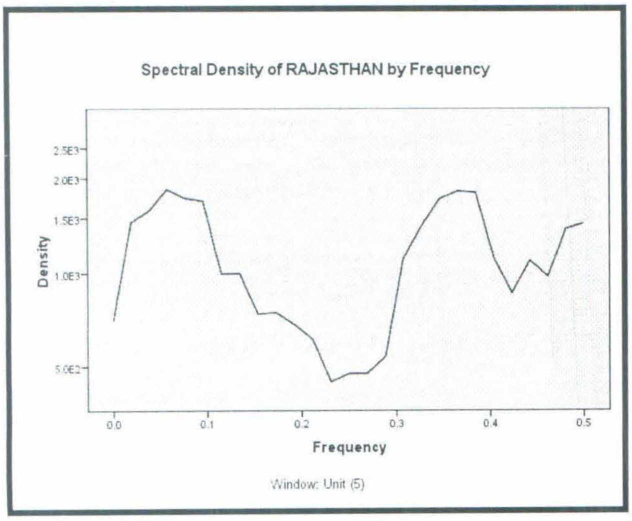
Orissa



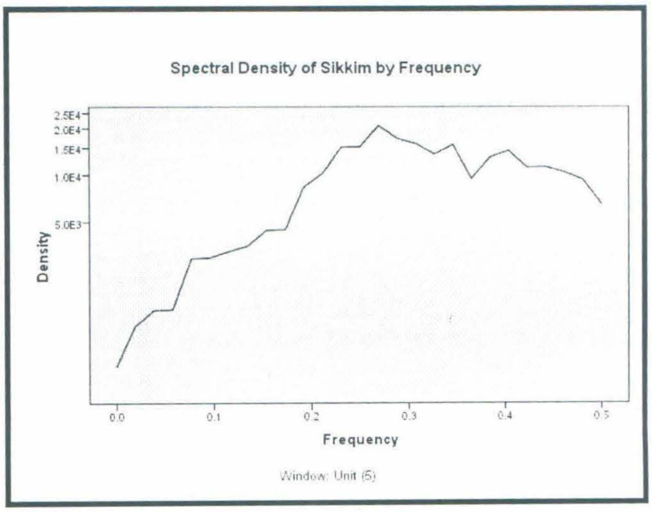
Punjab



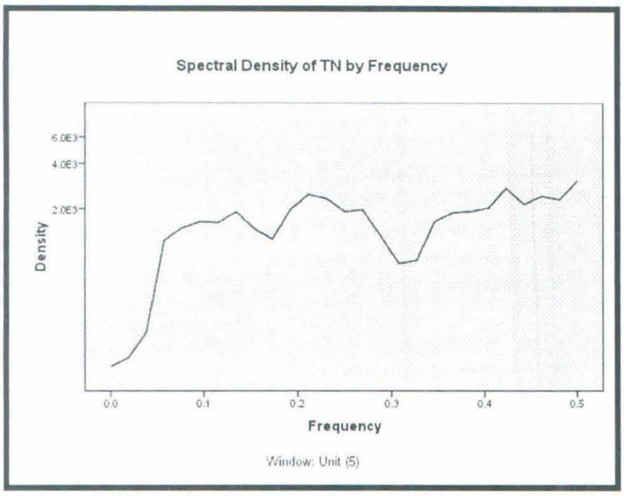
Rajasthan



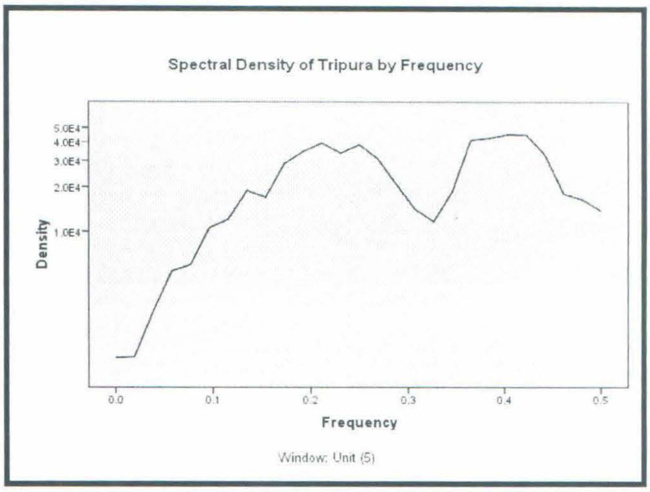
Sikkim



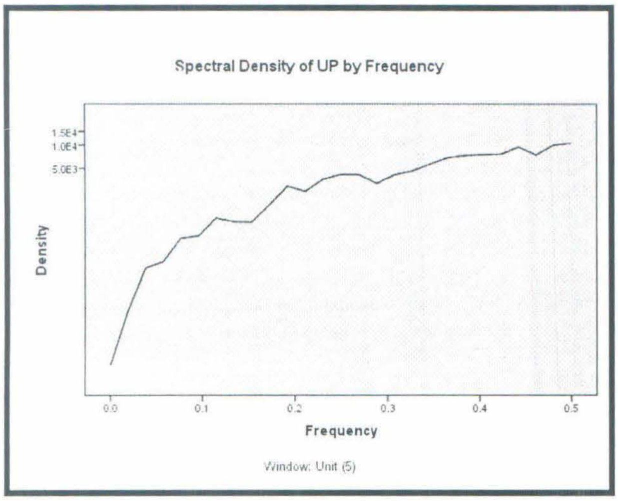
Tamil Nadu



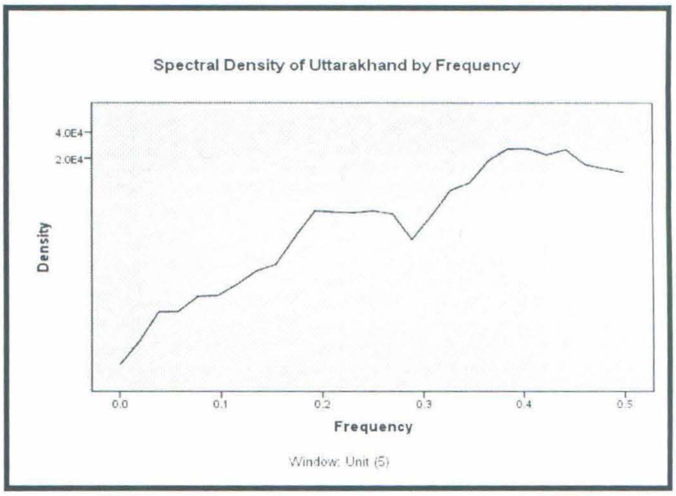
Tripura



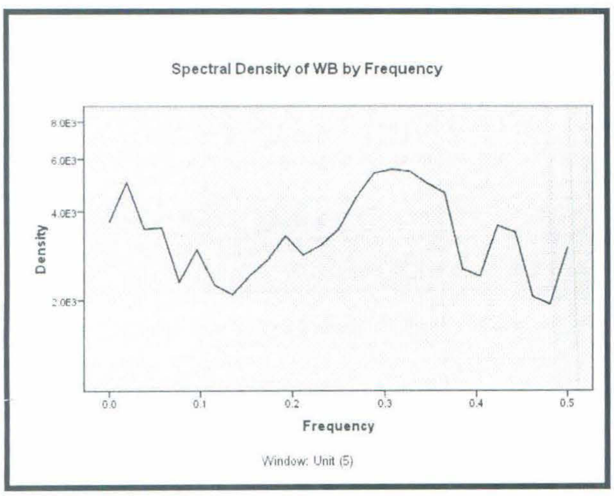
Uttar Pradesh



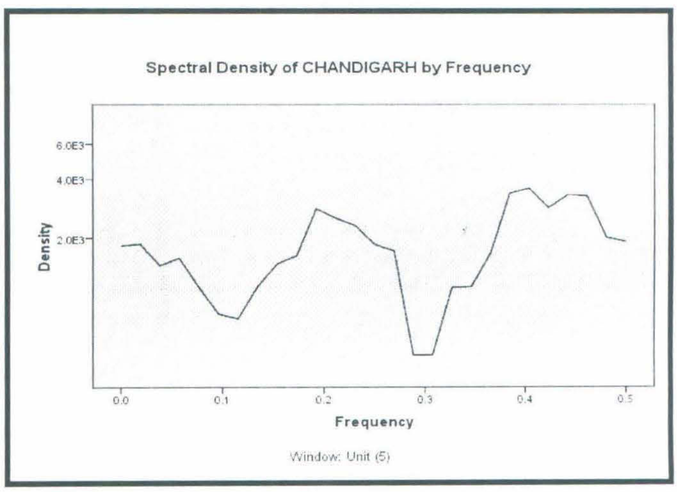
Uttarakhand



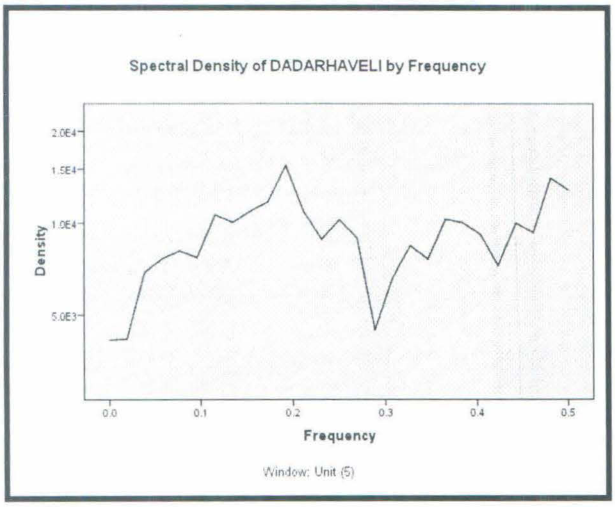
West Bengal



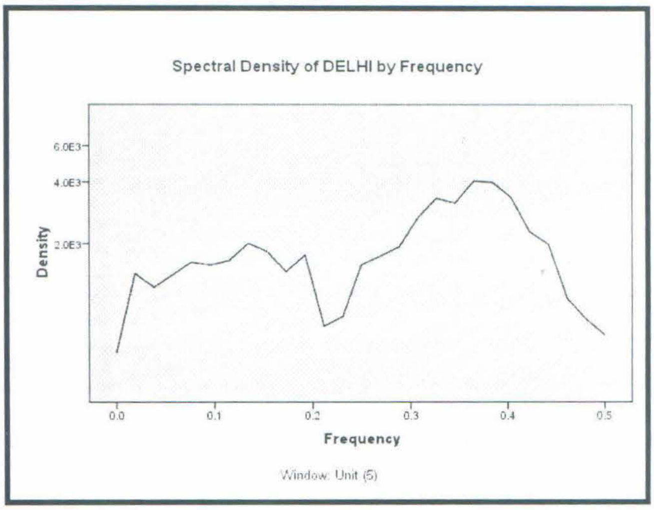
Chandigarh



Dadar and Nagar Haveli



Delhi



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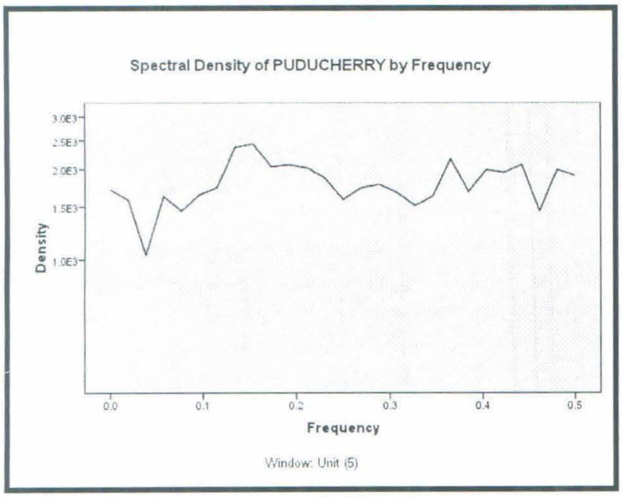


4

Productivity of Maize: A Spectral Analysis

"Maize is the crop of the future"
Nobel Laureate Dr. Norman E. Borlaug.
Father of Green Revolution

Zea mays (maize) is characterized as a warm weather crop and believed to be the basic food plant of the ancient American civilizations. The tribe Maydeae to which maize is assigned comprises eight genera, of which only three, Zea, Euchlaena and Tripsacum, are American (Mangelsdorf and Reeves, 1938). It has a unique characteristic of growing under divergent agro-temperate region[24] and due to which it is widely cultivated and has a tremendous potential as a staple food any climatic conditions.

Maize is classified into dent, flint, waxy, sweet and pop corn categories. Dent corn (*Zea mays* var. indentata) also known as field corn, containing both hard and soft starch, becomes indented at maturity. It is useful for starch processing by wet milling method. Flint corn (*Zea mays* var. indurate) having hard, horny, rounded or short and flat kernels; with the soft and starchy endosperm is enclosed by hard outer layer. Both of these varieties are used for industrial purposes. Popcorn (*Zea mays* var. everta) has small pointed and rounded kernels with very hard endosperm which on exposure to dry heat popped or evereted by the expulsion of the contained moisture and forming a white starchy mass many times the size of the original kernel. Sweet corn (*Zea saccharata* or *Zea rugosa*) is distinguished by the kernels which contain a high percentage of sugar in the milk stage and therefore suitable for table use. Therefore, due to its unique characteristic of growing and its potential uses, we further try to examine the

[24] *Maize can be grown in tropical, subtropical and temperate climates.*

productivity (in our case we have taken yield as a substitute for productivity) of maize in India for our study

This chapter is divided into five sections. The first section discusses the importance of maize, as a cereal crop with respect to the world. In the second section we move from world to India and this section discusses the importance of maize in India. In the third section we have undertaken the traditional decomposition approach to understand the relationship between area, production and yield in India. Moving forward to the next section, we have discussed the spectral analysis of productivity of maize which is followed by the conclusion in section six.

I. Maize and the World

More than 80 per cent of the world's cereal production is from the three main crops that is maize, wheat and rice. Among food grains crops, in terms of production and yield, maize occupies first position globally, followed by rice and wheat. Maize being the raw material for number of industrial products is the most important cereal crop in the world accounting to 30.74 percent of the world's production. The second and third most important crops are wheat and rice since they are the staple food for majority of the world population accounts for 26.81 and 28.39 percent respectively. Along with rice and wheat, maize provides at least 30 per cent of the food calories to more than 4.5 billion people in 94 developing countries (Braun, 2010).

Table 4.1: Share of Area, Production and Yield of the Cereal Crops in the World, 2003-04.

Sl. No.	Cereal	Area (1000 ha)	World Average Area (per cent of total)	Production (Lakh tones)	World Cereal Production (per cent of total)	Yield (kg/ha)
1	Maize	142685	21.16	6,380.43	30.74	4472
2	Wheat	208765	30.96	5563.49	26.81	2665
3	Rice	153522	22.77	5891.26	28.39	3837
4	Barley	57238	8.45	1415.03	6.82	2472
5	Coarse grains	312051	46.27	9298.35	44.80	2980
6	Coarse grains without maize	169366	25.11	2917.90	14.06	1723
7	World (Total)	674338	100	20753.10	100	3078

Source: FAO Production Year book, 2004

It is currently produced on nearly 100 million hectares of land in 125 developing countries and is among the three most popular growing crops in 75 of those countries (FAOSTAT, 2010) and has the highest yield potential among cereals. It has successfully witnessed an annual increase in production of 6 per cent in Asia, 5 per cent in Latin America and 2.3 per cent in sub- Saharan Africa in the year 2003□08 (FAOSTAT, 2010). About 67 per cent of the total maize production in the developing world comes from low and lower middle income countries (CIMMYT, 2010), hence maize plays a vital role in the livelihoods of millions of poor farmers. They grow maize for food, feed, and income in 24 diverse and mostly rain-fed farming systems accounting for about 90 per cent of the total area and are often too poor to afford irrigation. Countries like USA, China and Argentina, are the leading producers and exporters of maize, while Japan, South Korea and Egypt are in the category of major importers. Japan alone imports about 10 million tones of maize from USA, Bangladesh and Sri Lanka.

Table 4.2: India's Position in Production of Maize in the World, 2007-08

Rank	Countries	Production (Lakh tones)
1	USA	3311.75
2	China	1524.19
3	Brazil	235.13
4	Mexico	521.12
5	Argentina	217.55
6	India	189.55

Source: FAOSTAT, 2010.

Globally, USA ranks the first position in total production, followed by China, Brazil, Mexico, Argentina and India (sixth position). However, India's ranks fifth in area and 82^{nd} in productivity. Among Asian countries, India ranks 2^{nd} next to china in terms of area and production (Sharma et al., 2007).The productivity of maize hardly reached 2 t/ha, whereas, many countries like Kuwait, Isreal, Jordan, Italy, etc harvest more than 10-15 t/ha (Singh et al., 2003). In India, maize is grown in almost all the states covering an area of about 7.4 million ha with total production of around 14.5 million tones (FAO, 2005). It ranks 5^{th} in area but 3^{rd} in production and productivity in the category of cereals in India. A significant shift in area planted to high yielding dwarf varieties of rice and other high value crops like sugarcane and groundnut is one of the major reasons for such a situation. Moreover, maize cultivation has shifted remarkably to marginal lands relatively low production potential, as farmers reserved their productive lands for more profitable crops. It has so far been consider as a staple food, but due to change in the maize utilization pattern, coupled with rice and wheat production; consumption of maize as a food has decreased significantly. On the other hand the maize feed market is growing very rapidly especially in India and China, where economic growth is enabling larger numbers of people to afford milk and meat. Rapid development in those countries is also driving up demand for maize as an industrial raw material, including use for bio-fuels, thus making it a commercial crop.

II. Maize in India

The Portuguese were the one who introduced maize from America to Southeast-Asia in the 16th century and finally was introduced in India, during the seventeenth century. States like Andhra Pradesh, Madhya Pradesh, Rajasthan, Karnataka, Uttar Pradesh, Bihar, Gujarat, Maharashtra, Himachal Pradesh and Jammu and Kashmir are the major maize producing states in India. It is traditionally grown as a staple food destined primarily for human consumption. In terms of total area under cultivation, it ranks fifth in India and third in total productivity (*Handbook of Agriculture, ICAR, 2006*).

Indian maize has white, red, purple, brown or multicolor kernels and is characteristically dent corn. It plays an important role in the Indian economy in general and rural economy in particular. The young maize ear shoots called baby corn are harvested as soon as the plant flowers and are used for preparing corn soup and vegetables; the tender green ears of sweet corn are used in various ways like roasting and boiling it so that it can be consumed as food; the plants as a whole are used as green fodder for animals and the dying plants are used as dry fodder as well as it is used as a fuel in rural households. It is also used as flour for "chapattis". However, in recent years significant changes have occurred as a result of growing commercial orientation of the agriculture economy and rising demand on maize on account of its diversified end uses. The maize yield has increased mainly due to the use of high yielding seeds and extension in the area under winter maize and that the yield of rice and wheat have almost reached at its highest level. Therefore, in the coming years maize may emerge as a staple food for human consumption in India if the demand for rice and wheat is not met.

It is an important coarse cereal crop and has wide agro-ecological amplitude extending from the Himalayas to the southern plateaus. Maize is successfully cultivated under varying environmental conditions throughout the country especially during *kharif, rabi* and spring seasons in peninsular India; *kharif* and spring seasons in Indo-Gangetic plains and only during *kharif* season in hilly regions (where it forms the staple food of the people). Geographically, the area spreads form 11.0 to 34.0′ N and 74.14 to 94.16′ E and also at 9.73 to 2680 meters above mean sea level. The soil cultivated generally varies from sandy clay, medium black to silty clay loam. Deep heavy soils are considered more suitable in views of their better water-holding capacity. Saline and alkaline soils should be avoided, since these affect crop growth and development adversely right from the initial phase of germination to maturity.

III. Area, Production and Productivity of Maize in India

In 1951, the area under maize production was 3.3 million hectares contributing 2.08 million tones in production with average yield of 6.27 tonnes per hectare. Uttar Pradesh was the leader in the total area and production, whereas Jammu and Kashmir was the leader, in yield. States like Punjab and Uttar Pradesh stood second and third respectively, with average yield of 8.17 and 7.82 tonnes per hectare. Bihar showed a poor performance, albeit it ranked second in terms of total area and production but ranks sixth in terms of the average yield which was less compared to other states. On the other hand Punjab showed a steady position with an average yield of 8.17 tonnes per hectare. In the successive decades there was a remarkable jump in the total area under maize from 3.3 million hectares in 1951 to 4.5 million hectares in 1960-62 to 5.7 million hectares in 1970-72. In the latter decades the area under maize was not significantly increased till 2001-03, when the total area increased from 5.9 million hectares in 1990-92 to 6.7 million hectares in 2001-03. There was a visible increasing trend in the average yield per hectare. The average yield increased to 19 tonnes per hectare in the year 2001-03. The increase in the yield was mainly due to the introduction and use of high yielding variety seeds and the use of more chemical fertilizers.

Table 4.3: Trend Analysis of Area, Production and Yield of all the States Producing Maize

States	1951			1960-62			1970-72			1980-82			1990-92			2001-03		
	A	P	Y	A	P	Y	A	P	Y	A	P	Y	A	P	Y	A	P	Y
A.P	64.52	39.3	276	183.47	159.67	885	244.33	272	1110	324.5	648.9	1996	320.67	720.8	2245	558.67	1807.33	3221
Br	644.76	365	576	816.8	822	1024	889.67	682	740	846.67	914.2	1081	675.17	1184.8	1754	489.6	1149.9	2225
Gj	-	-	-	209.95	264	1278	265	377.33	1415	307.77	368.43	1193	360	479.2	1324	464.17	836.37	1806
H.P	112.9	64.7	584	115.59	142	1249	252.33	402	1588	284.23	429.03	1511	314.9	628.6	1996	298.93	659	2202
J&K	134.56	115.7	876	231.72	218.33	959	275.67	369.67	1341	275.33	453.83	1645	296.43	465.53	1571	325.73	511.93	1573
Kta	-	-	-	-	-	-	120	425	3546	155.77	387.67	2491	278.4	827.9	2943	616	1387.97	2262
M.P	366.53	134	372	473.25	464.67	1002	590.33	557	944	775.53	750.47	966	864.87	1156.67	1337	871.47	1686.47	1932
Mh	186.98	103.3	563	26.48	15	577	29.67	25.33	813	74.67	119.5	1604	133.93	179.5	1302	360.5	696.03	1925
Pb	376.61	302	817	554.57	597.33	1102	553	870.33	1574	340	589	1739	184.67	372.33	2015	157	406	2580
Rj	335.48	109	331	673.66	695.33	1050	778	781	974	902.33	733	812	958.73	1022.73	1063	1037.17	1472.9	1401
T.N.	-	-	-	-	-	-	14.33	15.33	1088	22.07	43.2	1940	36.7	54.53	1486	129.9	213.53	1654
U.P	807.66	621	782	1065.99	761.33	726	1485.67	1313.33	882	1180.17	916.67	779	1081.27	1447.93	1336	883.1	1233.57	1368
W.B	60.36	40	675	54.44	33	616	47.67	41.33	868	51.77	57.77	1116	55.37	120.17	2262	33.97	79.4	2317
Ot	219.64	182	*	113.08	160.34	*	240.33	194.35	*	345.19	389.33	*	347.89	345.31	*	371.99	493.47	*
All India	**3310**	**2076**	**627**	**4519**	**4333**	**958**	**5786**	**6326**	**1091**	**5887**	**6801**	**1155**	**5909**	**9006**	**1523**	**6735.17**	**12852.2**	**1900**

Source:Chauhan et al (2007)

Note: A= Area; P= Production; Y= Yield; A.P= Andhra Pradesh; Br=Bihar; Gj= Gujara; H.P= Himachal Pradesh; J&K= Jammu and Kashmir; Kta= Karnataka; M.P= Madhya Pradesh; Mh= Maharashtra; Pb=Punjab; Rj= Rajasthan; T.N= Tamil Nadu; U.p= Uttar Pradesh; W.B= West Bengal; Ot=Others.

Albeit there has been an increase in the total yield and production over India, there are interesting stories to seen inside the states. Andhra Pradesh is one among them. In 1951, it was a state with only .039 million tonnes production to 1.8 million tonnes production. It is presently the hub of supplying important hybrid seeds like Kanchan, Pioneer and Proagro to both domestic and international maize growers. Rajasthan also showed an increasing trend with respect to total area under maize, i.e. from 0.3 million hectares in 1951 to 1.03 million hectares in 2001-03, while Punjab which was earlier one of the important maize growing states lost its ground significantly during the decade of 1980-82 and the process continued evident from the table mainly due to shifting of cropping pattern in favour of Paddy (wheat rotation) after the green revolution and the introduction of minimum support price effectively. It can also be seen that Jammu and Kashmir did not witness any remarkable progress in maize production. Rice, followed by maize, wheat and barley are the major crops grown in this area but due to excessive dependent on rain, there might may a possible reason for the decline in its production as well as yield.

The table below (Table 4.4) reveals that over 90 per cent of the total area under maize and production is shared by the states like Andhra Pradesh, Madhya Pradesh, Rajasthan, Karnataka, Uttar Pradesh, Bihar, Gujarat, Maharashtra, Himachal Pradesh and Jammu and Kashmir. The table ranks the states according to there area, production and yield of maize in India. While Andhra Pradesh ranks first in both total production (14.06 per cent of total production in India) and yield (32.21 q/ha), Rajasthan stands first with respect to area (15.40 per cent of the total area in India) under maize cultivation. States like Himachal Pradesh, Jammu and Kashmir and Uttar Pradesh lies in the bottom most rank in area, production and yield respectively.

Table 4.4: Ranks of States by Area, Production and Yield (Triennium Average, 2001-03)

State(s)	Area (% of total)	Ranking	Production (% of total)	Ranking	Yield (q/ha)	Ranking
Andhra Pradesh	8.29	5	14.06	1	32.21	1
Madhya Pradesh	12.94	3	13.12	2	19.32	5
Rajasthan	15.40	1	11.46	3	14.01	9
Karnataka	9.15	4	10.80	4	22.62	2
Uttar Pradesh	13.11	2	9.60	5	13.68	10
Bihar	7.27	6	8.95	6	22.25	3
Gujarat	6.89	7	6.51	7	18.06	7
Maharashtra	5.35	8	5.42	8	19.25	6
Himachal Pradesh	4.44	10	5.13	9	22.02	4
Jammu and Kashmir	4.84	9	3.98	10	15.73	8

Source: Chauhan et al., 2007.

Table 4.5 shows the percentage change of area, production and yield for all the major maize producing States in India. The overall percentage increase in yield is seen highest in Andhra Pradesh (1132.10 per cent) followed by Maharashtra (597.50 per cent) and Karnataka (583.73 per cent). The state affected most according by the climate change that is Jammu and Kashmir[25], which basically grows Maize and Rice ranks fifth in terms of overall change in yield (403.80 per cent), sixth in terms of area (-10.76 per cent) and ninth in terms of production (349.40 per cent) change in the past fifty years. Apparently, Karnataka has witnessed an increase in terms of area and Production but then it has not seen any remarkable change in yield. States like Andhra Pradesh[26] which has witnessed a good amount of positive change in precipitation as well as a small increase in temperature has been among the top most states with highest yield so

[25] *Refer to the results of the previous chapter 3.*
[26] *Refer to the results of the previous chapter 3.*

Table 4.5: Percentage Change in Area, Production and Yield by States Producing Maize

States	%change in 60s over 50s			%change in 70s over 60s			%change in 80s over 70s			%change in 90s over 80s			%change in 2000s over 90s			%change in 2000s over 50s		
	A	P	Y	A	P	Y	A	P	Y	A	P	Y	A	P	Y	A	P	Y
A.P	-45.7	455	-54.3	38.4	67.6	1110.8	25.2	110.8	68.3	-3.5	-11	-7.7	70.6	144.9	43.5	54.8	4173	1132.1
Asm	-70.2	-53.8	-31	-12.9	11.7	28.3	85.2	100	8	-8.8	-3.7	5.6	-1.9	13.2	15.5	-57	12.31	16.6
Bh	-46.9	68.7	41.7	33.4	114.9	61.3	-12.5	-61	-13.4	7.1	78.1	31.3	-3.3	-21.9	44	-35.8	96.8	274
H.P	Nil	Nil	Nil	Nil	Nil	Nil	10.7	-11.2	-19.8	10.9	52.8	37.8	-6.6	4.4	11.7	4.6	935.8	341.8
J&K	-54.9	50.4	233.5	61.3	108.1	29	2.15	34.7	31.8	8.2	-9.7	-16.5	10.9	18	6.3	-10.8	349.4	403.8
Knta	-54.2	80	75.2	478.2	2180	294.4	146.9	83.5	-25.6	60	67.4	5.3	167.9	238.7	26.4	2687.1	42612	583.7
M.P	-48.7	14.5	129.7	28.7	115.5	67.5	-34.9	-2.2	-8.4	26.8	83.3	35.5	-4.3	8.4	-43.1	-47.8	1007.1	171.4
Mh	-50.7	Nil	Nil	51.4	Nil	Nil	-170	-50	15.8	10.2	173.6	-11.3	-4.6	-11	-37.7	-34.8	468.7	597.5
Ori	-74.4	-30.8	20.6	228.6	558.9	100.5	150	193.9	17.7	-62.9	18.9	28.3	-23.1	-66.7	2.3	-40.1	430	273.4
Pb	-42.7	228.7	156.2	-38	-30.2	2.2	-32.4	-30.6	1.1	-50.7	-44	17.4	-19	28.6	66.8	-90.4	14.6	418.7
Rj	-21.2	466.3	221.3	24	78.5	42.4	19.9	-15.5	-28.9	9.2	65.9	51.9	-1.4	-22.1	-21	26.3	1004.1	290.7
T.N.	-50	50	33.9	178	155	-8.3	41	37.2	-2.7	40.3	108.6	48.9	196.4	219.4	7.7	715	3397.5	91.6
U.P	-47	75.9	48.2	38.1	59	15.3	-17.4	-74.7	-6.6	-11	58.9	19	-18.1	6	23.1	-55.9	19.5	133.6
W.B	-58.8	51.6	64.2	-8.9	2.3	12.4	3.14	15.6	12.1	22.81	46.8	19.5	-45.4	8.2	98	-74	184.8	389.4

Source:Agricultural Census of India (Various issues)

Note: A= Area, P= Production, Y= Yield; A.P= Andhra Pradesh; Asm= Assam; Bhr=Biharand Jharkhand;; H.P= Himachal Pradesh; J&K= Jammu and Kashmir; Kta= Karnataka; M.P= Madhya Pradesh and Chattisgarh; Mha= Maharashtra and Gujarat; Pb=Punjaband Haryana; Rj= Rajasthan; T.N= Tamil Nadu; UP= Uttar Pradesh and Uttarakhand; and W.B= West Bengal far. Thus, the traditional approach shows that there has been an inter-relation between the precipitation, temperature and yield. Having done with the traditional approach, now let us take up spectral analysis discussed in the earlier chapter to analyze yield of maize in India. Since yield is the major component of productivity and is determined by climatic factors.

IV. Maize Yield: Spectral Analysis

In the previous chapter we have done spectral analysis of climatic factors namely temperature and precipitation, similarly, in this section we are going to do spectral analysis of yield of all major producer of maize in India. Here also we undergo the trend analysis, the periodogram, the Fisher test, the Harmonic analysis and the spectral density in order to detect and describe the pattern of the time series data of yield and to further proceed for cross spectral analysis. Initially the series are adjusted for the trend and cyclical components. The resulting series is used for estimation of the spectral density.

IV.a. Trends in Yield: A Long-run Analysis

Trend can be defined as the 'long term' movement in a time series. The Table 4.6 shows the presence of a linear trend in the time series data sets of yields for a period of 53 years. The Table 4.6 depicts the State-wise as well as all India's values of R^2, F statistic and probability values of the significance of linear trend in the series of maize yield. The R square describes the proportion of variability that can be explained by the linear trend. Interestingly, all the States as well as the overall India show a significant linear trend. The R square in the table shows that the linear trend accounts for 88 per cent of variance in the time series for all India. Therefore, the trend removal was applied to these data sets prior to doing spectral analysis. It is interesting to note that linear trend is significant in all States unlike in the case of climate.

Table 4.6: Trend Analysis of All the States Producing Maize

State(s)	No of Observations.	R Square	F	P Values
Andhra Pradesh	53	.850	289.335	.000
Assam	53	.805	214.940	.000
Bihar	53	.517	55.733	.000
Gujarat and Maharashtra	53	.672	102.637	.000
Haryana and Punjab	53	.621	85.048	.000
Himachal Pradesh	53	.730	135.165	.000
Jammu and Kashmir	53	.736	144.961	.000
Karnataka	53	.605	79.691	.000
Madhya Pradesh	53	.651	96.835	.000
Orissa	53	.777	180.984	.000
Rajasthan	53	.186	11.861	.001
Tamil Nadu	53	.557	65.257	.000
Uttar Pradesh	53	.693	117.540	.000
West Bengal	53	.760	164.708	.000
All India	53	.883	384.872	.000

Source: Agricultural Census of India (Various issues).

We have taken the first order differencing which is the most common method in econometric analysis of time series data. The detrended series is then taken to test the significance of cycle.

IV. b. Cycles in Yield: A Short-run Analysis

In this case we have frequency domain analysis of the differenced series. In other words, it is the analysis of variance of the frequency domain in the time series. In order to know the whether there is any cyclical fluctuations in the series, we first do the periodogram analysis and then we undergo the Fisher cyclical test, as done in chapter 3. The results of the test are mentioned in Table 4.7. The periodogram are given in Appendix 4.1. The peaks are then taken for its statistical significance using Fisher test. The results of the statistical test are given in Table 4.7.

Table 4.7: Fisher's Significance Test of All the States

State(s)	Significance
	Yield
Andhra Pradesh	Nsig.
Assam	Nsig.
Bihar	Nsig.
Gujarat and Maharashtra	**Sig.**
Haryana and Punjab	Nsig
Himachal Pradesh	Nsig
Jammu and Kashmir	Nsig.
Karnataka	Nsig.
Madhya Pradesh	Nsig.
Orissa	Nsig.
Rajasthan	**Sig.**
Tamil Nadu	Nsig.
Uttar Pradesh	**Sig.**
West Bengal	NSig.

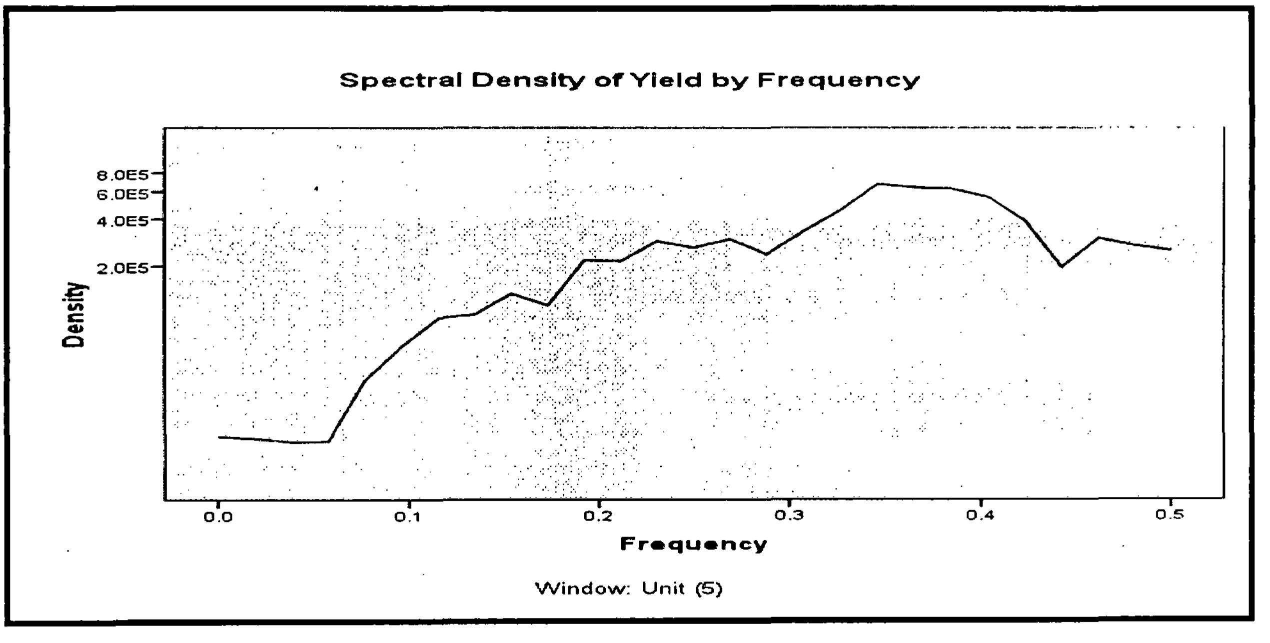
Note: Sig= Significant and Nsig= Non-significant
Source: Agricultural Census of India (Various issues)

The Table 4.7, explains the Fisher test undertaken for the study. The Fisher test was used to test the statistical significance (α=.05) of these peaks observed in the periodogram (appendix 4.1). The peaks which were judged to be statistically significant are those peaks which have exceeded the critical value (0.3). States like Gujarat and Maharashtra (3rd and 4th peak), Rajasthan (1st peak) and Uttar Pradesh (3rd and 4th peak) shows a significant result, which mean that there is presence of cyclic component in the differenced series of yield. Interestingly, nearly 80 per cent of the total States producing maize do not show any significant cyclical fluctuations. Harmonic analysis is undertaken to make the series cycle free. Visual examination of the graphs that is the new series super imposed upon the original series helps us to understand conclude that there is a significant presence of cycle in all the three States mentioned above. Therefore, we have to remove the cycles only from the rest 20 per cent so that cross- spectral analysis can be undertaken to understand the linear relationship among the three variables (temperature, precipitation, yield).

IV. c. Spectral Density of Yield

The spectral analysis can now be applied to the series free from trend and cycles. We smoothen the time series or frequency domain using window. We plot the smoothen periodogram (by using Daniel Window with a width of 5) in order to understand the value of the frequencies during the period of our analysis. We illustrate yield at the all India level. The State level spectral density graphs are reported in appendix 4.3. As mention in the earlier chapter that the spectral density graphs are continuous, sloping lines but in case of yield also the graphs shows tells us a different but interesting story.

Figure 4.1: Spectral Density of Yield, All India



The above figure (Figure 4.1) shows the spectral density of the all India yield. In the vertical axis we have the smoothen variance (power) and in the horizontal axis we have the frequencies (cycle per observations). The above figure shows a continuous but rising line. It means that there is a high concentration of power in higher frequencies for all India yield. These figures are on the all India basis and almost all the States shows the similar pattern with respect to yield. It can be observed that the density is less in the lower frequency and more at the higher end. In other words, in the long run the variance is less than the short-run. Partly we can explain these as in the long run the due to technological up-gradation and higher yielding seeds there is less variability in terms of yield, whereas in the short these things are not possible.

All most all the States show a similar pattern like that of the whole India, but still each and every States has there own story to reveal. States like Assam, Karnataka, Orissa, show a sharp dip in the frequency bandwidth between 0.1 to 0.2, this can be possibly due to the occurrence of some crisis like drought and flood during the period. Some States show a continuous increasing trend like that of Bihar, Gujarat and Maharashtra, Jammu and Kashmir, Punjab and Haryana. However, it is worthy to note here that such a distribution of power is not common in economic time series (Granger, 1964) and that further work needed to be done.

V. Summary and Conclusion

This chapter takes up the partial productivity of maize. Taking up both the traditional approach and the spectral or modern approach we have tried to understand maize's yield in India. It is found that Jammu and Kashmir* which is one of the most vulnerable States with respect to climate has the least change in yield, whereas, Andhra Pradesh* on the other hand has witnessed a higher

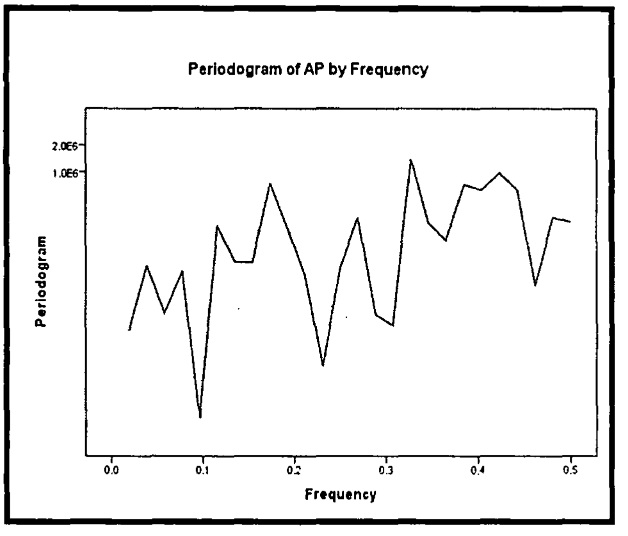
* *Refer to earlier chapter 3.*

partial productivity and a favorable climate in the past five decades. It is observed that there is a linear trend in yield in all the States producing maize. Only three States show a significant cycle in the series. These States (Gujarat and Maharashtra, Uttar Pradesh and Rajasthan) are subjected to short-term fluctuations in yield.

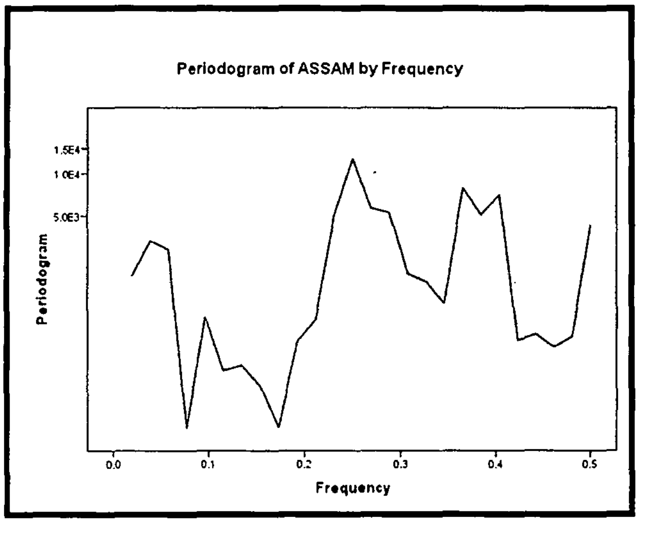
The spectral density shows again an interesting picture. The power spectrum (value) shows a rising trend, indicating that there exist an inverse relationship between the period and the density. Moreover, the variance is higher than in the long run. This is a contrast to the pattern for economic series (Granger, 1964). With the series on yield and climate, we can undertake whether climate affects yield of maize in India, This is the subject matter of next chapter.

APPENDIX 2
A4.1Periodogram (Yield)

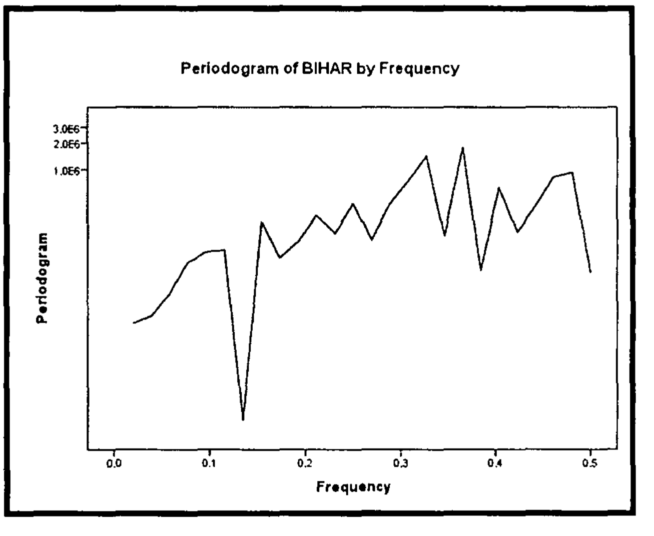
Andhra Pradesh



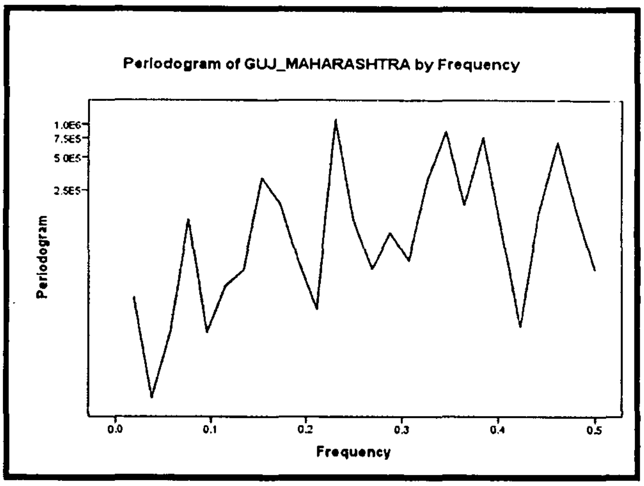
Assam



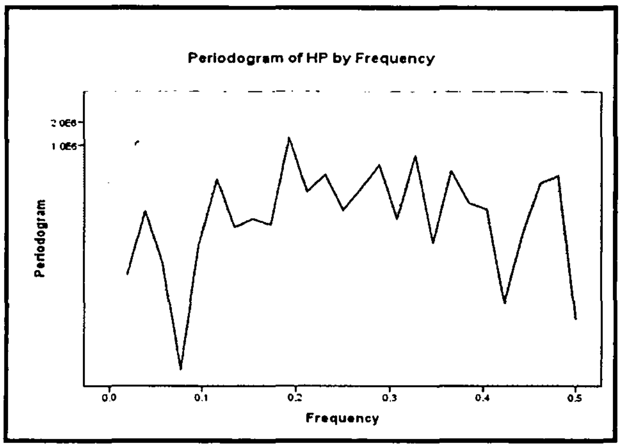
Bihar



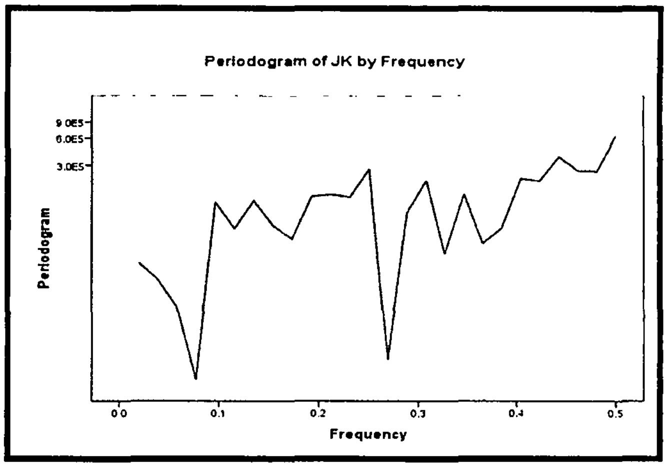
Gujarat and Maharashtra



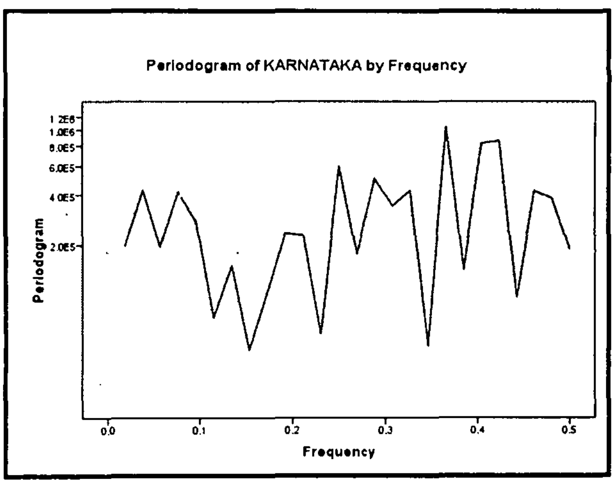
Himachal Pradesh



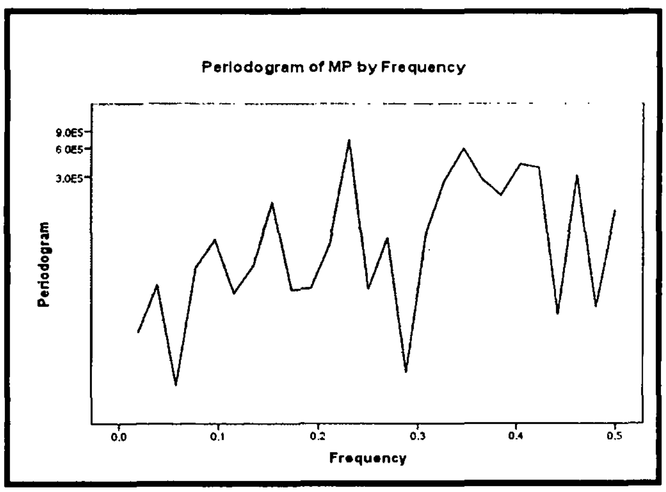
Jammu and Kashmir



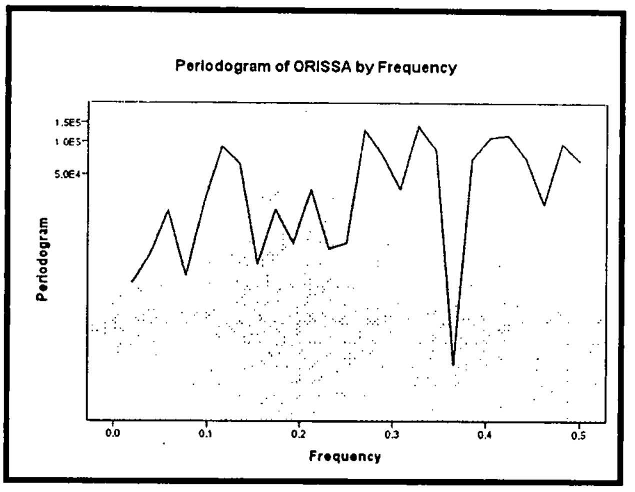
Karnataka



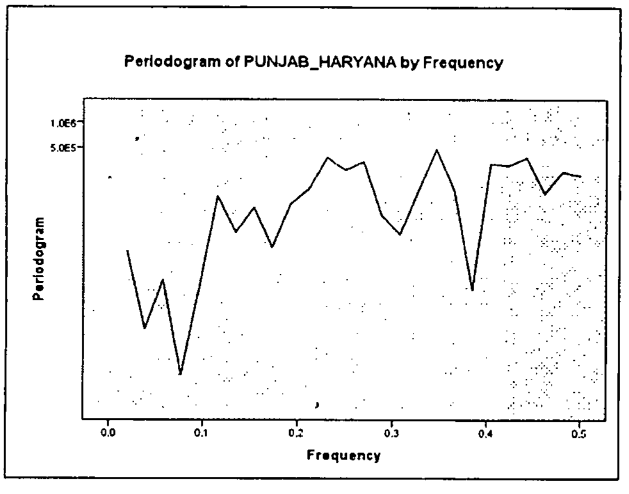
Madhya Pradesh



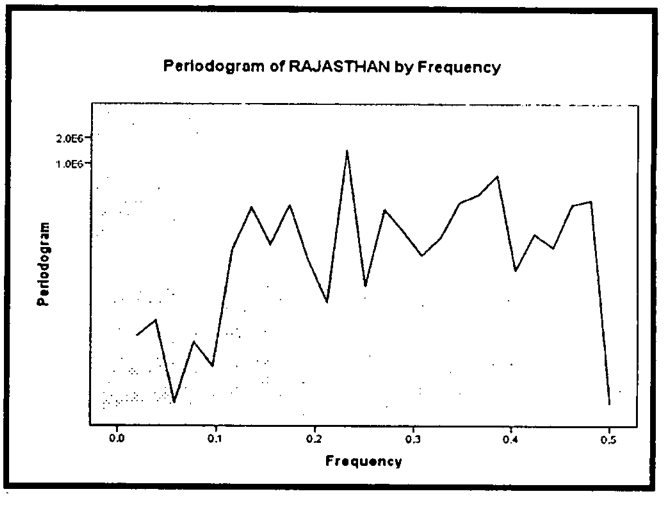
Orissa



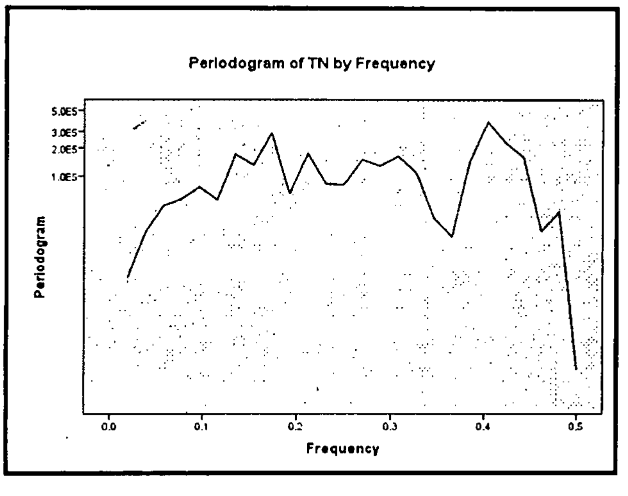
Punjab and Haryana



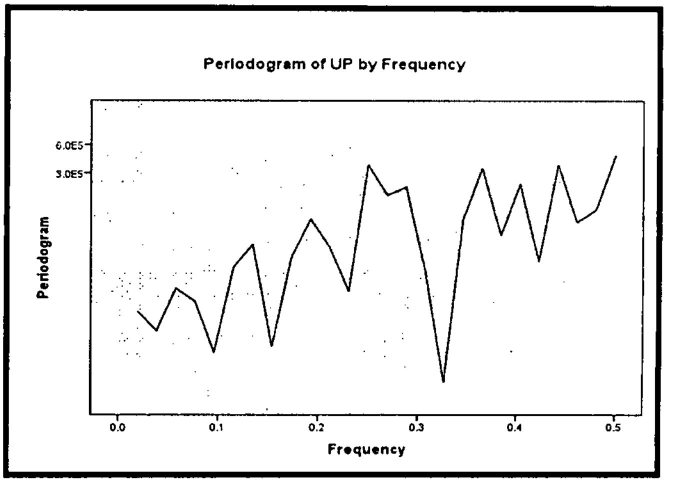
Rajasthan



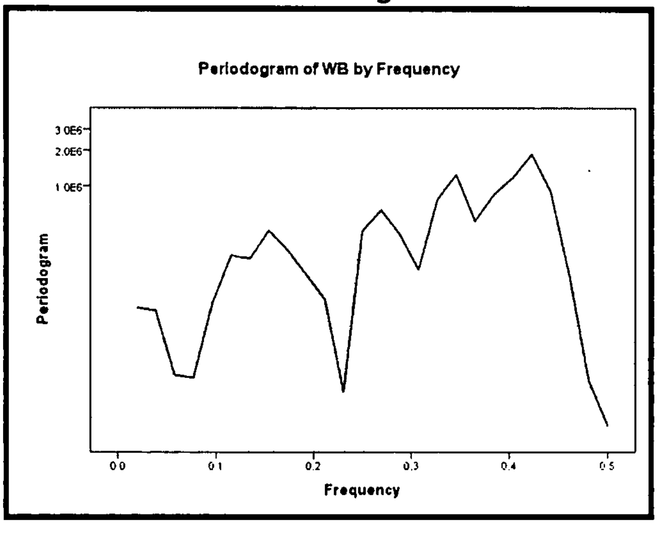
Tamil Nadu



Uttar Pradesh

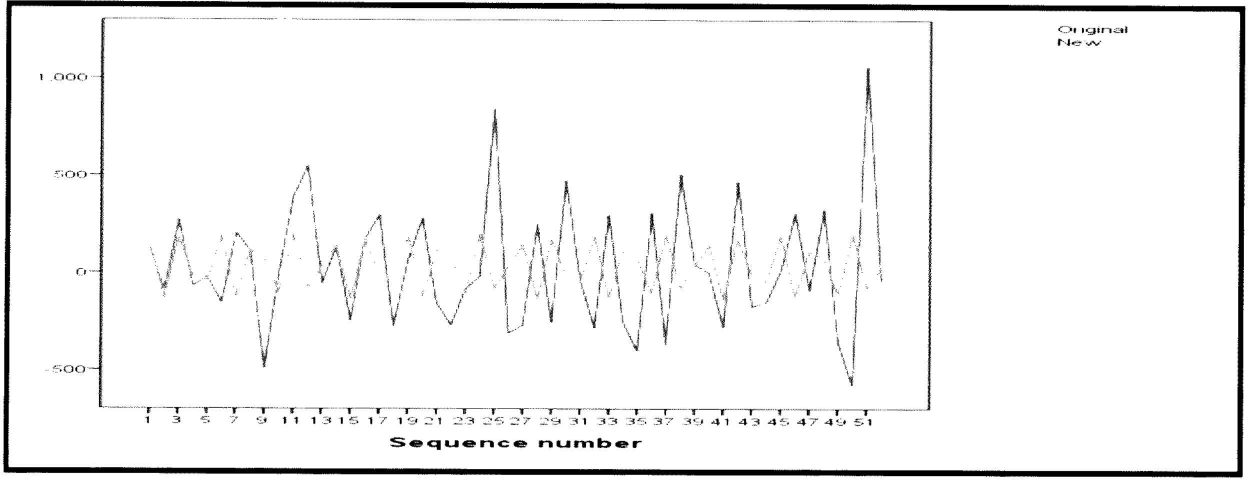


West Bengal

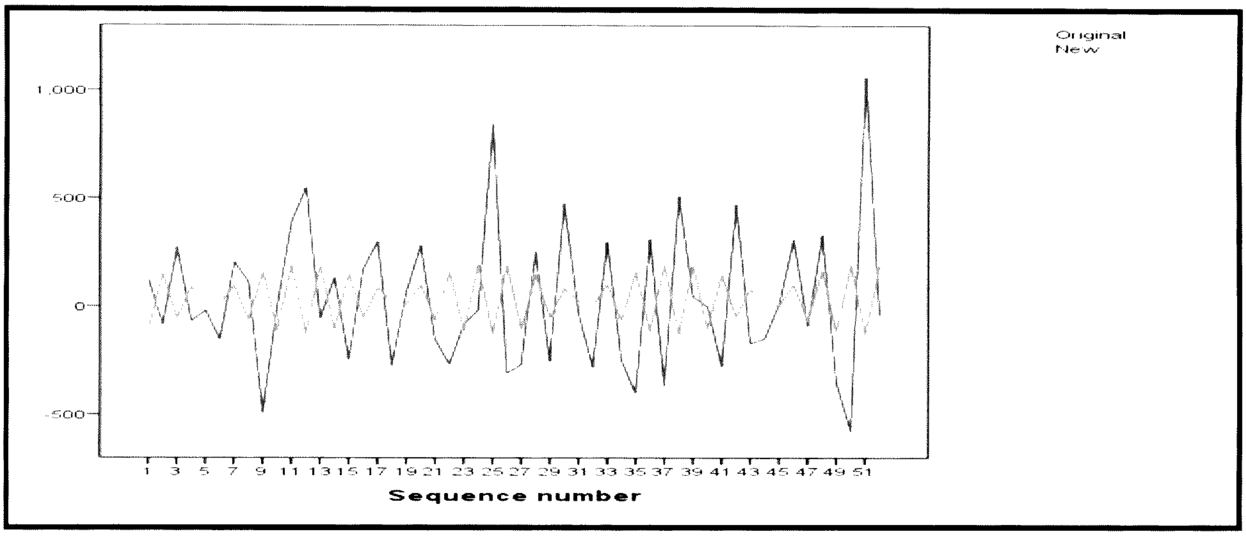

Periodogram of WB by Frequency
3.0E6
2.0E6
1.0E6
Periodogram
0.0
0.1
0.2
0.3
0.4
0.5
Frequency

A4.2 Fisher Cycle Test (Yield)

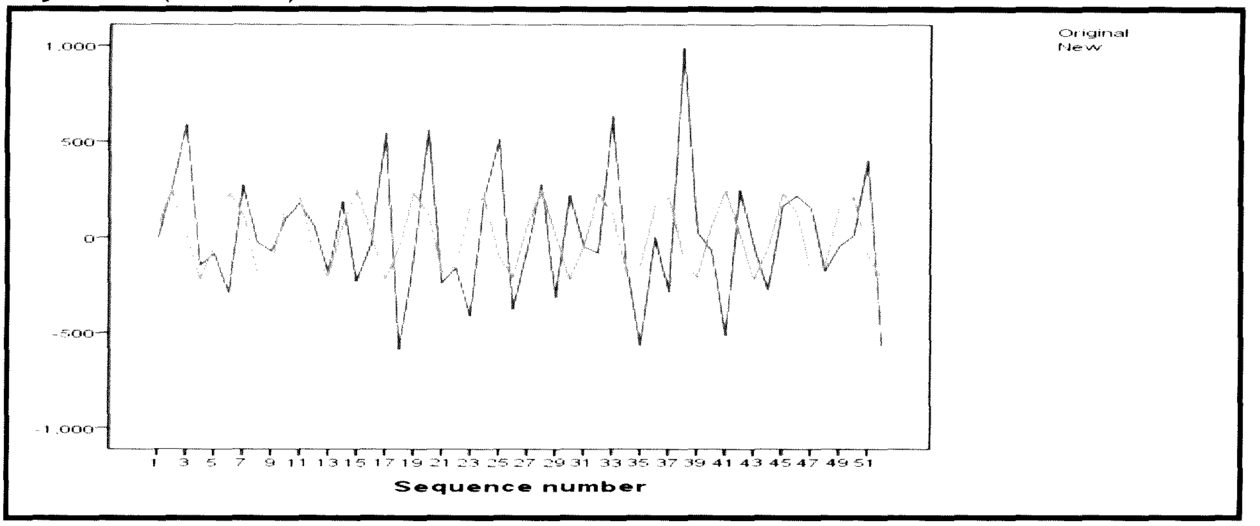
Gujarat and Maharashtra (3rd Peak)



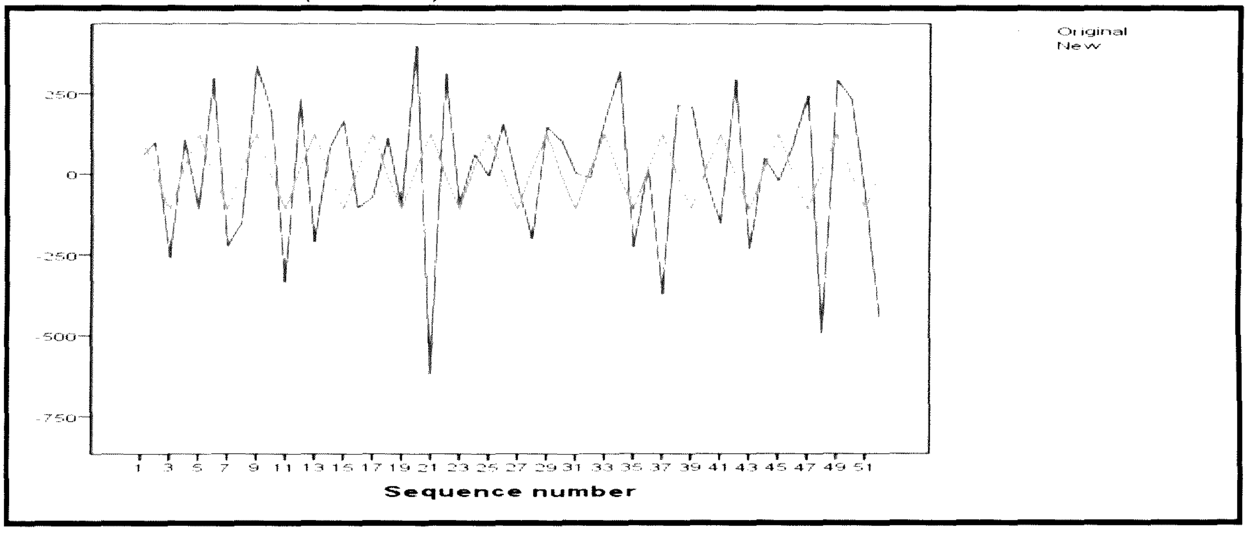
4th Peak



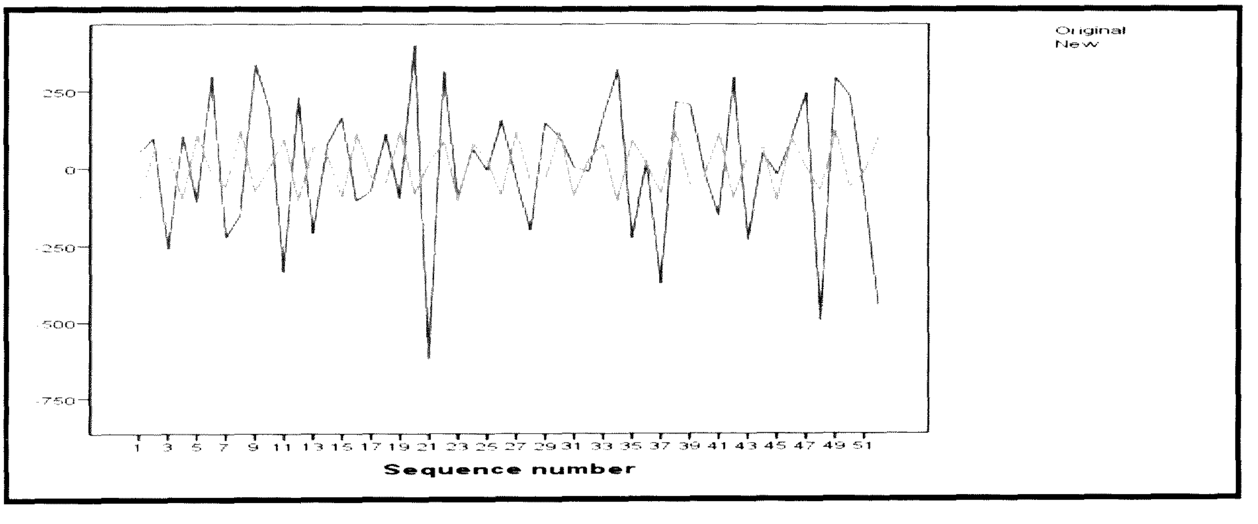
Rajasthan (1st Peak)



Uttar Pradesh Yield (3rd Peak)

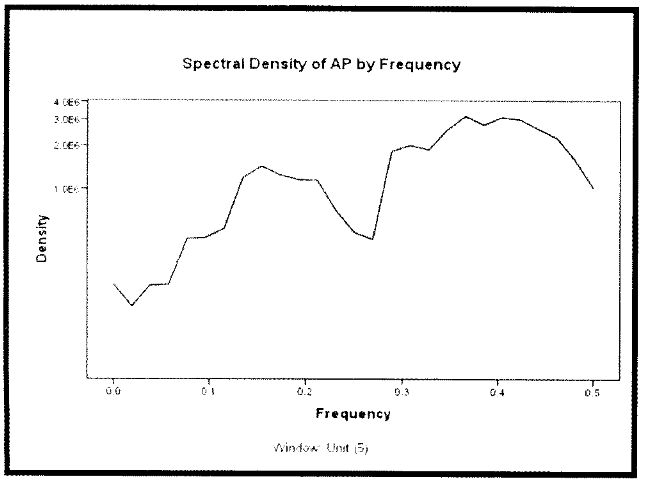


4th Peak

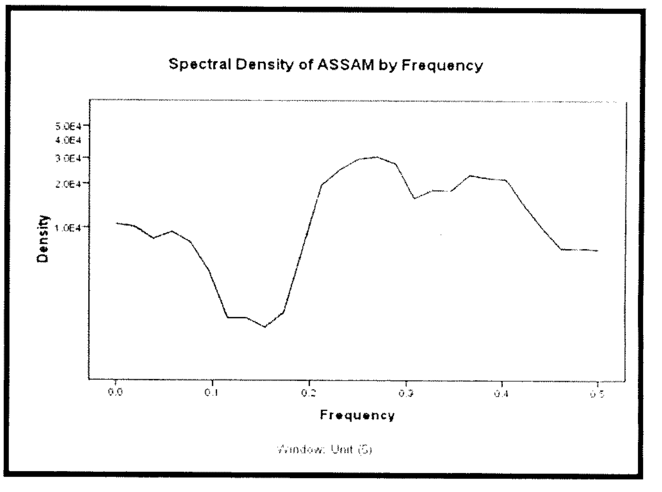


A4.3 Spectral Density (Yield)

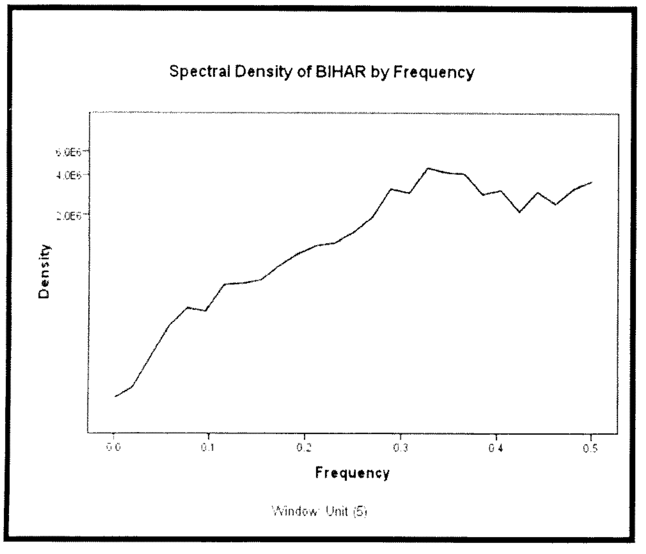
Andhra Pradesh



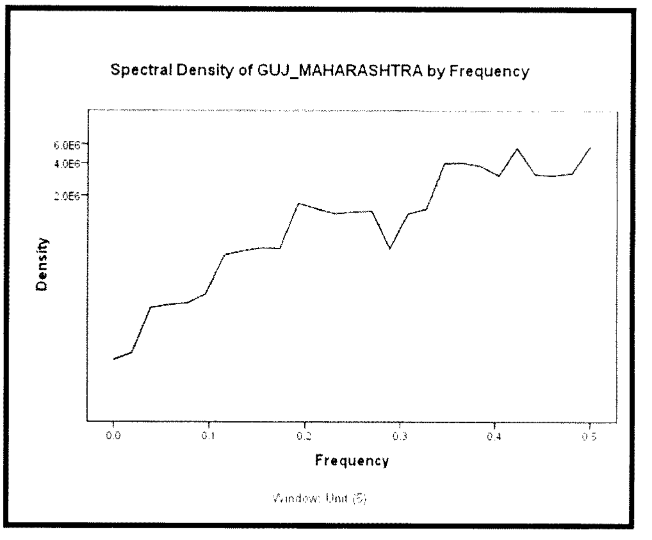
Assam



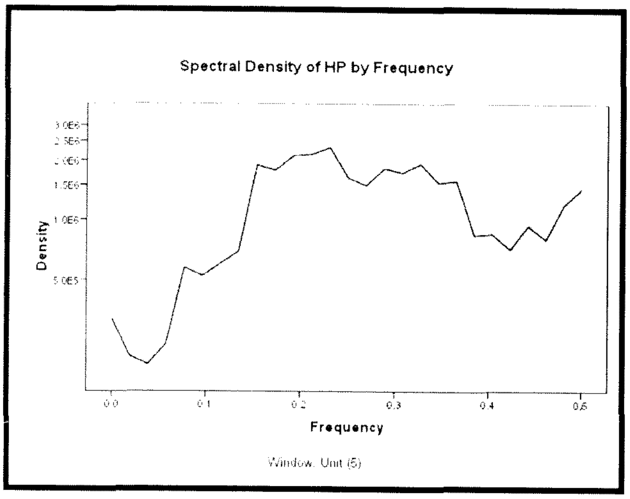
Bihar



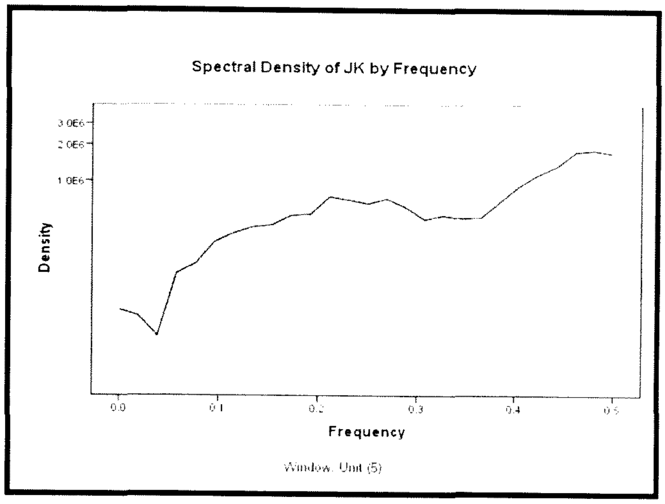
Gujarat and Maharashtra



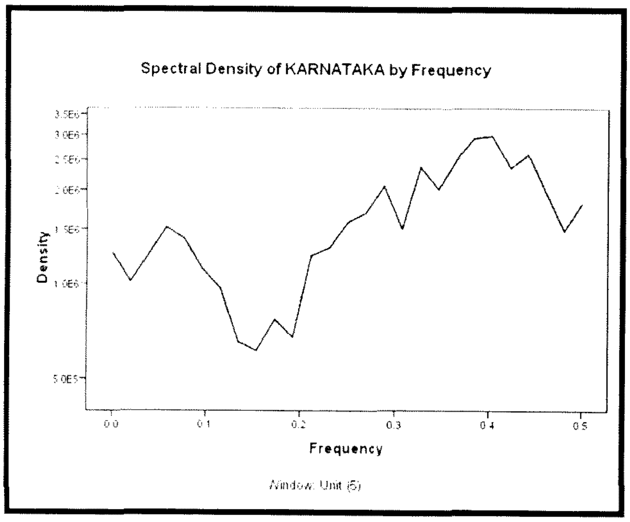
Himachal Pradesh



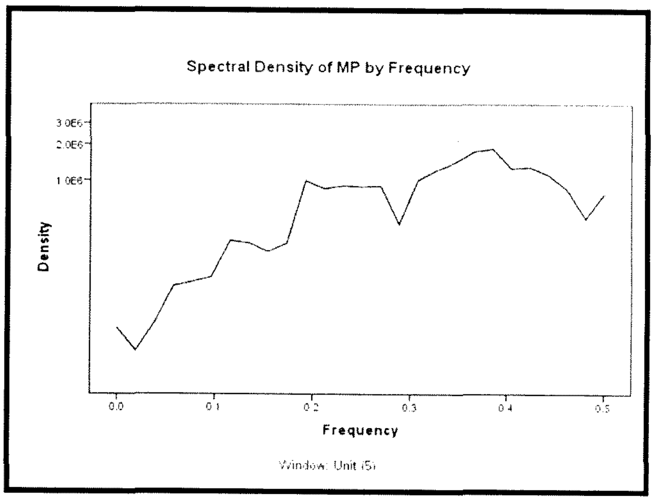
Jammu and Kashmir



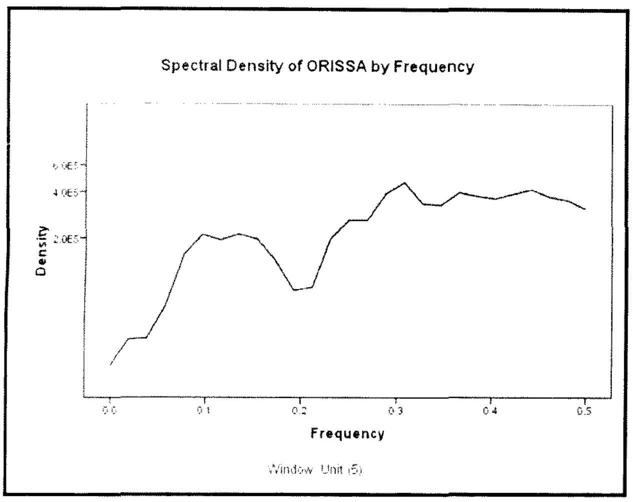
Karnataka



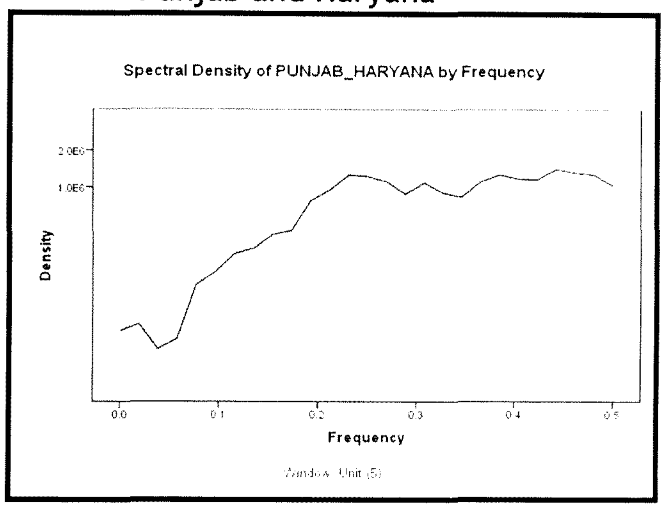
Madhya Pradesh



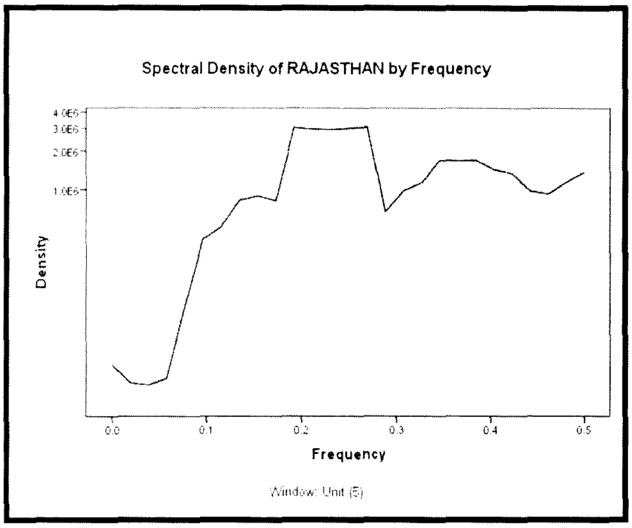
Orissa



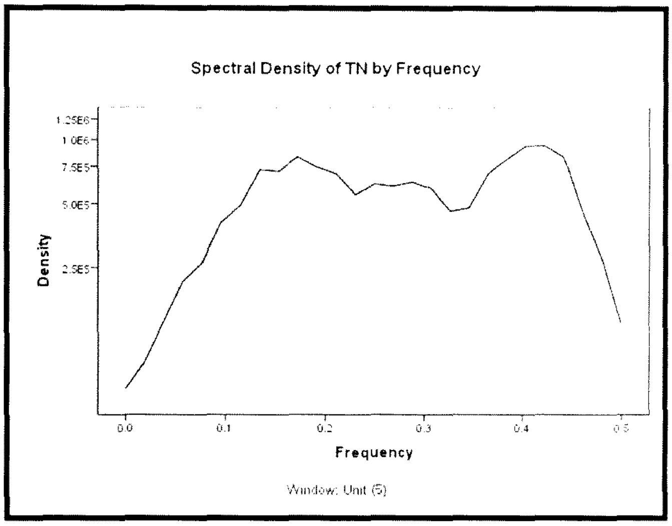
Punjab and Haryana



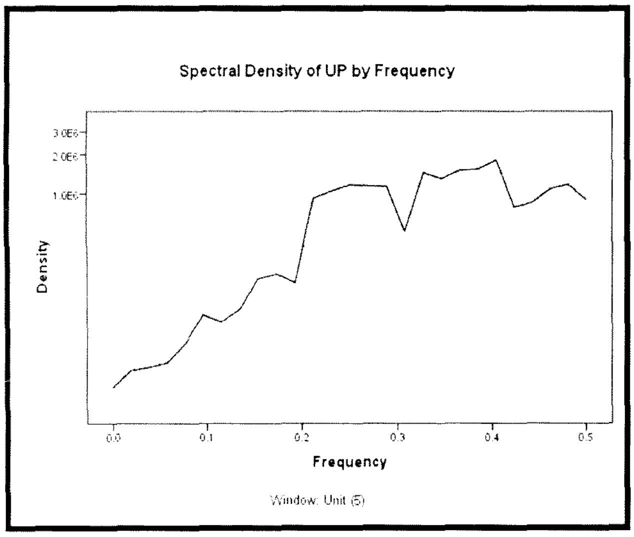
Rajasthan



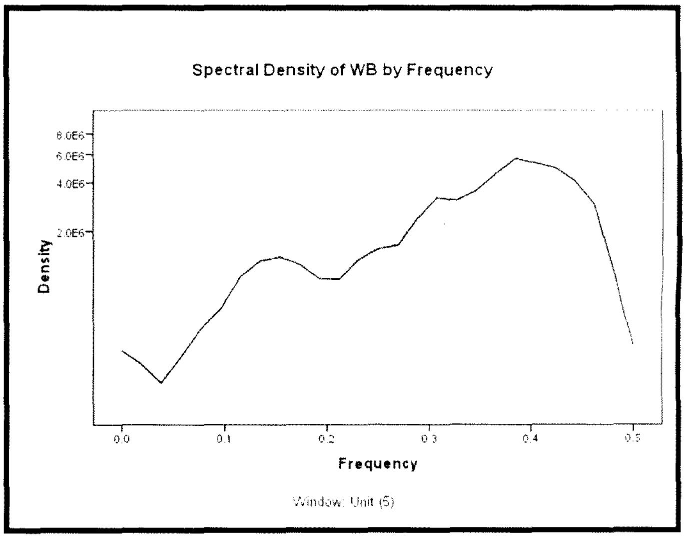
Tamil Nadu



Uttar Pradesh



West Bengal



5

Climate and Yield: Cross- Spectral Analysis

In the previous chapter we have discussed ways of detecting and describing a pattern within a single time series. Here in this chapter we will use the cross spectral analysis to understand the bivariate relationship between the climatic variables and maize yield. The goal of bivariate analysis of time series is to detect and describe any statistical relation between two time series in frequency domain[27], by decomposing their covariance in frequency components. Cross spectral analysis is a generalization of univariate spectral analysis methods to the bivariate case. The very purpose of taking up cross spectral analysis is that it can provide a great deal of information about the relationship between a pair of stationary time series, including the percentage of variance and the description of lead-lag relationship between frequencies. Thus, in order to understand the inter-relationship between the change in climate and the agriculture productivity that is, in our case the yield of maize in India, we extend our analysis to cross-spectral methods.

We have divided this chapter into six sections. The first section will give us a brief idea of data used for this study, followed by the methodology adopted by us in section II. In the third section we used the cross- spectral analysis (particularly coherence and phase estimates) of temperature and yield, precipitation and yield, to understand their inter-relationships. In the fourth section we have tried to re-examine the sensitivity of our results for non-linear trend. As climate change is a long run phenomenon, we have examined the long

[27] The frequency domain refers to the same data, but with reference to the collection of sine and cosine waves that would be required to produce those data.

run climate and yield using the lower frequencies of the spectral density in the fifth section. Finally, in the sixth section we conclude the chapter.

I. Data

The principal feature of this chapter is that it provides a state wise analysis of the relationship between the change in climate and maize productivity in India. In order to see the partial productivity in maize since 1950-51, data provided by Ministry of Agriculture and Cooperation was employed. The main limitation of the study is the non-availability of meteorological data source which was precisely the reason that we opted for the website- *www.indiawaterportal.org/metdata*. The meteorological data available from this website consists of only district wise data. Therefore, in this chapter we have made certain adjustment for certain States with respect to the temperature and precipitation series due to the formation of new States. States like Gujarat (which got separated from Maharashtra in the year 1960), Jharkhand (was separated in the year 2000 from Bihar), Uttarakhand (became a State in the year 2000 from Uttar Pradesh), Haryana (separated from Punjab in 1966) and Chattisgarh (in 2000 it got separated from Madhya Pradesh) were combined together and analyzed since, separate data was not available for these States with respect to yield of maize for the years starting from 1950.

The linear trend analysis is repeated for newly combined regions based on the data at hand. Two combined States showed the presence of significant trend in the series for temperature with R^2 accounting for 19 per cent variance in Maharashtra and Gujarat and 12.1 per cent variance in Madhya Pradesh and Chattisgarh. Following the standard economic practices, we have taken first order differencing to eliminate the trend from the series. Similarly, we have done the trend analysis of the combined States for precipitation. Three States showed significance of the trend with R^2 explaining 8 per cent (Bihar and Jharkhand), 12 per cent (Madhya Pradesh and Chattisgarh) and 11 per cent

(Uttar Pradesh and Uttarakhand) of variance. Here also we have detrended the series by differencing.

After removing the trend from the series, we have done the periodogram analysis for the combined States to see the cyclical patterns, as was done in the earlier chapters, followed by Fisher test for peaks (Warner, 1998). All the graphs of the periodogram analysis are given in the appendix A5.4 and A5.5 of the chapter. States like Uttar Pradesh shows significant cyclical peaks in both temperature and precipitation, and Bihar (combined with Jharkhand) show a significant cyclical peak for precipitation. In order to remove the significant cycle test from the series we undertake the harmonic analysis and make the series free from cycles. The tables and graphs with this respect to the analysis of the combined States are given in the appendix A5.1, A5.2, A5.3, A5.6 and A5.7 of this chapter. As the pre-whitening is already done for the rest of the remaining States in our previous chapters we now straight away go to cross-spectral methods particularly coherence and phase estimates. The methodology explained below.

II. The Methodology

Several measures are available in cross spectral analysis but in our study we have undertaken only the coherence and the phase estimates to understand the relationship between climate and yield of maize. The linear relationship between the two series is tested using significance of coherency spectrum. If the value of the coherence estimates are more than 0.3 (Koopman's, 1974), then the coherence is significant or else it is not. We have also calculated the coherence at different frequencies and averaged them in different frequency band starting from 0.0-0.9 to 0.4-0.5.

The phase estimate is the phase values for cross spectral methods. Since there are large numbers of estimates, we have confined only the summary statistics. In fact, we have taken the average of the phase estimates for frequencies region. The negative/positive value to the phase estimates have a particular meaning. For example if the phase estimate is positive then, the first variable is leading and the second variable is lagging. The phase value is then validated, only if the coherence value of the frequency corresponding to the average phase taken in the summary statistics is significant. If the corresponding coherence value is not significant then we can conclude that there is no lead- lag relationship. This is valid only if the coherency values of this frequencies relating to the average values of the phase estimate is significant. This methodology is applied, the results are reported below.

III. Cross Spectral Analysis

We have now taken the series on yield, temperature and precipitation to perform a cross spectral analysis. The cross spectral analysis helps us to describe the pairs of time series, by decomposing the covariance in frequency components. It is used to reveal the correlations between two series at different frequencies. It provides a rigorous and versatile way to define formally and quantitatively each series components and, by means of filtering, it provides a reliable extraction method. In the present context we have used the Daniel window (width=5) in order to filter the series for a more reliable results.

We have used the trends and cycles adjusted series, as done in the earlier chapters, to avoid any spurious results. The residual of the series on yield, temperature and precipitation which are free from trend and/or cycles are now subjected to cross-spectral analysis.

III. a. Coherence

Coherence indicates the percentage of shared variance between the two time series at a particular frequency. It measures the linear association between the components of two series and to what degree one series can be represented as a linear function of the other. It is interpreted in the same way as a coefficient of determination in correlation analysis. In the bivariate analysis, the cross-spectrum allocates total covariance over the frequencies and reveals the importance of each frequency band in relation to the others. At any given frequency, if the coherence is one then the components are perfectly covariant. On the other hand, it is zero, if the components are completely independent. It is used to measure the strength of association between the two components of the time series. The results are given in Table 5.1.

Table 5.1: Coherency of Climate and Yield by States and by Frequency

Frequency	Yield - Temperature	Yield - Precipitation
All Frequencies	Andhra Pradesh, Tamil Nadu	Madhya Pradesh, All India
0-0.09	Andhra Pradesh, Madhya Pradesh, Uttar Pradesh, Jammu and Kashmir, Karnataka, Tamil Nadu, Haryana and Punjab,	Madhya Pradesh, Uttar Pradesh, Orissa, All India
0.1-0.19	Orissa	Madhya Pradesh, Jammu and Kashmir, Rajasthan, Bihar, Gujarat and Maharashtra
0.2-0.29	Gujarat and Maharashtra, Karnataka, Tamil Nadu	Gujarat and Maharashtra, Haryana and Punjab, Madhya Pradesh
0.3-0.39	Andhra Pradesh, Tamil Nadu, Rajasthan	Madhya Pradesh, Uttar Pradesh, Karnataka, Rajasthan,
0.4-0.5	Andhra Pradesh, Madhya Pradesh, Haryana and Punjab, Uttar Pradesh	Madhya Pradesh, Karnataka

Source: www.indiawaterportal.com and Agricultural Census of India (Various issues).

Table 5.1, we have divided the frequencies into five groups and tried show the significance level of the bivariate relationship between yield and temperature, yield and precipitation. If the coherence estimate is greater than 0.3 as suggested by Koopmans (1974) then the relationship is statistically significant, otherwise not. By this test, we can infer that States like Andhra Pradesh and Tamil Nadu are having a significant coherence between yield and temperature, for all frequency. Similarly, for all frequency, only Madhya Pradesh shows a significant coherence between yield and precipitation. It may be noted here that the coherence of Madhya Pradesh is almost perfect (0.9).

It has been seen that the number of States with significant coherence estimates are more in the lower frequencies for yield and temperature. This indicates that, in the long-run temperature is influencing the yield in many States compared with precipitation. States like Andhra Pradesh, Madhya Pradesh, Uttar Pradesh, Jammu and Kashmir, Karnataka, Tamil Nadu, Haryana and Punjab are significant in the lower frequency with respect to yield and temperature, accounting for 57 per cent of the total production in 2002-03. Similarly, Madhya Pradesh, Uttar Pradesh, and Orissa are significant in the lower frequencies in case of yield and precipitation, together accounting for only 23 per cent. Nevertheless, all India series shows a significant result only in the lower frequency for yield and precipitation. Here, we can also say that yield and precipitation have significant coherence for all runs than temperature at the all India level.

On the other end that is on the higher frequencies side (medium and short-run) we can see States like Andhra Pradesh, Madhya Pradesh, Haryana and Punjab, Uttar Pradesh are significant for yield and temperature and Madhya Pradesh and Karnataka are significant in case of precipitation and yield. It is note worthy to mention here that Andhra Pradesh, Haryana and Punjab, Uttar Pradesh show a significant relationship in yield and temperature and Madhya Pradesh, on the other hand show a significant relationship between yield and temperature and yield and precipitation in both the high and low frequencies. In some States both the relationships are valid for the same frequency. For example, Madhya Pradesh and Uttar Pradesh are significant in the frequency bandwidth 0.0-0.9, Gujarat and Maharashtra for 0.2-0.29, Rajasthan for 0.3-0.39 and finally Madhya Pradesh for 0.4- 0.5.

Let us examine the relationship at the all India level. Figure 5.1 and 5.2, show a high coherency in the frequency bandwidth 0.1 and 0.2. In case of temperature there is a peak in 0.1 frequency bandwidth for temperature and yield whereas in precipitation and yield there is a flatter coherency in between the 0.1 to 0.2. However, the short run coherency is more than the long run in temperature and yield and the vice-versa in case of precipitation and yield. We can conclude from this that the over-all maize yield depend more on precipitation (which is very erratic and is statistically significant in the long run) in India than temperature.

Figure 5.2: Coherency of Yield and Temperature in India

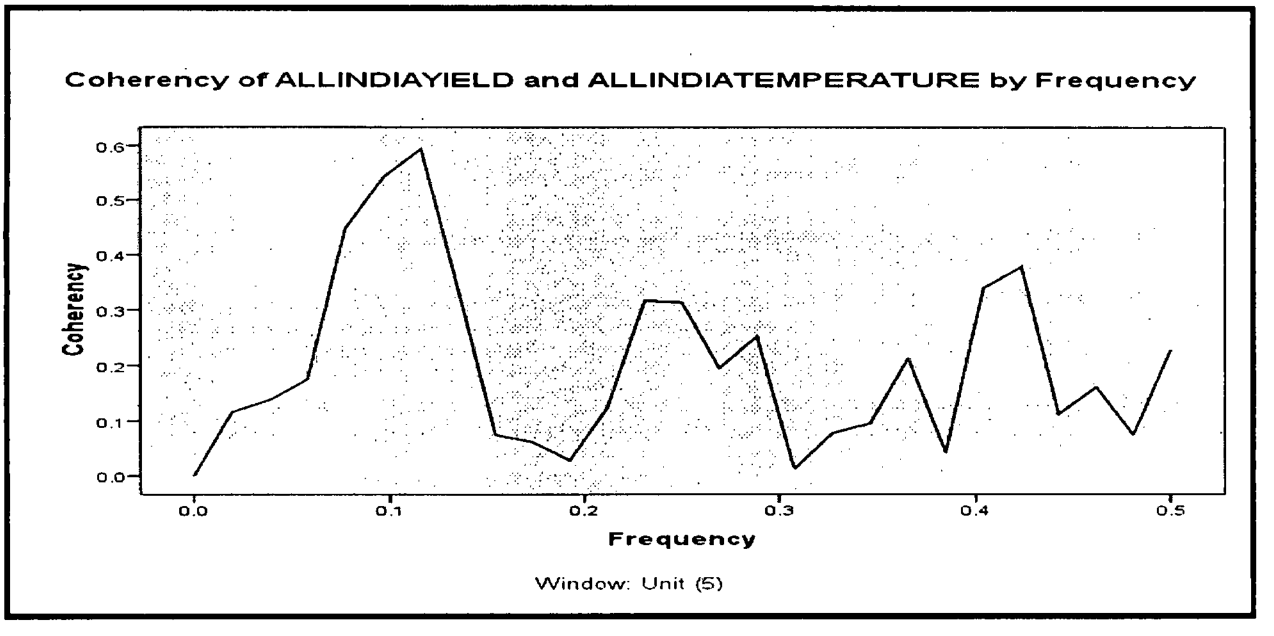
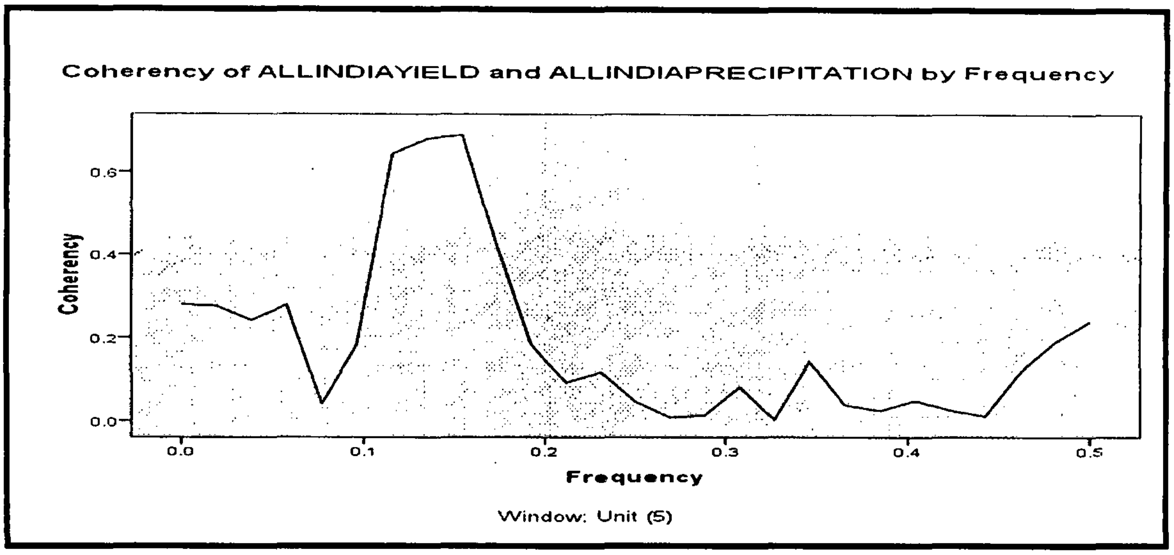


Figure 5.2: Coherency of Yield and Precipitation in India



Some interesting results can be seen if we go deeper and see the State wise analysis given the appendix 5.4 and 5.5. It can be seen that States like Andhra Pradesh shows a converging trend in the high and low frequency. States like Bihar, Jammu and Kashmir Tamil Nadu and Uttar Pradesh show a very high coherency in the low frequency, describing the strong coherence between yield and temperature in the long run in these States. Albeit, Bihar is the only State which does not show any statistical significance but the rest of the three States are statistically significant in the long-run.

Similarly, the relationship between precipitation and yield is even more interesting to see. As precipitation is very erratic in nature the results are also very much different than that of temperature. States like Andhra Pradesh, Karnataka and Madhya Pradesh shows a short-run coherency that is the coherency is high in the higher frequency. Andhra Pradesh is the only State from the above mentioned three States which is statistically insignificant. States like Bihar, Jammu and Kashmir, Tamil Nadu shows a long-run coherency but are not statistically significant. Further deep analysis is required to understand the various dimensions of these States. Having done with the coherency, we now move next to the Phase estimates.

III. b. Phase

Phase indicates the timing of peaks in Y series relating to the timing of the peaks in the X series at a given frequency. The phase estimates are used to define the lead-lag relations between the two series. As long as the two series are not independent, i.e., coherence is not zero, the phase estimates may be used to determine whether the components in one series leads or lags the components, at the same frequency, in the other series. If the phase is positive, base series leads the crossed series. Conversely, if the phase is negative, the shift is such that the base series lags the crossed series. Based on this we can conclude in our study by looking at the phase values that whether the base series will lead or lag the crossed series, when the phase is positive or negative respectively.

We have two separate tables for the yield and temperature and yield and precipitation. The phase analysis helps us to understand the lead-lag relationship between the variables. Table 5.3 explains the lead-lag relationship between yield and temperature.

Table 5.2: Phase Summary of Yield and Temperature

State(s)	No of observations	Average phase (ph)	Coherence	Significant
Andhra P	26	-0.64	0.14	NSig
Assam	26	-0.04	0.05	NSig
Bihar	26	1.00	0.05	NSig
Gujarat & Maharashtra	26	-0.31	0.44	**Sig**
Haryana & Punjab	26	0.3	0.28	NSig
HP	26	0.35	0.03	NSig
J&K	26	-0.93	0.13	NSig
Karnataka	26	-0.42	0.25	NSig
MP	26	0.01	0.41	**Sig**
Orissa	26	0.25	0.20	NSig
Rajasthan	26	-0.04	0.21	NSig
TN	26	0.05	0.35	**Sig**
UP	26	1.01	0.13	NSig
WB	26	-0.60	0.15	NSig
All India	26	-1.09	0.12	NSig

Note: Sig= Significant and Nsig= Non-significant
Source: www.indiawaterportal.com and Agricultural Census of India (Various issues)

The summary statistics, average of the climates, are only examined here. Further the phase estimates is interpreted only if the coherence value of the corresponding frequency is significant. By our methodology, three States have lead-lad relationship. They are Gujarat and Maharashtra, Madhya Pradesh and Tamil Nadu. These States have a significant coherency of the frequency relating to average phase value. Gujarat and Maharashtra shows a negative estimate, indicating that temperature is leading in these states. It simply means that temperature is the leading variable and yield is the lagging variable. It indicates that temperature is a key element in this state in determining the productivity of maize. On the other hand, Madhya Pradesh and Tamil Nadu show a positive phase, this indicates that these States yield lags behind. This may be due to modernization of farming products including better adaptive seeds by the farmers, etc.

Table 5.3 shows the lead-lag relationship between precipitation and yield. There is a bivariate significant relationship between yield and precipitation in States of Karnataka, Madhya Pradesh and Rajasthan. Madhya Pradesh shows a negative phase indicating that in this State the precipitation is the leading factor and yield is lagging. In the other two States it is just the opposite. The result of the findings needs detailed analysis across different runs.

Table 5.3: Phase Summary of Yield and Precipitation

State(s)	No of observations	Phase Mean(ph)	Coherence	Significant.
Andhra P	26	0.41	0.16	NSig
Assam	26	-0.4	0.08	NSig
Bihar	26	-0.07	0.14	NSig
Gujarat & Maharashtra	26	0.99	0.17	NSig
Haryana & Punjab	26	0.70	0.24	NSig
HP	26	-0.66	0.25	NSig
J&K	26	0.25	0.03	NSig
Karnataka	26	0.53	0.33	**Sig**
MP	26	-0.08	0.96	**Sig**
Orissa	26	-0.76	0.15	NSig
Rajasthan	26	1.18	0.50	**Sig**
TN	26	-0.07	0.14	NSig
UP	26	-0.11	0.07	NSig
WB	26	0.23	0.25	NSig
All India	26	0.35	0.19	NSig

Note: Sig= Significant and Nsig= Non-significant
Source: www.indiawaterportal.com and Agricultural Census of India (Various issues)

Looking into the table of yield and precipitation, Madhya Pradesh is the only state which shows a significant coherence between both yield and temperature and yield and precipitation. Albeit, there it has a positive phase value for temperature and yield, this States shows a negative value for precipitation. It is one of the States which is not blessed with more annual precipitation (92 mms). Maize requires a 150 mm of irrigation[28] to mature (*Handbook of Agriculture, 2006*). Though, this State has 11. 04 per cent of gross area irrigated under food grains, it still depends on rain-fed agriculture. As the above table suggests in spite of a high irrigation facility as compared to others, this State is vulnerable with respect to precipitation influencing yield in the State.

Albeit, nearly seventy percent of the States in case of temperature and fifty per cent of the States in case of precipitation show a negative phase estimates, we cannot derive any information from them, as the corresponding frequency coherence is not statistically significant. In our trend analysis, we have come across States with higher R^2 for non-linear trend. The taking of first order differencing might have contributed to our conclusions. To what extend the detrended method is sensitive to our conclusion is taken up in the next section.

Therefore, before coming to a conclusion, we have done the non-linear analysis for better understanding. Let us now examine the other limitation of the analysis that is we have assumed the presence of a linear through the series and have detrended it uniformly. Therefore, before we make final conclusion about climate and yield let us see the possible results with respect to non-linear analysis.

IV. Non-Linear trend Analysis

Let us re-examine the whole series again with respect to non-linear trend analysis. We have tried to look at the R^2, F and P values and tried to detrend the series subjected to non-linear trends. The higher R^2 values are taken into consideration and then the series is detrended by deducting the predicted values from the original values. Before undertaking cross spectral analysis we have done the similar periodogram analysis, Fisher test and harmonic analysis, described in the earlier chapters, to make the series free from cycles and/or

[28] *Irrigation requirements refer to the amount of water required for the crop to mature, excluding precipitation.*

trends. The following are the results of coherence and phase estimates of such an exercise.

Table 5.4: Coherence Summary-Significance

Frequency	Yield - Temperature	Yield - Precipitation
All Frequencies	Andhra Pradesh, Rajasthan, Tamil Nadu, West Bengal	Karnataka, Rajasthan, Madhya Pradesh
0-0.09	Andhra Pradesh, Bihar, Haryana and Punjab, Jammu and Kashmir, Tamil Nadu, West Bengal	Assam, Bihar, Haryana and Punjab, Himachal Pradesh, Jammu and Kashmir, Karnataka, Madhya Pradesh, Orissa, Uttar Pradesh
0.1-0.19	Himachal Pradesh, Jammu and Kashmir, Orissa, Rajasthan, West Bengal	Bihar, Gujarat and Maharashtra, Jammu and Kashmir, Madhya Pradesh, Rajasthan, Tamil Nadu
0.2-0.29	Andhra Pradesh, Karnataka, Orissa, Rajasthan, Tamil Nadu, West Bengal	Gujarat and Maharashtra, Haryana and Punjab, Madhya Pradesh, Rajasthan
0.3-0.39	Andhra Pradesh, Assam, Haryana and Punjab, Rajasthan, Tamil Nadu, West Bengal	Karnataka, Madhya Pradesh, Rajasthan
0.4-0.5	Andhra Pradesh, Assam, Madhya Pradesh, Uttar Pradesh, West Bengal	Madhya Pradesh, Karnataka

Source:* *www.indiawaterportal.com and Agricultural Census of India (Various issues).

It can seen from the above table that though Andhra Pradesh and Tamil Nadu are still significant for all frequency in temperature, but two new States are added namely Rajasthan and West Bengal. On the same note, Karnataka and Rajasthan are added in the table with respect to significance of all frequency with precipitation. In the lower frequency band we can see that six States (accounting for 37 per cent of the total production in 2002-03) are significant for temperature and nine States (accounting for 61 per cent of the total production in 2002-03) are significant for precipitation. States like Andhra Pradesh, Haryana and Punjab, Jammu and Kashmir, and Tamil Nadu are the common States that are present in both the analysis in the long run for temperature. Similarly, Madhya Pradesh, Orissa and Uttar Pradesh are the common States in both the linear and non-linear coherence table in the long run for yield and precipitation. Strikingly, both analysis shows the same States as significant in the short run for yield and precipitation (Madhya Pradesh and Karnataka). Here also, the numbers of States in the long-run out- number the number of States in the short-run in both the cases, indicating the importance of temperature and precipitation on yield. After the coherence summary statistics we move on to next step of cross spectral analysis that we continue with the phase estimates to know the lead-lag relationship.

Table 5.5: Phase Summary of Yield and Temperature by States, Non-Linear Analysis

State(s)	No of observations	Average phase (ph)	Coherence	Significant
Orissa	26	0.22	0.34	Sig
Rajasthan	26	-0.87	0.30	Sig
UP	26	-0.46	0.30	Sig
WB	26	0.01	0.95	Sig

Note: Sig= Significant and Nsig= Non-significant
Source: www.indiawaterportal.com and Agricultural Census of India (Various issues)

The phase estimates shows a different result than what was seen in the earlier Table 5.2. Accordingly, four more States are significant, from which only two States have a negative phase value. States like Orissa and West Bengal do show a significant result but that the States have a positive value indicating that the yield is leading and temperature is lagging. On a second thought, States like Orissa and West Bengal, are those States which comes in the lower margin of the list of the maize producing States of India, so there impact cannot be traced properly. On the other hand States like Rajasthan and Uttar Pradesh has a negative phase as well as a significant relationship, indicating that temperature is a key element in these states in determining the productivity of maize. Both these States are the two major giants in the field of maize producing states in India and there dependence on precipitation is also very vivid from the analysis. In addition to the above analysis, we need to look at the results of the phase estimates of yield and precipitation before deriving a conclusion. The lead-lag relationship cannot be explained in the binary framework. It has to incorporate, other factors like the irrigated area, the fertility of the soil, etc. Unless and until, such multivariate frame is developed, the lead-lag relationship is an open question.

Table 5.6: Phase Summary of Yield and Precipitation by States, Non-Linear Analysis

State(s)	No of observations.	Phase Mean(ph)	Coherence	Significant
Assam	26	0.64	0.32	Sig
Gujarat & Maharashtra	26	0.60	0.35	Sig
Haryana & Punjab	26	0.20	0.30	Sig

Note: Sig= Significant and Nsig= Non-significant
Source: www.indiawaterportal.com and Agricultural Census of India (Various issues)

The yield and precipitation is valid to three new states - Assam Gujarat and Maharashtra and Haryana and Punjab. States like Punjab (10.7 per cent*) and Haryana (6.2 per cent*) can be judged as there is a presence of irrigation but States like Assam (1 per cent*) and Gujarat (5 per cent*) and Maharashtra (3.6 per cent*), shows a typical result since these States are not blessed with highly irrigated land. Further in depth analysis is required to understand the nature of these States. The relationship between climate and yield is a long-run phenomenon. Let us examine these aspects from our analysis.

V. Climate and Yield: Long-run analysis

To check the long-run phenomenon we have taken the coherence and the phase value that lie between the frequency bandwidth 0.0-0.9. Both the linear as well as non-linear trend results are taken to see the significance. The results are summarized in the Table 5.7 for temperature and yield and Table 5.8 for precipitation and yield. The long run relationship clearly indicates that the maize production in India is influenced by climate conditions as indicated by the significance of all India estimates.

Table 5.7: Long Run Relationship between Yield and Temperature by States

State(s)	Average Phase (ph)	Coherence	Significant
Andhra P	1.64	0.62	Sig
Assam	0.19	0.09	NSig
Bihar	0.33	0.30	Sig
Gujarat & Maharashtra	1.26	0.23	NSig
Haryana & Punjab	1.72	0.30	Sig
HP	-0.59	0.05	NSig
J&K	0.49	0.62	Sig
Karnataka	-1.58	0.43	Sig
MP	0.94	0.56	Sig
Orissa	1.54	0.17	NSig
Rajasthan	0.45	0.06	NSig
TN	0.12	0.57	Sig
UP	1.90	0.18	NSig
WB*	0.01	0.96	Sig
All India*	-1.45	0.30	Sig

Source: www.indiawaterportal.com and Agricultural Census of India (Various issues
Note 1. (*) denotes Nonlinear trends, all other are linear trend
2. Sig= Significant and Nsig= Non-significant

From Table 5.7 we can depict that out of eight States, seven show a significant relationship in linear analysis and one State in case of non-linear analysis. The State with significant relationship in yield and temperature in the long run account for 70 per cent of the total production in 2002-03. Adding to which we can conclude that temperature plays a vital part in determining production and yield but does not give us a conclusive lead-lag relationship.

Table 5.8: Long Run Relationship between Yield and Precipitation by States

State(s)	Average Phase (ph)	Coherence	Significant
Andhra P	0.82	0.12	NSig
Assam	-1.22	0.22	NSig
Bihar*	-0.99	0.30	Sig
Gujarat & Maharashtra	-1.77	0.22	NSig
Haryana & Punjab*	-0.77	0.30	Sig
HP*	2.48	0.55	Sig
J&K	-0.15	0.30	Sig
Karnataka	1.49	0.08	NSig
MP	-0.03	0.95	Sig
Orissa	-1.33	0.38	Sig
Rajasthan	-0.88	0.03	NSig
TN	-0.94	0.13	NSig
UP	-1.27	0.45	Sig
WB	0.09	0.30	Sig
All India	2.41	0.11	NSig

Source: www.indiawaterportal.com and Agricultural Census of India (Various issues)
Note 1. (*) denotes Nonlinear trends, all other are linear trend
2. Sig= Significant and Nsig= Non-significant

Table 5.8, shows eight States as significant in the long-run between yield and precipitation. States like Bihar, Haryana and Punjab and Himachal Pradesh are significant in the non-linear analysis, whereas the rest of the States are significant in the linear analysis which accounts to total four States. However, it can be concluded that both the indicators show significant results in Jammu and Kashmir, Madhya Pradesh, Orissa and Uttar Pradesh. The share of these States production to the total production in 2002-03 was 59 per cent. Thus, majority of the production is being affected by the climatic variables.

By looking at both the tables we can conclude that Bihar, Harayana and Punjab, Jammu and Kashmir, Madhya Pradesh and West Bengal are the worst affected States in India with respect to temperature and precipitation which accounts for 37 per cent of the total production produced in India in 2002-03. This can be an incentive to further go ahead and look for other crops. Whether this kind of long-run relationship exists in other crops or not? This question can be analyzed in much details.

VI. Summary and Conclusion

With the above understanding of the cross spectral analysis of yield, temperature and precipitation for both linear as well as non-linear analysis we can conclude that temperature and precipitation plays a dominant role in the long run. According to the results of the coherence estimation, there is a significant correlation among temperature, precipitation and maize yield in the long run than in the short run in both analysis. Secondly, with respect to phase estimates, it is not very clearly visible about the lead-lag relationship since most of the States are non-significant. This requires further study.

Though, under the linear trend analysis Gujarat and Maharashtra is vulnerable to temperature and Uttar Pradesh in non-linear trend analysis is vulnerable to temperature. Strikingly Rajasthan show a negative result in both temperature and precipitation, since it is not a States that is blessed with highly irrigated land it and most of its area comes in western dry region (*Planning Commission of India, (Khanna, 1989)).* The most interesting result according to the cross spectral analysis is Madhya Pradesh. In this State, precipitation plays the leading role in both the analysis undertaken by the study, though it did not witness a negative change on precipitation in the past five decades[29] and has a considerably favorable irrigated land, it show a vulnerability to precipitation and further analysis need to be taken up to study its results.

However, certain States like Madhya Pradesh and Tamil Nadu in case of temperature in linear trend analysis shows that yield is leading and there is a presence of significant relationship. Similarly, Madhya Pradesh, Orissa, Tamil Nadu and West Bengal show a significant relationship with temperature and

[29] *Refer to earlier chapter 3.*

yield in the non-linear analysis. The result of precipitation is also the same - States like Karnataka and Rajasthan (in case of linear analysis) and States like Assam, Gujarat and Maharashtra, Haryana and Punjab (in case of non-linear trend) show a positive significant relationship, meaning yield is leading and precipitation is lagging or the meteorological variables have no effect on the yield. One of the possible reason for this kind results may be the use of high yielding variety seeds which has increased considerably. The area under high yielding variety seeds of maize in India has increased from 8.71 per cent in 1970-73 to 58.40 per cent in 1994-97 (Sharma, et al., 2007).

We can further conclude that there is a significant relationship between yield and climate change. This relationship is a long-run phenomenon rather than a short-run. Almost 50 per cent of the States show a long run phenomenon with respect to yield and the climatic variables (temperature and precipitation). The State with significant relationship in yield and temperature in the long run account for 70 per cent of the total production in 2002-03 and 59 per cent of the total production, with respect to yield and precipitation in the same year. Thus, majority of the production is being affected by the climatic variables. This can be an incentive to further go ahead and look for other crops. Whether this kind of long-run relationship exists in other crops or not? This question can be delineated more closely.

Although the long run results show that Bihar, Haryana and Punjab, Jammu and Kashmir, Madhya Pradesh and West Bengal are the worst affected States in India, it is very difficult to conclude the lead -lag relationship on the basis of the above results. The relationship can be lead-lag or contemporaneous. Again lead-lag relationship need not be uniform since the other factors have to be brought in a multivariate framework. These kinds of results could be further analysed and can be reconsidered. One more possible reason of such kind of results is the assumption of a symmetric distribution. Since we have taken the mean phase values for the series, assuming a symmetric distribution, this might have affected the results of the series. Instead of mean, if we would have opted for mode or median, the results might have varied. A more provoking answer to the question might be that both the series do not show a lead-lag relationship rather they move simultaneously with each other. Therefore, further in-depth analysis is needed to be taken up to understand the relationship between temperature, precipitation and yield, which is out of the purview of this study.

APPENDIX 3

Table A5.1: Trend Analysis of Temperature of the Combined States

State(s)	Temperature			
	No. of observations	R Square	F	P Values
Bihar and Jharkhand	53	.018	.912	.344
Maharashtra and Gujarat	53	.192	12.082	.001
Madhya Pradesh and Chattisgarh	53	.121	7.047	.011
Haryana and Punjab	53	.009	.477	.493
Uttar Pradesh and Uttarakhand	53	.006	.309	.581

Source: www.indiawaterportal.com

Table A5.2: Trend Analysis of Precipitation of the Combined States

State(s)	Precipitation			
	No. of observations	R Square	F	P Values
Bihar and Jharkhand	53	.084	4.675	.035
Maharashtra and Gujarat	53	.025	1.311	.258
Madhya Pradesh and Chattisgarh	53	.121	7.047	.011
Haryana and Punjab	53	.001	.031	.861
Uttar Pradesh and Uttarakhand	53	.115	6.611	.013

Source: www.indiawaterportal.com

Table A5.3: Fisher's Significance Test of All the Combined States for Temperature and Precipitation

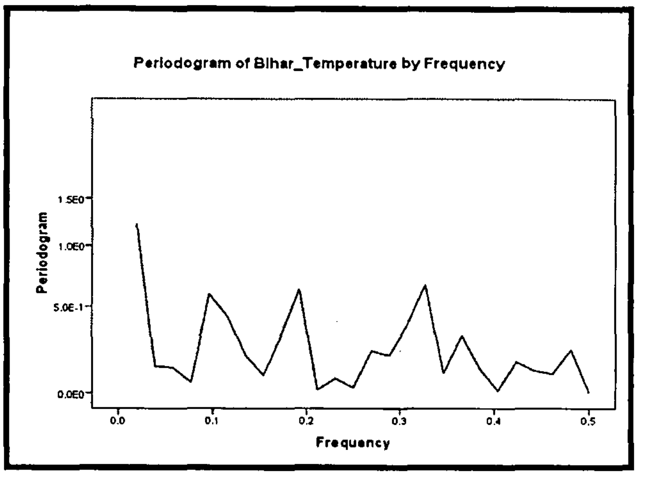
State(s)	Significance	
	Temperature	Precipitation
Bihar and Jharkhand	NSig	**Sig**
Maharashtra and Gujarat	Nsig	Nsig
Madhya Pradesh and Chattisgarh	NSig	Nsig
Haryana and Punjab	NSig	Nsig
Uttar Pradesh and Uttarakhand	**Sig**	**Sig**

Note: Sig= Significant and Nsig= Non-significant

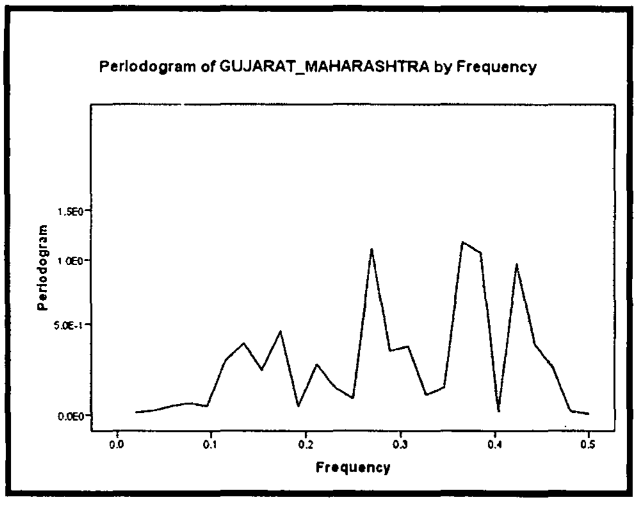
Source: www.indiawaterportal.com

A5.4 Periodogram of Combined States (Temperature)

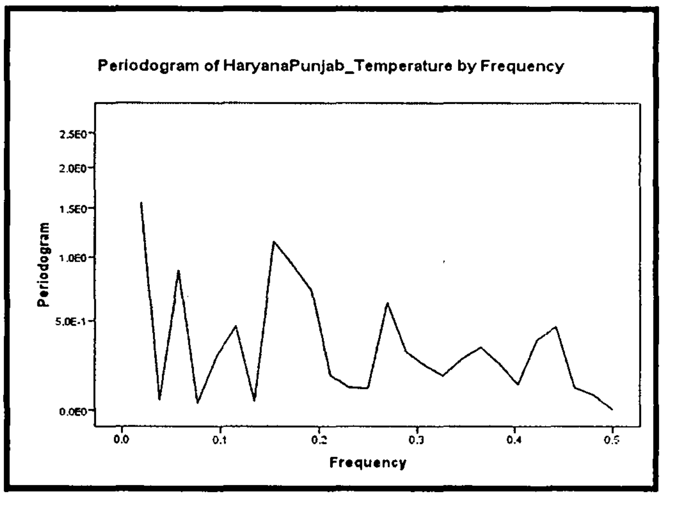
Bihar and Jharkhand



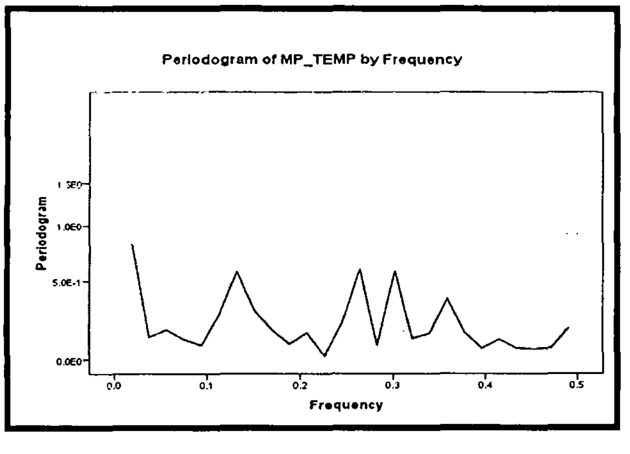
Gujarat and Maharashtra



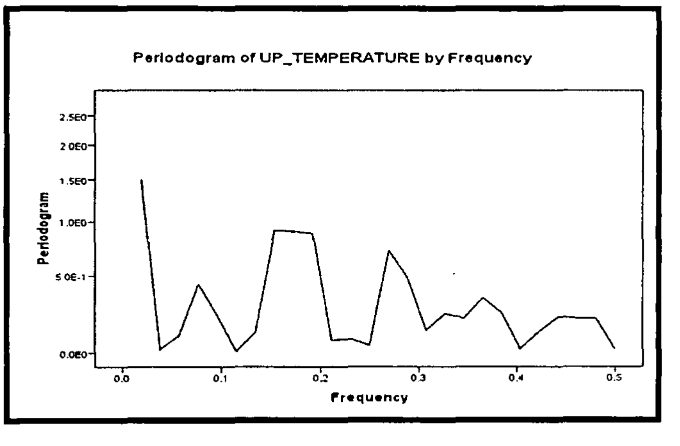
Haryana and Punjab



Madhya Pradesh and Chattisgarh

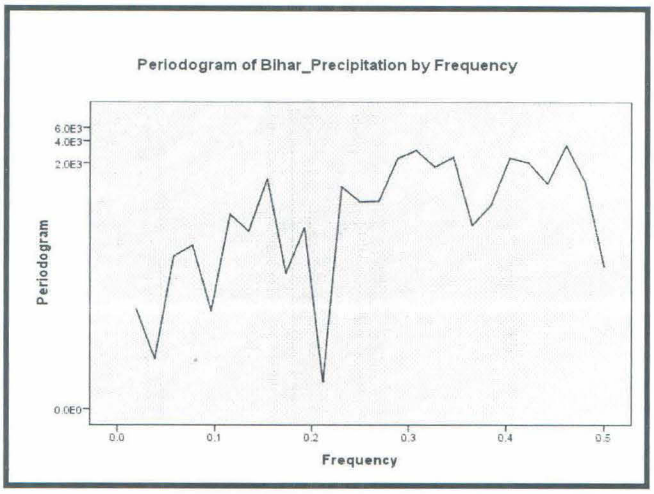


Uttar Pradesh and Uttarakhand

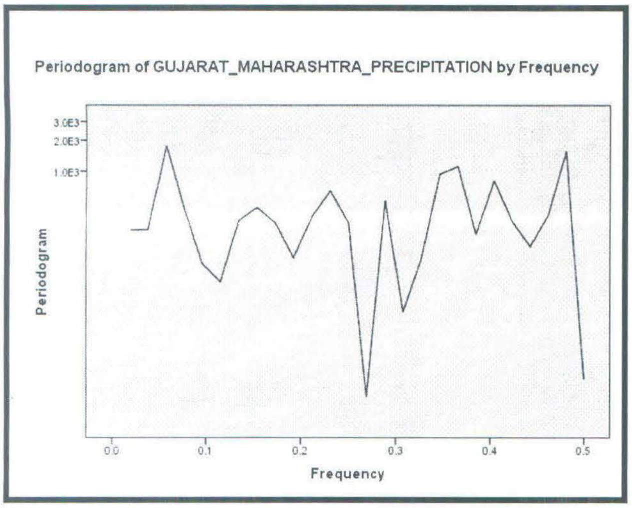


A5.5 Periodogram of Combined States (Precipitation)

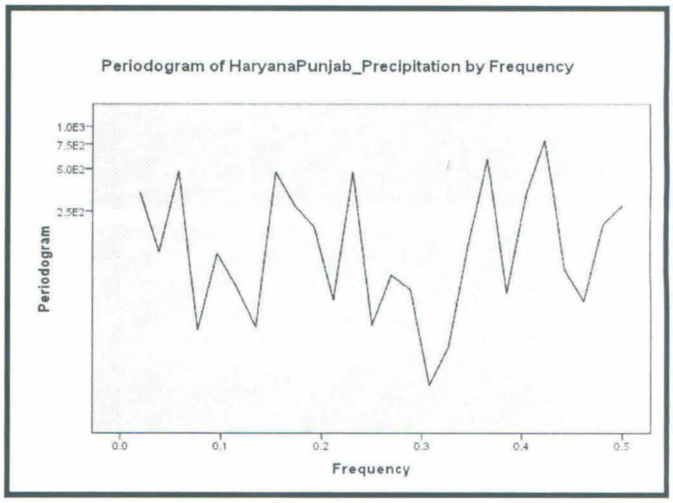
Bihar and Jharkhand



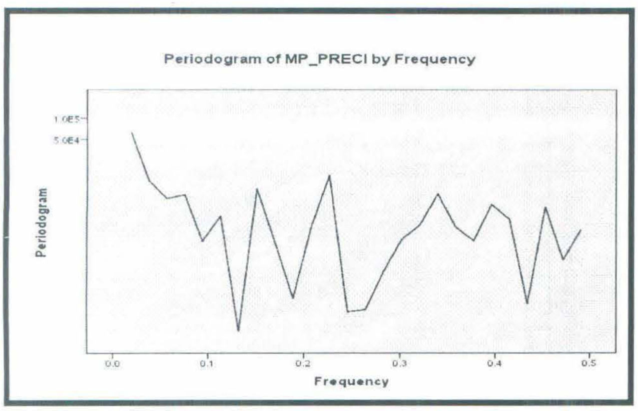
Gujarat and Maharashtra



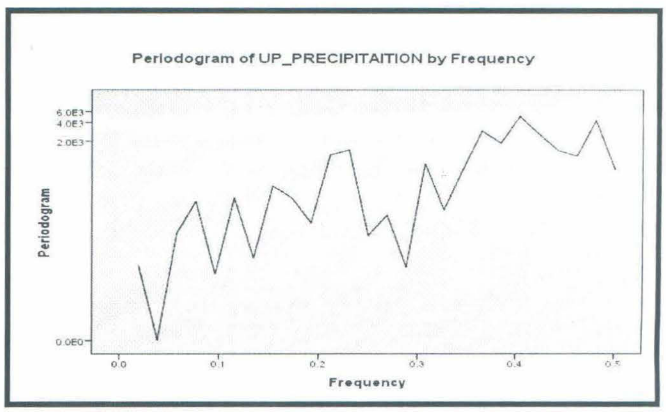
Haryana and Punjab



Madhya Pradesh and Chattisgarh

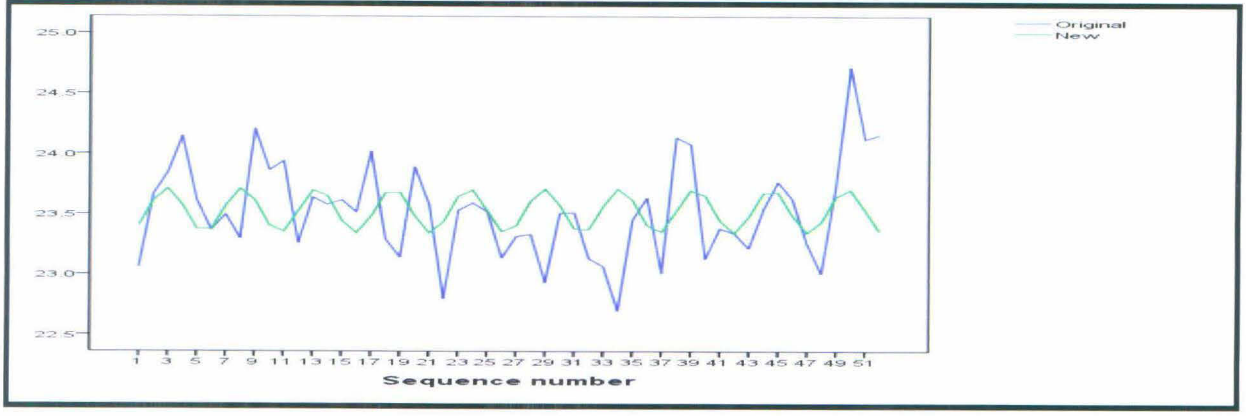


Uttar Pradesh and Uttarakhand



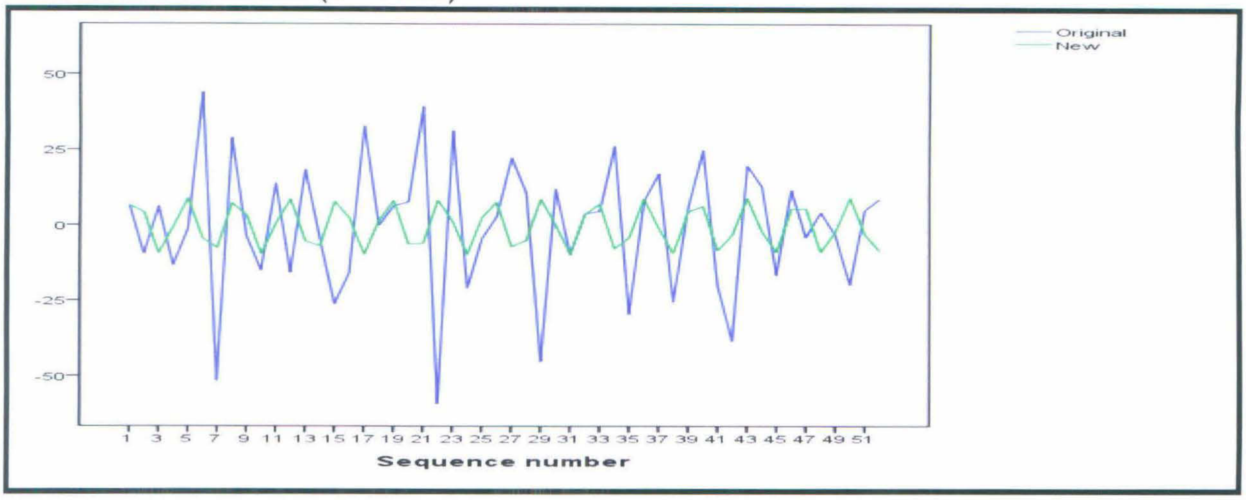
A5.6 Fisher Cycle Test of Combined States (Temperature)

Uttar Pradesh and Uttarakhand (4th Peak)

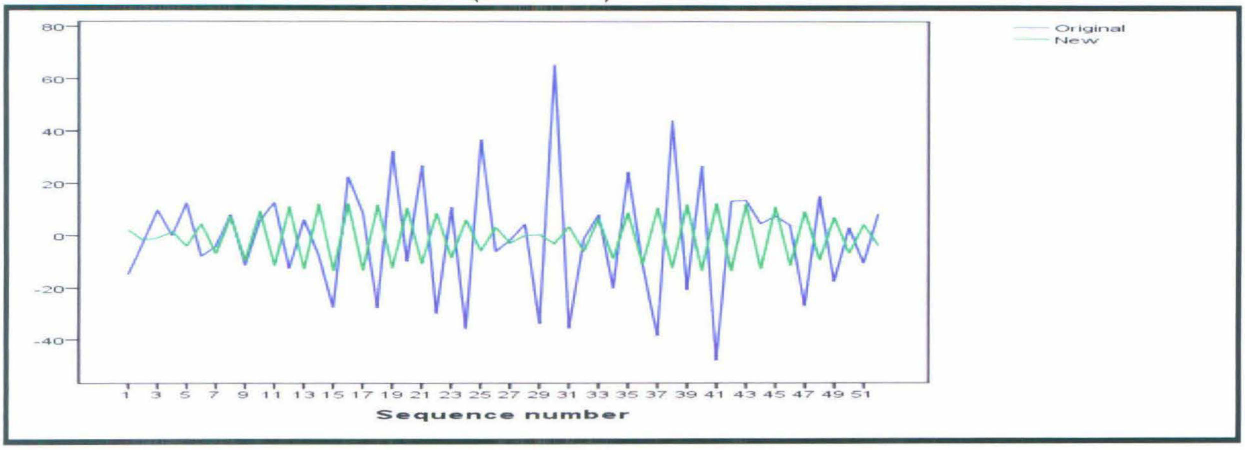


A5.7 Fisher Cycle Test of Combined States (Precipitation)

Bihar and Jharkhand (5th Peak)

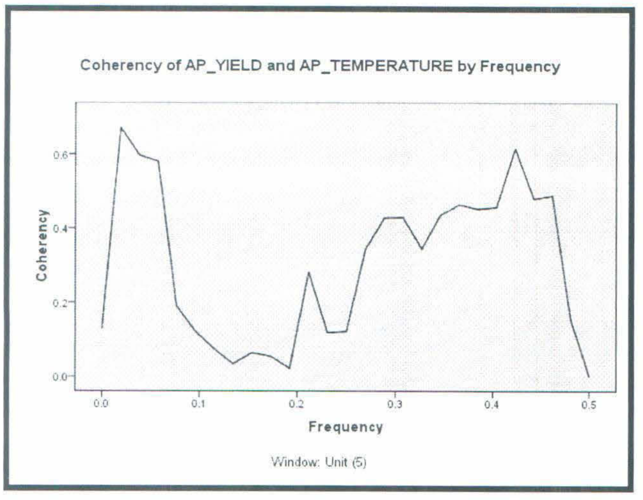


Uttar Pradesh and Uttarakhand (2nd Peak)

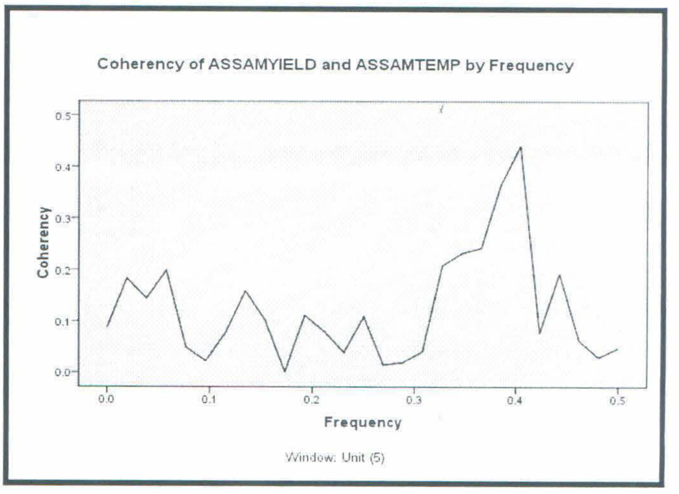


A5.8 Coherence (Yield and Temperature)

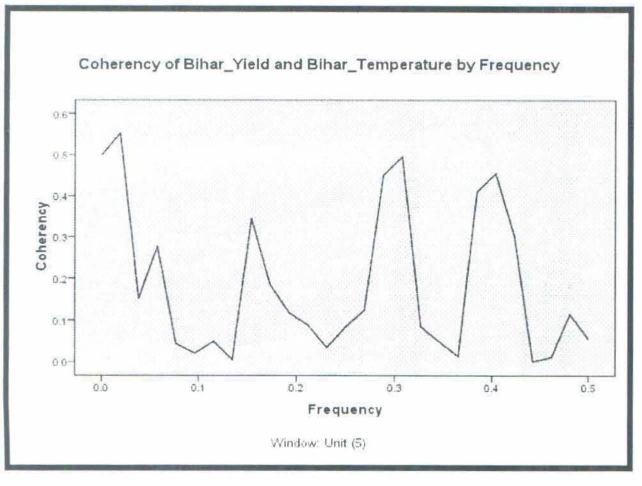
Andhra Pradesh



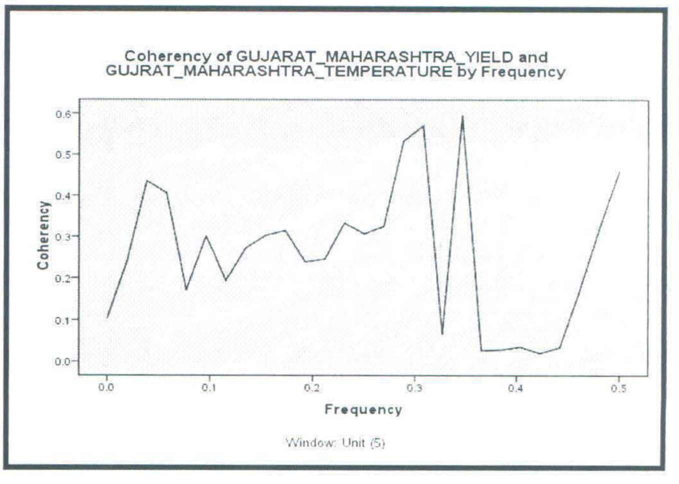
Assam



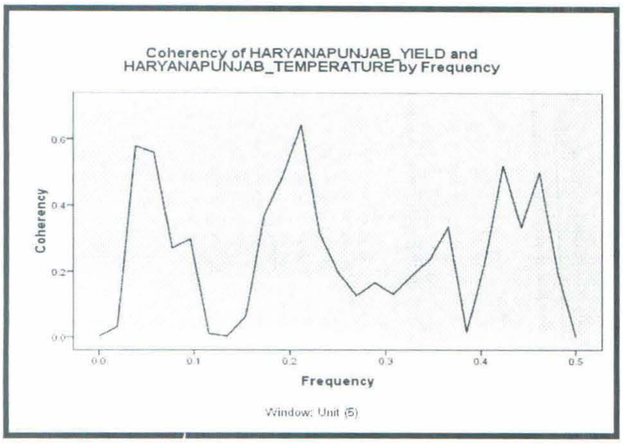
Bihar and Jharkhand



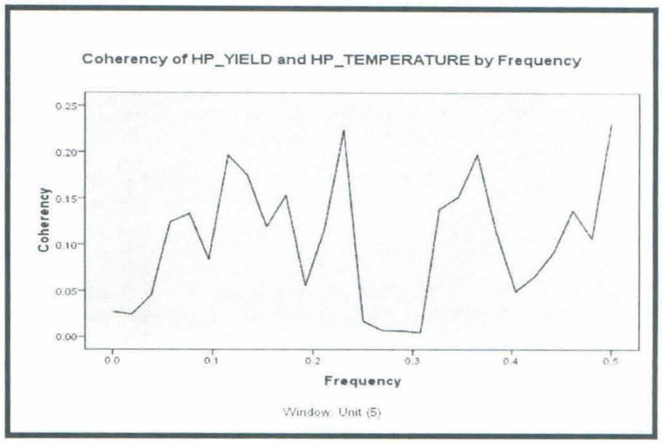
Gujarat and Maharashtra



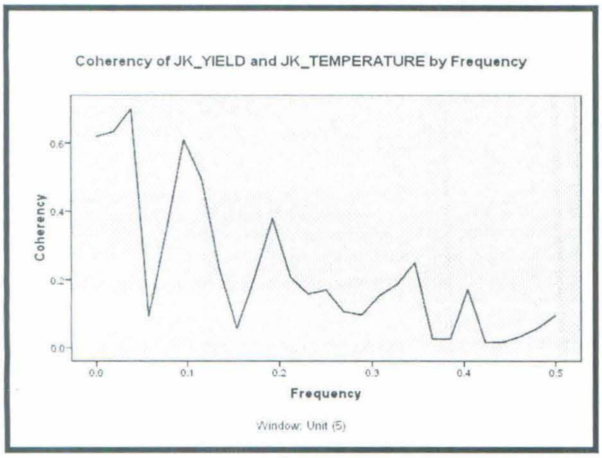
Haryana and Punjab



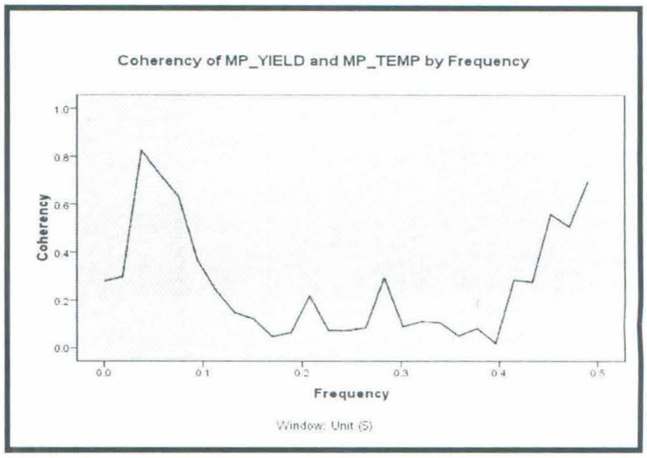
Himachal Pradesh



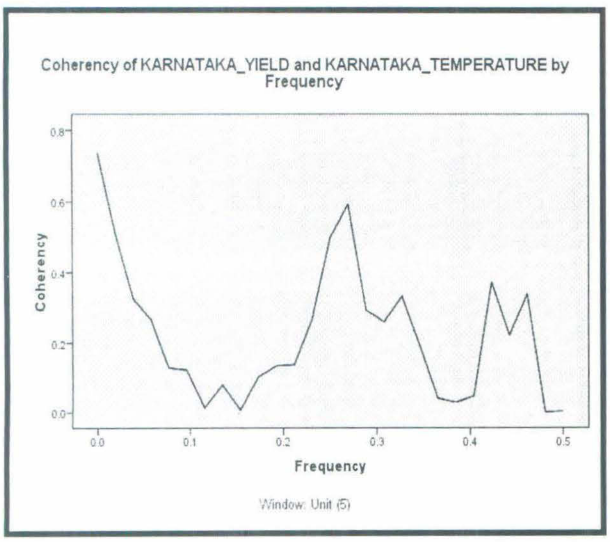
Jammu and Kashmir



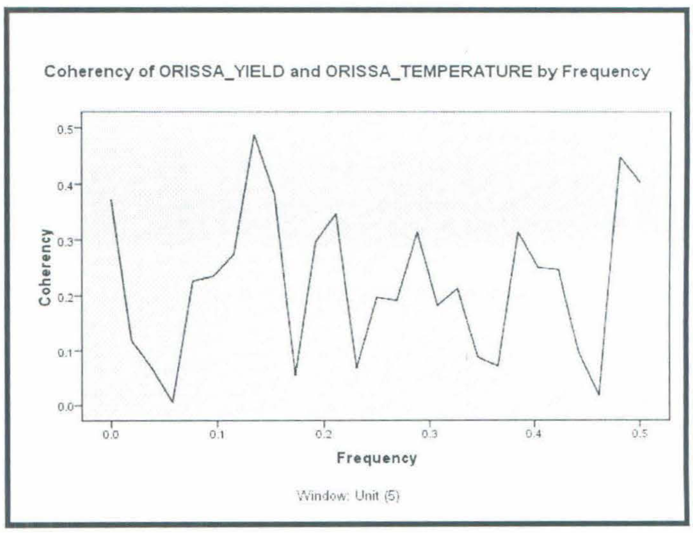
Madhya Pradesh and Chattisgarh



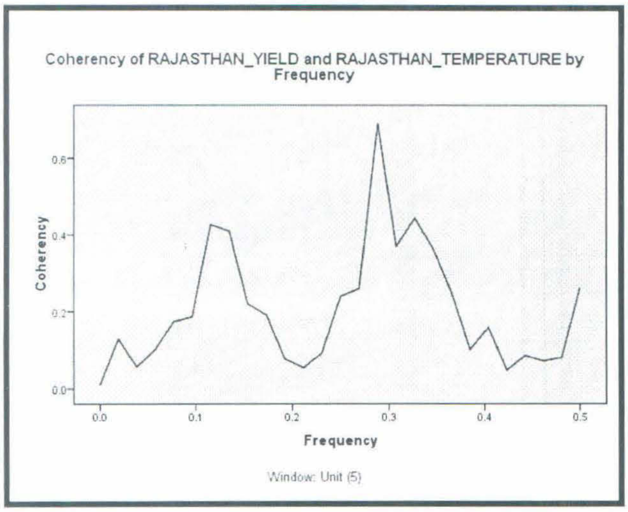
Karnataka



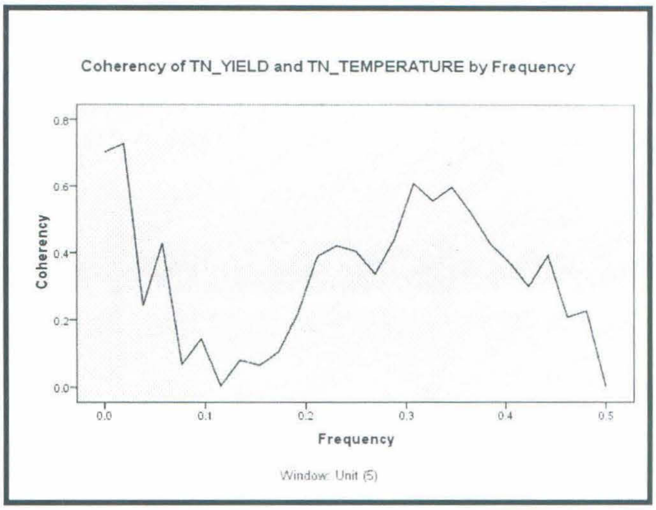
Orissa



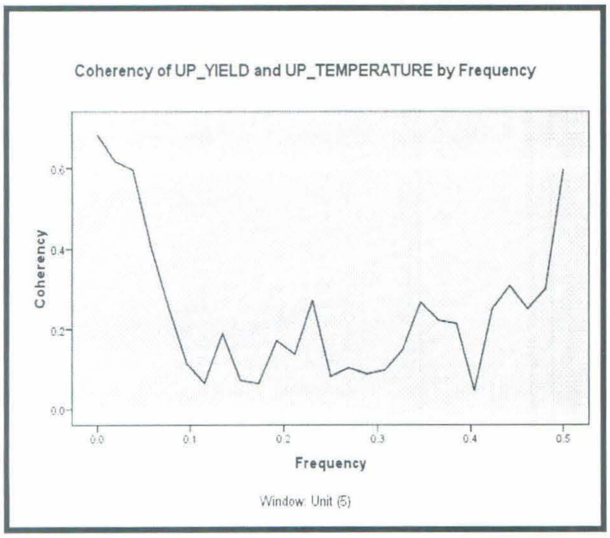
Rajasthan



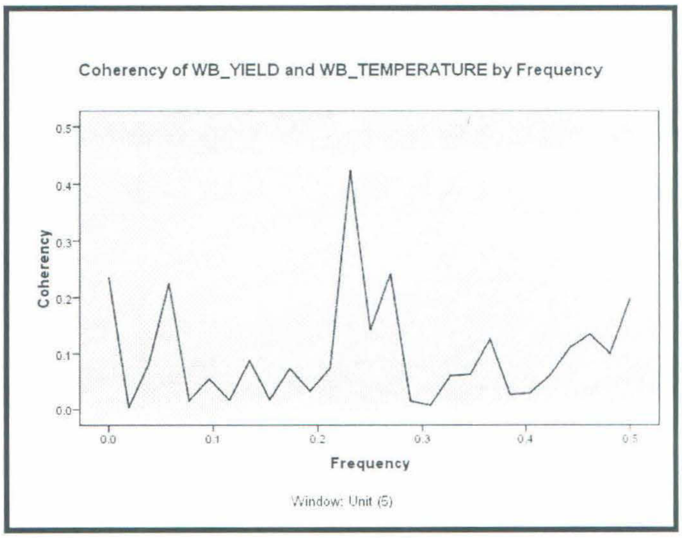
Tamil Nadu



Uttar Pradesh and Uttarakhand

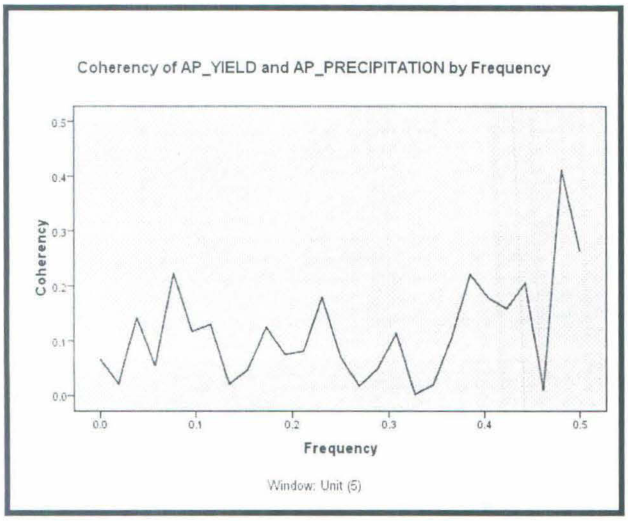


West Bengal

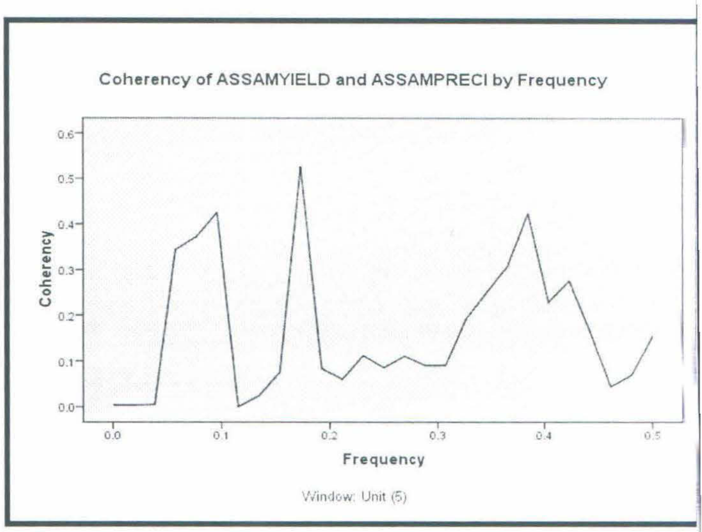


A5.9 Coherence (Yield and Precipitation)

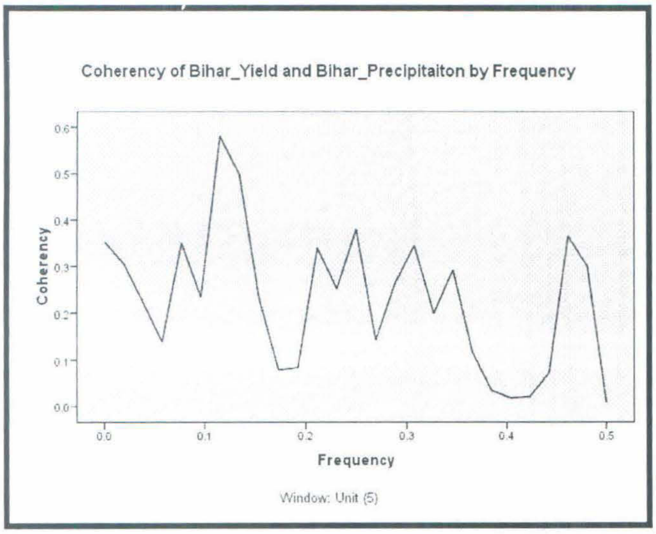
Andhra Pradesh



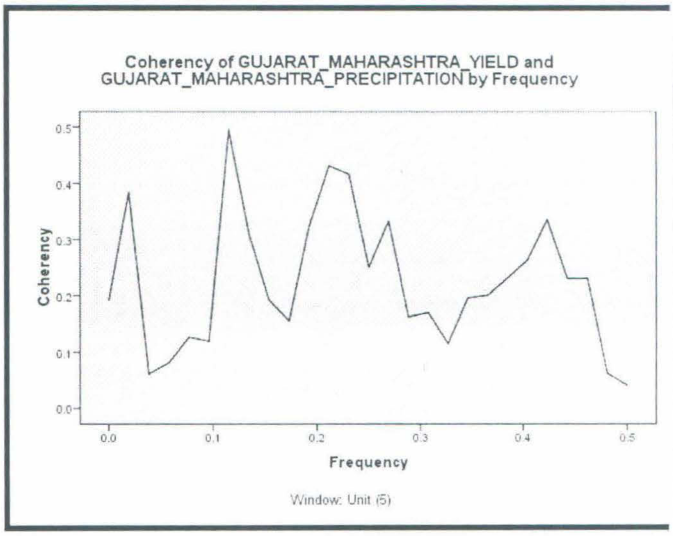
Assam



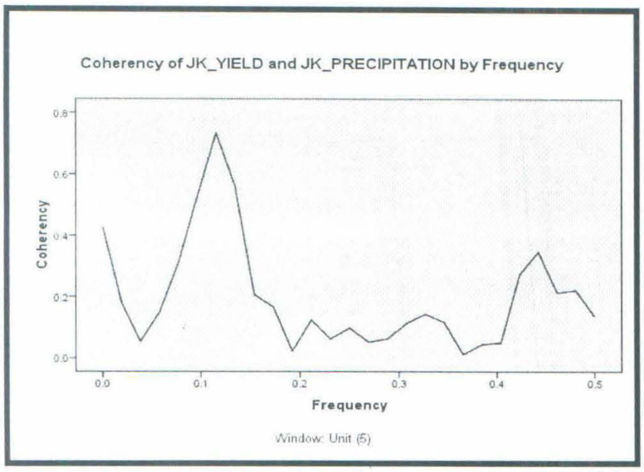
Bihar and Jharkhand



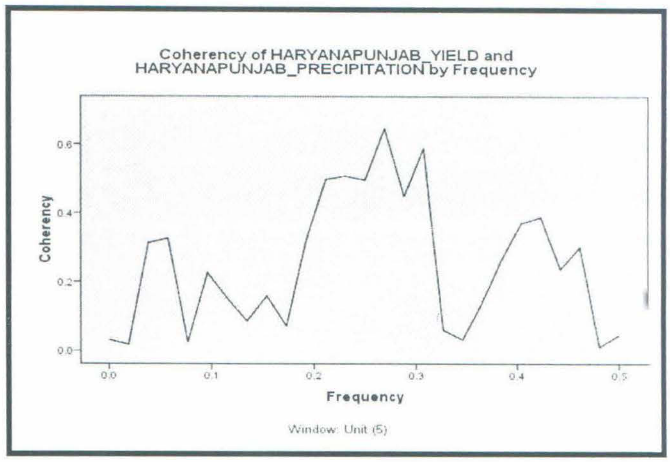
Gujarat and Maharashtra



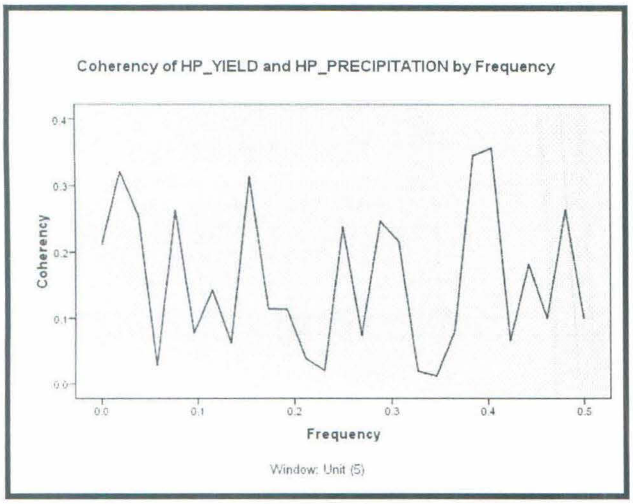
Jammu and Kashmir



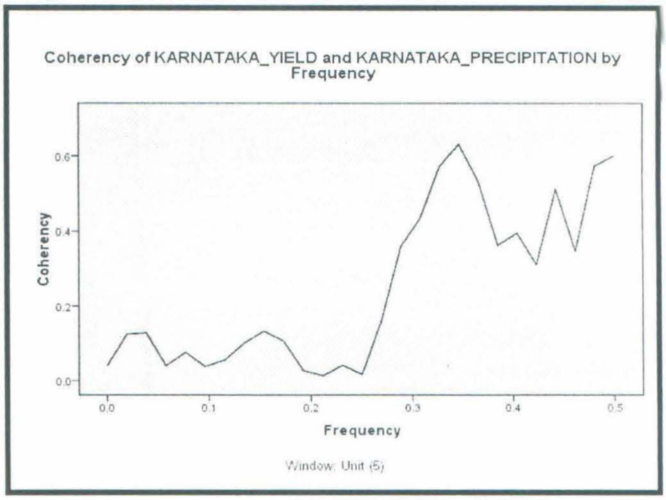
Haryana and Punjab



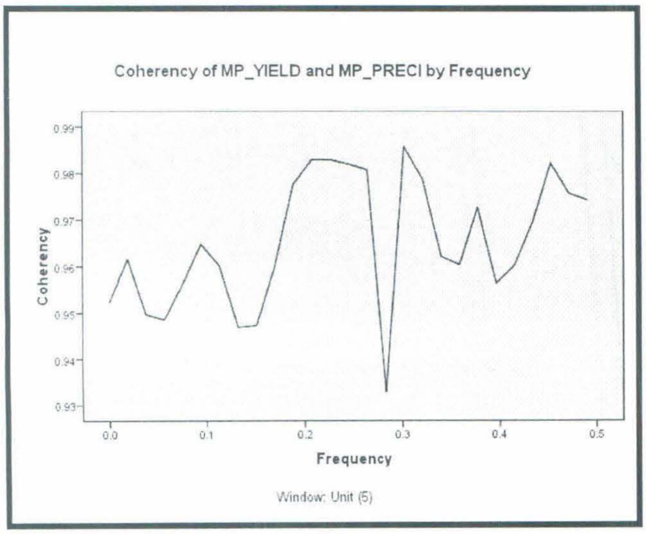
Himachal Pradesh



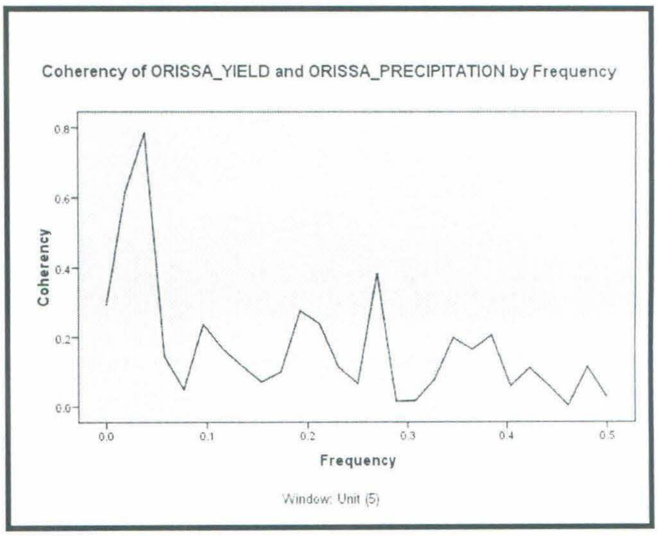
Karnataka



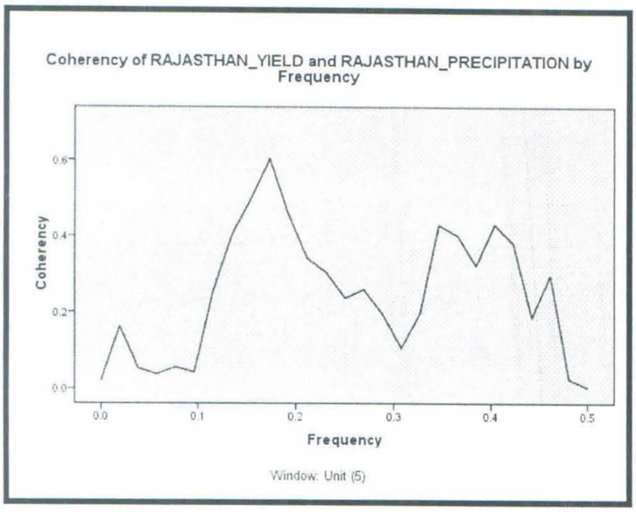
Madhya Pradesh and Chattisgarh



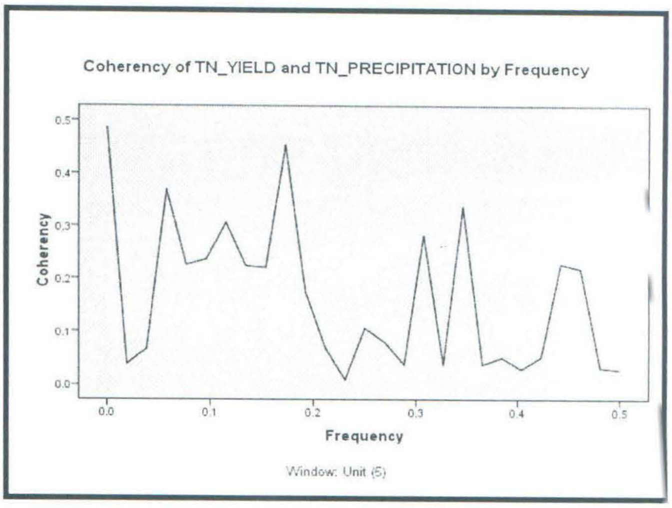
Orissa



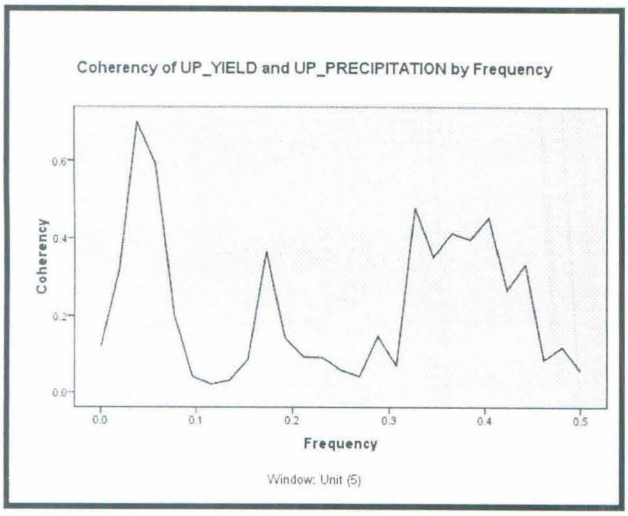
Rajasthan



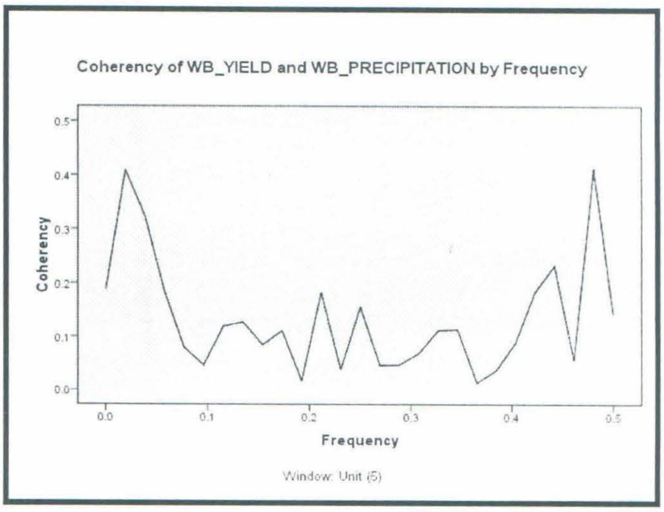
Tamil Nadu



Uttar Pradesh and Uttarakhand



West Bengal



6

SUMMARY AND CONCLUSIONS

"The choice to 'do nothing' in response to the mounting evidence is actually a choice to continue and even accelerate the reckless environmental destruction that is creating the catastrophe at hand."

Albert Arnold Gore
Earth in the Balance: Ecology and the Human Spirit (2006)

I. Summary

Much talk has been initiated in the recent years with respect to climate change and its impacts. Though all the consequences of such a change are yet to be fully understood, but three main issues can be address with this regard. They are the impacts on agriculture, sea level rise leading to submergence of coastal areas, and the increase number of frequency of extreme events which pose a serious threat to India. In this study we have concentrated on the first issue that is the change in climate with agriculture. We have further narrowed down our study to the impact of climate change in India by a study of maize, a very sensitive crop to climate. The study looks at the relationship of climate change and yield (partial productivity) of maize.

Before going to the analysis of the problem, we have first tried to understand the nature of change in climate and how it has taken its shape in the present context. The historical chapter on climate change suggests that the change in climate is mainly occurred the emissions of anthropogenic gases arising from human activities. Strong evidence suggests that in the past there has been a decline in the human civilisation due to the change in climate. Keeping this in view, our study aimed to extend our knowledge about climate change and agriculture across all the states in India.

Our Study has taken both the modern and traditional approach to understand climate change and their relationship with yield of maize. As the traditional approach is concerned we have estimated an index and tried to see the change in the climatic conditions. We have taken the Spectral analysis as a new approach to analysis the change in climate and yield and their inter-relationships. We have done both univariate and bivariate analysis. In order to do spectral analysis, we had to first remove all the trends and cycles from the series and make the series stationary. The detrended series is then subjected to periodogram analysis for cyclical behaviour of the series. If the Fisher test shows statistically significant cycle, then the cycle is removed by using harmonic analysis. The trend-cycle adjusted series is then used for the estimation of spectral density of univariate series and cross spectral analysis for bivariate analysis. We report the major findings of the analysis below.

I.a. Univariate Analysis

We have analyzed all the three series (temperature, precipitation, maize) separately. The traditional approach, the method of indexing, reveals the following:

Kerala's climatic conditions show a more or less stable condition in the past five decades; Jammu and Kashmir here have a warming trend, where as in Tripura there is a decline trend for the past fifty years. But in the case of precipitation, Andhra Pradesh has witnessed an increase in precipitation and Jammu & Kashmir, a decline in precipitation over the period. Jammu and Kashmir is the worst affected region in the country with respect to change in climate and maize yield. Andhra Pradesh, a major producer of maize, has witnessed a higher partial productivity (yield) and a favorable climate in the past five decades. It can be seen that with the improvement of the climatic conditions there has been an increase in the yield in this State. Just the opposite situation has occurred in Jammu and Kashmir and it has witnessed very poor growth in yield. Let us now discuss the results thrown by spectral analysis of univariate series in temperature, precipitation and yield.

I.a.i. Trend Analysis

The first step is to detrend the three series, yield and the two components (temperature and precipitation) of climate. In case of linear trend analysis the series is detrended using first differencing, the standard econometrics practice. If the trend is non-linear by R^2, then the series is adjusted by subtracting the predicted value from the original series.

I.a.ii. Periodogram Analysis

With the help of the periodogram sinusoid analysis and fisher tests we are able to find out that there are short-term cyclical fluctuations in various States for the three variables. The cycle originated series are then smoothened using Daniel window and the major results are as follows

Arunachal Pradesh, Assam, Himachal Pradesh, Manipur, Mizoram, Nagaland, Tripura, Uttarakhand and West Bengal are those States which shows a significant cyclical fluctuation in temperature with a certain periodicity for temperature. But in case of precipitation few States showed the presence of any cyclical movements. Only Andhra Pradesh, Bihar, Karnataka and Meghalaya show significant cyclical fluctuations in precipitation. The all India data shows significant cyclical fluctuations in precipitation. Similarly, only three States, Gujarat and Maharashtra, Rajasthan and Uttar Pradesh have significant cycle, according to periodogram analysis and Fisher tests. The spectral density smoothened series of temperature, precipitation and yield, using Daniel window has the following nature.

I.b. Spectral Density

Some interesting facts have been revealed in this study. The spectral density of all the three series (temperature precipitation and maize yield) does not follow the standard shape of economic series. The standard shape is sloping downwards (Granger, 1964). In our study all the three series, show that the spectral density is rising by frequency implying that there exist an inverse relationship between the period (long, medium and short-run) and the density. Now let us examine the bivariate relationship of our variable which is the major concern of enquiry.

II.b. Bivariate Analysis

Having done with the univariate analysis, we proceed further for cross spectral analysis. Several relationships are available in cross spectral analysis but in our study we have considered only the coherence and the phase estimates to understand the relationship between climate and yield of maize. The coherence gives us the correlation of two variables and its significance is judged if the coherence estimates are more than 0.3 (Koopmans, 1974). Similarly, Phase estimate are used to know the lead- lag relationship between variables. The average phase value is taken into consideration, only if the coherence value of the frequency corresponding to the average phase taken in the summary statistics is significant (more than 0.3), otherwise not. If the corresponding coherence value is not significant then we can conclude that there is no lead- lag relationship. After the validation of the phase we have checked, whether the average phase value is negative or positive. Since positive phase value means that the first factor is leading and the second is lagging and vice versa. Based on the above methodology we have come to the following conclusions.

Interestingly in case of bivariate series the results show that temperature and precipitation plays a dominant role in the long run. In other words temperature and precipitation affects maize yield in the long run than in the short run. The most affected States are Bihar, Harayana & Punjab, Jammu & Kashmir, Madhya

Pradesh and West Bengal by temperature and precipitation but their lead -lag relationship is not unique.

In principle, there are three situations in the bivariate analysis; one when the series leads, second when it lags and the third when there it is simultaneous relationship. The results based on our methodology do not show a uniform lead-lag relationship. In other words, we have mixed results in the lead-lag relationship where, yield is leading and climatic variables are lagging and in some States it is the other way round. It is very difficult to conclude about the lead-lag relationship among the variables. For example, Madhya Pradesh, Orissa, Tamil Nadu and West Bengal show yield is leading and temperature is lagging. Such kind of results is not limited to temperature only; we find the same result in precipitation. States like Assam, Gujarat & Maharashtra, Haryana & Punjab, and Karnataka have positive significant relationship, in the phase analysis with yield leading and precipitation lagging. Certain practices such as use of better quality seeds, modernization of farming, etc might affect our results. This requires more in-depth study before reaching a finite conclusion. However, there are some States where the climatic conditions are leading like Gujarat & Maharashtra, Rajasthan, Uttar Pradesh where the temperature is leading, and Madhya Pradesh, where the precipitation is leading. The possibility of all the series moving in the same direction and that the relationship is based on the current period and not on any lag period cannot be ruled out. Factors like technology, infrastructure, etc play a dominant role in determining the productivity of the crop. One needs to carefully reformulate the hypothesis, and remodel using other factors into account in order to have a true picture of the lead-lag relationship. Therefore, further in-depth analysis is requires and a multivariate framework is needed to be undertaken in order to understand the relationship among these climatic factors and maize yield, which is out of the scope of this study.

II. Concluding Remarks

As the analysis suggests a strong long-run relationship, between climate change and yield in the case of a sensitive crop like maize, a strong public policy framework is required for improving the productivity that is affected due to climate change. The challenge is to produce an efficient, effective and equitable set of principles and policies to guide the national action so that productivity can be sustained. In 2008, India's had its first National Action Plan on Climate Change. It includes the National Mission for Sustainable Agriculture, which aims to support climate adaptation in agriculture through the development of climate-resilient crops, expansion of weather insurance mechanisms, and modernization of agricultural practices.

Various issues are needed to be reconsidered in the National Action Plan on Climate. Various renewable energy sources, namely, wind farms, micro-hydroelectric plants, biomass & cogeneration power plants, biomass based gasifiers systems and solar photovoltaic systems should be undertaken by the government.

New innovation is required, like the launch of weather insurance[30], by the government so that the farmer affected by the climate change can overcome the financial stress. Similarly, investments in new technology, better HYV seeds, climate-resilient crops, fertilizers, irrigation facility can also be initiated for mitigating climate change in agriculture.

It is also needed that the farmers should be better equipped in order to cope up with the risk associated with climate change. Better climate risk management training should be provided by the government to the farmers, has a potential to

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[30] *Weather insurance is insurance for losses that may arise due to abnormal weather conditions. These abnormal weather conditions can be events such as excess of rainfall, shortfall in rainfall or variations in temperature, etc.*

benefit the farmers. Appropriate information distributed through efficient delivery system will help the farmers to cope up in better way in times of disasters. Thus, policies should be undertaken so that the change in climate does not cause any more human misery. The need for similar analysis for other crops is very urgent to initiate a comprehensive public policy to tackle the impact of climate change in food production in India.

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