Impact of Climate Change and Variability on Paddy cultivation in Sri Lanka

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Systematic Review

Keywords: Climate Change, Climate Variability, Paddy Cultivation, Sri Lanka

Posted Date: October 11th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-2149945/v1

Abstract

Climate change and variability are two of the most widespread topics in recent studies. Most of the researchers study the impact of climate change on the agriculture sector in the world. Because the agricultural sector is directly affected by climatic variability. Within agriculture, paddy cultivation could be named as one of the most vulnerable sectors to the variabilities of climatic parameters such as rainfall and precipitation. Rice is the staple food for 3 billion people in the world, and Sri Lankans are among them. Thus, it is crucial to study the impact of climate variability on paddy cultivation in order to safeguard the country's food requirements. This study has reviewed publications that have been published related to the topics of climate change and paddy cultivation before 2022. The findings of the study proved that there is a positive relationship between rainfall increase and paddy production during the Maha season, but it is not equally distributed. Moreover, the increasing temperature has a negative impact on paddy production. To overcome these adverse impacts, various adaptation strategies have been suggested by scholars. Promoting crop insurance, having drought resistant and short-term crops, increasing irrigation efficiency, rainwater harvesting, and intercropping are common adaptation strategies to mitigate the adverse impacts of climate change.

1 Introduction

Average weather conditions in the region over a time period known as the climate. The word "climate" has become a popular topic among researchers because the changes in climate have a high influence on every sector in the world. There are two terms that are used to denote these changes in the climate. They are climate variability and change. There is a difference between climate change and climate variability. It depends on time. The short-term variation of the climate is known as climate variability, and the long-term variation is climate change. Moreover, it is a change in the statistical distribution of weather over periods of time that range from decades to millions of years (Nawarathna Banda, nd). Climate change is a broad range of global phenomena which are primarily and predominately created by burning fossil fuels, which add heat trapping gases to the Earth's atmosphere. These phenomena include the increased temperature trends described by global warming but also relate to sea level rise, ice mass loss, shifts in plant blooming and extreme weather events (NASA, 2011). Climate change in IPCC usage refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period (UNFCCC, 2011). According to Costa (2008), climate is the totality of above-ground environmental factors and their long-term variation. Variation in time is inherent in the climate. Therefore, a visible shift in the long-term variation pattern of the climate could be named "climate change".

Climate variability refers to the variation of the mean state and other climate statistics on all temporal and spatial scales of individual weather events. Climate variability may be a result of natural internal processes in the climate system or variation in natural or anthropogenic processes. The changes of natural internal processes are known as internal variability, and natural or anthropogenic forces are known as external variability of climate (Ramamasy & Bass, 2007). The UN Framework Convention on

Climate Change (UNFCCC) uses the term “climate change” to denote human-caused changes and the term “climate variability” for other (natural) changes in the climate (Adhikari, Shah, Baral, & Khanal, 2011). Changes in the climate are considered a result of natural processes. However, as industries develop, these changes become more visible, and as a result, these climate changes are regarded as the result of human activities (FAO F. a., n.d). Stone (2014) also refer to climate variability as the variation of climate statistics on a temporal or spatial scale. The variation of statistics of climatic parameters which is not less than decade is known as climate change, and it is affecting human activities by altering the atmospheric composition. Climate variability has an impact on natural phenomena (Stone, 2014).

The findings of most studies have provided evidence for the presence of climate change in the world. According to the climatic data from 1850–1900 to 2006–2015, the global average land surface air temperature has increased more than the global average surface temperature. During that time, the land surface air temperature rose by 1.530°C, while the surface temperature rose by 0.870°C (IPCC, 2019). As a result of these changes in the climate, the global aridity has increased, and as a result of that, the land under the aridity zone has been increased globally. In 1970, the percentage of the global land which is known as the dry region that is situated between 60^0 S and 75^0 N latitudes was 17% and in 2000 it was 27% (Dai, 2011). According to the IPCC, global sea levels have risen by 10–20 cm, and global ice cover and snow cover have decreased (Nguyen, n.d.).

Climate change and variability have an impact on various sectors in the world, including agriculture, economics, industrial and even human health. Among all the sectors the agricultor sector is more vulnerable to climate change and it has a direct influnce on food production (Enete & Amusa, 2016). Though climate change is a global event, the effects of climate change are not evenly distributed. Developing countries like Africa are adversly affect by climate change because of their low adaptive capabilities (Lemi & Hailu, 2019; Jagtap, 2007). Changes in climatic parameters such as precipitation and temperature have an obvious influence on crop productivity and sever events of climatic change are expected to have an influenced on the crop yield in many developing countries which are situated in Africa, Sub-Saharan and parts of Asia (Gornall, Betts, Burke.E, Clark, & Camp, 2010). Most parts of Africa experience climate variability on seasonal and decadal time scales. And as a result of that, climatic hazards such as droughts and floods frequently occur in the region. And the frequent occurrence of the above hazardous events leads the way to famine, and it is an obstacle to the development of social and economic conditions (UNFCCC, 2007). In Asia, it is expected to increase precipitation, converting most of South Asia, East Asia, and Southeast Asia to flood-prone areas, while Central and South Asian crop yields are expected to fall by 30%, increasing the region's vulnerability to hunger (UNFCCC, 2007). The changes in the climate in Asia may cause a decrease in crop yield, an increase in hunger and a decrease in soil moisture while increasing evapotranspiration, land degradation and desertification. Furthermore, the productivity of agriculture may increase on the northern side of Asia as a result of climate change (UNFCCC, 2007).

Rice cultivation is the major economic activity and main income source for the 100 million families in Asia, and it is a staple food for 3 billion people in the world (Bouman, Haefele, Izzi, Peng, & Hsiao, 2012),

Africa, and the Latin American regions (Nguyen, n.d.). In 2010, rice production was 696 million, and 90% of total production produced by Asia (IRRI, 2013). According to the Food and Agricultural Organization (2004), the demand for rice consumption has surpassed the production rate of rice in 2000. In most of the remote villages that are situated in the Southeast Asian region, rice is not only the staple food. It has ceremonial and religious value in addition to its economic value (Crystal & Whittlesey, 2004).

Rice farming in the world is more than 10,000 years old (IRRI, 2013). It is belived that rice was domisticated befor 8000 years ago in Northern Southeast Asia or Southwestern China (Crystal & Whittlesey, 2004). There are two main varieties of rice that are cultivated in the world today, namely African rice (Oryza glaberrima Steud) and Asian rice (*Oryza sativa L.*). In addition to that, *Oryza sativa L.* is furthermore divide in to 3 groups: Indica, Japonica, and Javanica (NARO, n.d). The cultivation of paddy land extends from 53^0 North Latitude to 40^0 South Latitude. And rice cultivation can be identified in the area that has an altitude of 2600 m above mean sea level in Nepal. (Nguyen, n.d.). There are three types of paddy cultivation: lowland plots, upland dry fields, and terraces on the hillside (Crystal & Whittlesey, 2004). Most of the rice is grown under rainfed cultivation and in the flooded plain. Some are growing under the irrigation (Beighley, n.d). Of the world's total rice production, 75% of rice is produced by irrigated lowland paddy cultivation, which covers 93 million hectares of land (IRRI, 2013; Bouman, Haefele, Izzi, Peng, & Hsiao, 2012).

The life span of rice varies from 80/90 days to 180/200 days, and it depends on the variety and the environment where it is growing (Beighley, n.d; IRRI, 2013; Bouman, Haefele, Izzi, Peng, & Hsiao, 2012). Rice is a highly sensitive plant to climatic parameters. There are three main growth stages in rice cultivation: vegetative, reproductive, and ripening (Beighley, n.d; IRRI, 2013). The temperature that is required for plant growth is different growth stage by stage (Nguyen, n.d.).

Table 01
Temperatures that are critical for growing rice plants at various stages of development

Growth Stage	Critical Temperature (^{0}C)		
	Low	High	Optimum
Germination	16–19	45	18–40
Seeding emergence	12	35	25–30
Rooting	16	35	25–28
Leaf elongation	7–12	45	31
Tillering	9–16	33	25–31
Initiation of panicle primordia	15	-	-
Panicle differentiation	15–20	30	-
Anthesis	22	35–36	30–33
Ripening	12–18	>30	20–29
Source:- Nguyen, n.d.; Yoshida, 1978			

In most tropical countries, rice is grown as a monoculture crop. If the temperature dropped below 12^{0}C for more than three days in the early stages of rice growing, cultivars wold die (Bouman, Haefele, Izzi, Peng, & Hsiao, 2012). Water usage for rice production also differs from environment to environment where it is growing. According to Bouman et al.(2006), irrigated rice consumes 34–43 percent of irrigated water resources, or 24–30 percent of fresh water in the world. In the land preparation stage, the amount of water that is wanted for the land preparation can be as low as 100–150 mm. But for large scale farming, it will be 1000 mm. The evapotranspiration (ET) rate of paddy land ranges from 4–5 mm/day during the tropical wet season to 6–7 mm/day during the dry season, and it can sometimes reach 10–11 mm/day. (Bouman, Haefele, Izzi, Peng, & Hsiao, 2012).

Like this, paddy cultivation is more sensitive to climatic attributes such as rainfall, temperature, and evapotranspiration. Hence, the changes in these attributes would have a high impact on the crop's growth and production. This study focuses on identifying the impact of climate change and variability on paddy cultivation in Sri Lanka through past studies about climate change and paddy cultivation.

2 Methodology

2.1 Study area

Sri Lanka is located between latitudes 5^0 – 10^0 N and Longitudes 79^0 – 81^0 E. It is a pear-shaped island with a 65,610 square kilometer area, which includes 64,740 square kilometer of land. There are 21.92 million people living in the country (World Bank, 2020). Depending on the spatial variation of the rainfall, the country has been divided into three major climatic zones: the wet zone, the dry zone, and the intermediate zone. The topography of the country has been caused for this kind of climatic variation within the little land when compared with the other countries. Topographically country could be divided into three peneplains: the costal or first peneplain, which extends from 0 to 135 m from mean sea level; the second peneplain (135–835 m msl); and the third peneplain, which extends from 835 m up to 2770 m from mean sea level (Adams, 1929; Wadia, 1945; and Wickramagamage, Jayasena, Seneviratne, & Gunatilake, nd). The country is fed by two main monsoons, the south west monsoon and the north-east monsoon. The south-west monsoon blows through the island from May to September, and it brings rain to the south-west coastal areas and hill areas of the country. The north-east monsoon reaches the country during the period of December to February and it covers a large part of the country, including the entire dry zone. Depending on this temporal variation of rainfall, there are two major cultivation seasons in the country: Maha (October to March) and Yala (April to September). The main season is the Maha season, and in this season, paddy is grown on approximately 6,135 Km^2 of land. During the Yala season, the land area under paddy cultivation is less than half of the land area of the Maha season because of less water availability (Lareef, et al., 2015).

2.2 Data

The research articles that are freely available online and that have been published before 2022 relevant to climate change, paddy cultivation, and the study area have been used for the study.

3 Discussion

3.1 Climate Change and Variability in Sri Lanka

The weather patterns of the country are controlled by two main seasons that are named as Yala and Maha. The north-east monsoon period, which is active during the months of December to February, is known as the Maha season, and the Southwest monsoon, which arrives the country during the months of May to September, is known as the Yala season (Jacobi, 2014; Nizam, 2013; Wickramagamage, 2010). This rainfall pattern is known as the bi-model rainfall pattern, but it is not clearly distinguished in the wet-zone of the country but can be clearly identified in the dry-zone (Nizam, 2013). There are approximately 22 million people, with half of them living along the country's west, south-west, and southern coasts. .And the country is highly vulnerable to the impacts of climate change (USAID, 2018). Climate change and variability do not only impact the environment; they also impact the country’s economy, health, and society (Kottawa-Arachchi & Wijeratne., 2017). Climate parameter changes have been statistically proven. The increase in the mean air temperature from 1961–1990 has been identified as 0.016^0C and the annual maximum and minimum air temperature have shown an increasing trend. Temperature changes are more visible in the country's high latitudes than in the lowlands (Baba, 2010). According to USAID (2018),

temperature and precipitation of the country have been increased. For the period of 1961 to 2001, the mean daytime maximum temperature and the mean nighttime minimum temperature have been increased by 1^0C and 0.7^0C respectively. During this period, mean annual precipitation has decreased by 144mm island-wide.

Sujeewa (2011) conducted an emperical analysis to identify temperature changes within the hundred years from 1871 to 2010. According to the findings, the annual minimum temperature has been increased in all the climatic zones of the country. In the dry zone, the minimum temperature has been increased by 1.11^0C; in the intermediate zone, it has been increased by 0.65^0C and in the wet zone, it has been increased by 0.91^0C. And the maximum temperature has also has been increased in the country. De Costa in 2008 conducted a study under the topic “Climate change of Sri Lanka: myth or reality?”. The study covers a period of 140 years from 1869 to 2007. Study results have proved that there is an increasing trend in temperature in the selected locations. Also, the amount of precipitation has decreased during the study period. In the last decade, the highest rate of rainfall decrease recoded by the Nuwara Eliya meteorological station. The reduction of rainfall ranges from 28mm to 202mm per year for all the selected meteorological stations. The minimum value is recorded by Rathnapura and the maximum decrease in rainfall (202mm) is recorded by the Kurunegala meteorological station. Some regions of the country including the soth-eastern, eastern, north, and north-central indicated an increasing trend of precipitation during the period of 1987 to 2017, but the western, north-western and central regions of the country showed a decreasing trend of precipitation (Nisansala, Abeysingha, Islam, & Bandara, 2019). A study to identify climate change in the central highlands of Sri Lanka was carried out by De Silva & Sonnadara (2016). This study analyzed monthly rainfall and temperature data from 1869–2006 that were obtained from the five meteorological stations. A study has revealed that the rainfall of Nuwara Eliya has been reduced by 5.2 mm per year. It is a result of the reduction of south-west monsoon rainfall. The temperature of the central mountain region also has an increasing trend of 0.8 +/- 0.2^0C (De Silva & Sonnadara, 2016).

Alahacoon & Edirisinghe, (2021), carried out a study about the “spatial variability of rainfall in Sri Lanka from 1989 to 2019 as an indication of climate change”. Most of the research that has been conducted to understand the impacts of climate change in Sri Lanka concludes that generally there is a decrease in precipitation, but according to the results of this study, there is a significant increase in precipitation in all climatic zones of the country. Furthermore, a maximum increase in precipitation has been recorded from the wet zone and a minimum increase in precipitation has been recorded from the semi-arid zone. Here the authors (Alahacoon & Edirisinghe, 2021) argued that most of the studies have used meteorological station data (rainfall and temperature) to analyze climate change, and it is irrational because the area covered by the station is very small. Thus, they have used raster data analysis and the results are opposite to most of the previous findings. The results of all these studies have proved that there is climate change and variability in the country. The temporal and spatial variability of climatic parameters have an influence on the various sectors in the country.

The agricultural sector could be identified as the most sensitive sector to climate change. Specially changes in climatic parameters will have a high impact on irrigated agriculture and also on irrigation. Temperature increases cause evapotranspiration, and during a drought, the evapotranspiration rate increases, causing a decrease in water level in tanks and rivers (CCSME, 2011). Soil moisture stress in upland crops will increase and climatic changes will cause disasters like floods and drought, which have a high impact on the productivity of agricultural crops (Punyawardena, n.d.). Climatic changes causes the low predictability of rainfall patterns and it is influencing water management and agricultural planning (FAO, Climate change impacts on crop production Sri Lanka: Challenges and adaptation options, 2021). In 2009, a 5.8% reduction in paddy production was observed, and it was a result of delayed monsoon rains (CCSME, 2011). 30% of paddy cultivation in Sri Lanka depends on rain water and 70% of paddy depends on irrigation. Pollon desiccation, reducing productivity, increasing pest and disease outbreaks, land degradation, and yield reduction will occur as the consequences of climate change (Punyawardena, n.d.).

3.2 Impact of climate change and variability on paddy cultivation in Sri Lanka

Sri Lanka's Ministry of Environment (2011) emphasizes that, vulnerability to drought has been increased throughout the country as a result of climate change and that the dry zone and intermediate zone are highly vulnerable to the drought. 16 DSD (divisional secretariat division) which has 176,852 acres of paddy cultivation are highly vulnerable to the drought and 23 DSD moderately vulnerable to drought and these DSD are claiming for 174,839 acres of paddy land (USAID, nd.). According to Yoshino & Suppiah (1984), there is a positive relationship between rainfall and area of cultivation during the Maha season in the Dry Zone of the country. And the rainfed paddy cultivation is more susceptible for drought and flood. There is a relationship between rainfall and paddy cultivation extent. This relationship is more visible in the dry zone than in the wet zone because of its seasonal drought. Paddy cultivations which are depending on the major irrigation schemes are least vulnerable for the short term drought but vulnerable to the severe droughts (Yoshino & Suppiah, 1984). The Maha season's low rainfall resulted in severe crop loss during the season and the following yala season. Surplus rainfall in the Maha season and early land preparation for the Yala season are increasing the yield and reducing the crop loss (Alles, 1967; Yoshino & Suppiah, 1984). The rainfall and paddy yield are showing strong negative and positive relationships respectively in the Yala and Maha seasons (Mathanraj & Kaleel, 2016; Selvanayagam, 2018). This relationship is not always the same. When considering the climatic regions, the relationship between climatic variability and paddy production varies from climate region to region. During the Maha season, rice yield in the dry zone has a positive relationship with climatic parameters (rainfall), but it has a negative relationship in the wet zone. Though, in the Yala season same attributes show the opposite relationship within the two climatic regions. The variabilities of climatic parameters are not showing equal impacts on rice varieties. The medium-duration rice varieties are at higher risk than the short-duration rice varieties (Amarasingha, Suriyagoda, Marambe, Galagedara, & Punyawardena, 2018). Findings by Selvanayagam (2018) proved that there is a positive relationship between paddy production and rainfall in the Maha season. According to him, if Maha season rainfall increases by 1 unit, paddy

production would be increased by 0.05 times, and the high variability of rainfall results in flood hazards and prolonged drought conditions, which cause the high fluctuation in paddy production. Though increasement of rainfall has positive impact on the rice production the increase of temperature always do not have positive impact on it. Temperature increases of more than 2^0 degrees Celsius will have a significant negative impact on rice production. The influence of temperature variation on rice production is greater than the influence of rainfall variability on rice production. If the temperature increases by more than 4^0C it will cause a 30% crop loss. If it is combined with the 50% increase in rainfall, it will cause a decline in average paddy production of 32.13% (Ratnasiri, Walisinghe, Rohde, & Guest, 2019). Hence, temperature variability has a greater influence on paddy production than rainfall, and the combination of both high temperatures and high intensity of rainfall could have done severe damage to crop production.

Zubair, et al. (2014) discussed climate-related problems under four major categories as: climate, crops, water supply, and pests and diseases. Seasonal rainfall change, changes in growing seasons, the high occurrence of drought and the intense rainfall that follows frequent drought have been mentioned under the climate related problems in climate change. Crop related problems are an increase in crop damage and reducing the harvest as a result of drought. Lowering the ground water, reducing the water supply duration, and reducing the water supply for cultivation are the three water related problems that are associated with climate change. The presence of new diseases and pest attacks are the pest and diseases-related problems with climate change. 70% of paddy cultivation in Sri Lanka depends on irrigation. Climate change also has an impact on the irrigation scheme of the country. In 2011, Wijesekera conducted a study on the impact of climate change on irrigation infrastructure facilities. This study was carried out based on five climatic scenarios. According to the findings in the both seasson water demand will increasse 10–15% because of climate change impacts, decline of irrigation system efficiency and increase of cultivation extent.

To overcome these adverse impacts of climate change, the following adaptation strategies are sugested: usage of organic fertilizers, insecticides, and herbicides; growing drought tolerant crops and short-duration crops; changing cultivation season (days of planting), inter-croping and crop diversification; rain water harwesting; diversification of livelihoods; increase awareness and mobilizing communities for climate change adaptation; improving traditional agricultural practices; making and increasing efficiency of irrigation systems; promoting crop insurance systems; development of policies related to food security; and providing training and motivational support to the farmers (Mathanraj & Kaleel, 2016; Zubair, et al., 2014; Nawarathna Banda, nd).

4 Conclusion

According to the findings of these studies, climate change has a significant impact on Sri Lanka.. In particular, paddy cultivation, a staple food of the country, is highly vulnerable to the adverse impacts of climate change. Most of these studies have focused on how the changes in the main climatic parameters (rainfall and precipitation) influence paddy production. They have considered average rainfall and average paddy production as seasons (Maha and Yala) but they have not focused on the life-cycle of

paddy and the changes in requirements in growing stages. Thus, it is crucial to study the influence of variability of climatic parameters on the different growth stage requirements. However, according to the findings of the studies, there is a positive relationship between rainfall and the amount of paddy produced during the Maha season (Selvanayagam, 2018). But this relationship also differs from the climatic region to region. Increasing temperatures have a negative impact on rice production (Ratnasiri, Walisinghe, Rohde, & Guest, 2019). It is crucial to follow adaptation strategies to overcome the adverse impacts of climate change in order to achieve food security in the country. Therefore, more studies on climate change and its influence on paddy cultivation should be carried out.

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Declarations

Competing interests: The authors declare no competing interests.