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Agrometeorological assessment of extreme weather events and their implications for agricultural and allied sectors

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Abstract

This review is about the extreme weather events and their effects on agriculture and allied sectors. As in past few years there are certain unpredictable changes in climate has occurred such as droughts, heatwaves, cyclones, floods, and heavy rainfalls which damages the natural environment very badly. This affects the food security as extreme weather events are great threat to agriculture system which not only leads to poor yield but also causes damage to livestock and has serious burden on farmer and their families. To understand and manage these problems in future the researchers combined the data of past years, current weather data to observe the conditions and how it is affecting farming systems. With the help of agrometeorological modern tools and techniques these conditions can be managed and controlled which is very helpful for farmers. As it helps to identify the problems at difficult periods of time further leads to less losses in productivity, resource used in farming.

The extreme weather conditions cause damage and destroy the whole crop growth, food-fodder of livestock, destroys the shelter, infrastructure and pest-disease infestations like conditions which cannot be controlled easily. This study also includes the benefits and importance of using agrometeorological tools and assessment which provides early warnings, information about weather conditions, and management practises to reduce these kinds of risks on time. It also suggests farmers to apply climate resilient varieties, tolerant varieties, proper drainage, and irrigation system to help the farmers and for sustainability of livelihoods.

Keywords: Adaptive management practices, agricultural productivity, agrometeorology, extreme weather events, weather-based risk assessment

Introduction

As we know agriculture is the major source of livelihood for people around the world, majorly in developing countries. People from rural areas or communities do not only depend on crops but also on poultry, fisheries, livestock, and agroforestry to a large extent. Agriculture practices have been historically dependent on predictable seasonal weather changes. Farmers conventionally depend on local knowledge and experience to manage the challenges such as droughts, floods, heatwaves, and frost.

Despite significant advancements in crop genetics, irrigation systems, farm machinery, and agro-inputs, agriculture mainly still relies on unpredictable weather conditions. Crop productivity and livestock farming are influenced by key environmental factors such as temperature, rainfall, sunlight, humidity, and wind. Each and every crop has its own required climatic conditions, if failure to meet these parameters crops can experience physiological stress, restriction in growth, and loss in yield productivity.

Agrometeorology bridges the gaps between farmers and scientists, helps them by analysing the meteorological data with agricultural practices and enables them to manage the environmental risks more effectively and enhance the agricultural productivity. This research examines the extreme weather impacts on crop production and also highlights the vulnerability of agricultural systems under changing climatic conditions. These studies help us to understand better the impacts of extreme weather disrupts crop growth, reduction in yields, soil moisture, increases pests and disease outbreaks, and overall weakens the agricultural systems stability.

Agrometeorological assessment is now necessary for adapting to climate change's frequent, and unpredictable weather impacts. Improved forecasting and weather monitoring help farmers to manage the damage from droughts, floods, and heatwaves and also provides them early warning systems and effective risk management strategies. By providing accurate and real-time information to farmers enables better decision regarding sowing, irrigation, crop protection, and pest control. This balances potential losses and ensures long-term sustainability which is further beneficial. Agrometeorology strengthens agriculture and allied sectors by building them against climate variability and enhances resilience and adaptability.

Methods and Methodology

1. Extreme Weather Events

Extreme weather events describe the size, damage level, time of the weather conditions which further harms the natural ecosystem and humans [1]. It includes droughts, heatwaves, floods, cold waves, and unpredictable weather conditions that has great impact on agriculture and allied sectors [1,2]. As we know by time the world population is increasing and growing which also leading to more land utilization influencing agricultural systems becoming more susceptible to extreme weather [3]. As agriculture is expanding people are now settling their homes and business into flood plains and near coastal areas causes weakening of their natural ability [1]. Agricultural crops, farmers, livestock, natural ecosystem has been greatly affected by these extreme weather conditions which changes into disasters in minutes [4].

1.1 Classification of Extreme Weather Events and Their Agricultural Impacts

1.1.1 Drought

Drought represents a significant climatic extreme marked by an extended and notable decline in rainfall and moisture levels that fall below the usual standards for a specific area and timeframe [5]. In agrometeorology, drought is simply not just about low rainfall it is basically about an imbalance in the ecosystem. Crops start to suffer due to stress because of less or irregular rainfall and more moisture is pulled from soil by atmosphere in high temperatures and evaporation [6]. The growth of crops slows down and loss in yield due to less water [7]. This creates disturbance in ecosystem and affects crop yield, livestock health and all over the environment [8]. Drought is challenging for farmers not just a weather conditions changes by time it causes damage to livelihood and affects the sustainability [5,9].

There are four categories of drought includes meteorological, agricultural, hydrological, and socio-economic drought [5,10]. The occurrence of meteorological drought is due to prolonged period of rainfall; in hydrological drought there is less availability of ground water and surface water resources [10]. When there is inadequate moisture in soil and does not fulfil crop water requirements for growth which further results in yield loss is referred to agricultural drought [7,11]. Socio-economic drought is less availability of water which further influences the food security and livelihoods [10,12].

1.1.2 Heatwaves

A heatwave is simply defined as the long period of higher temperature as compared to normal temperature in seasons of a particular region [5,13]. Agricultural heat stress not only affects in daytime but also at night because of high temperatures which further prevents the plants and livestock to get relief and recovery at night also and also causes physiological damage and

loss in productivity [14,15]. The heatwave impact is driven by its duration, its intensity, and some environmental regional factors like wind, moisture, humidity, and soil which is coupled with meteorological conditions [5,16]. The farming conditions becomes more stressful due to high heat and humidity, and low wind causes damage to crops growth and livestock [17]. Continuous heatwaves with high temperatures at night also causes the crops to reduce energy through increased respiration which leads to poor crop health and low photosynthetic efficiency [14,18]. By forcing their improper growth there will be not proper development and productivity which further results in low quality and reduction in yield [18]. In such conditions with crops livestock also suffers as well which leads to reduced intake of feed, decrease in milk production, failures in reproduction, and weakening of their overall health and poor immunity [15,19]. Extreme of heatwaves slowly weakens agricultural system, making it more difficult of crops and livestock to survive in ecosystem resulting in low productivity and affects humans also by dropping their employment opportunities [13,20].

1.1.3 Floods

The sudden occurrence of floods is major and severe threat to farmers and farming systems which further causes ruined field, damaged infrastructure and loss for agricultural crops and livestock with minimal recovery options [5]. As for many communities' agriculture is more than just a job, for them it serves as initial way of life for many families in which floods directly threats for both their livelihoods and food security [21]. Floods can cause rapid crop destruction by submerging the field for many days makes difficult for plants to survive. The consequences of this destruction caused by flood is worse than visible physical surface damage. Floodwaters can wash away the top layer of soil containing essential nutrients, it diminishes soil quality, causes leaching of vital minerals required by crops and overall causes severe damage and reduction to soil fertility [17,22]. Waterlogging for more long time causes suffocation to roots and also delays the sowing of next crop according to growing season [21,23]. Beyond the crops, farmers also face devastating losses including livestock losses, seeds, fertilizers, machinery, and damage to infrastructure, floods also damage the irrigation systems [5]. Other problems such as stagnant water creates ideal habitat for insects, pests and pathogens which further causes diseases in crops and leads to production loss [17,23]. Floods cause damage to a large extent but they are not always harmful sometimes they help in deposit fresh nutrients and silt which helps in improving soil fertility by time [22]. By collecting the data through weather monitoring and agro climatic analysis which is very helpful for farmers and researchers to prepare better for future [5,13]. To reduce future risk of flood and building resilience is possible by adopting flood resistant varieties of crop, improvement of drainage system, and practicing climate-smart farming [13].

1.1.4 Hailstorms

Hailstorms are generally nightmare for farmers because they occur suddenly without any warning and leaves no time for farmers to prepare and destroy crops causes' loss of yield. Within minutes calm skies instantly turn into forceful hailstorm and creates a destructive scene by showering the icy pellets which damages whatever comes to its path [24,25]. These powerful winds carry water droplets into freezing atmosphere and create hailstones which further grows before falling onto the field. For farmers hailstorms is not only an extreme weather event but a challenge which causes damage to both their economic and

emotional health^[26]. All their hard work, financial investment, and care is wasted or destroyed in an instant^[25]. Due to the severe impact of hailstorm crops are destroyed, broken stems, scattered fruits and vegetables, and torn leaves on the ground^[24]. Mostly wheat, fruits and vegetables are damaged by hailstorm. Also destroys large orchards, damages their harvests including fruits, vegetables, flowers in minutes^[24,25]. Hailstorm not only damage the agricultural crops but also the human made greenhouse structure, damages the plastic sheet coverings, storage areas and other important facilities^[26]. By destroying the fodder and shelters of livestock it severely causes damage to their lives and creates a economic stress on farmers and their families directly impacting their source of income because in rural areas farmers income mainly depend on livestock^[26]. These type of challenges and problems can be overcome by proper management and preparedness. By utilizing and implementing of agrometeorological services and early weather forecast warnings these extreme events can be managed by farmers and helps in preventing major losses. Important and useful measures can be implemented such as harvesting crops early, providing protective net, and covering of crops can drastically improve yields^[27]. Adopting these useful strategies empower farmers to resist damage caused by hail and safeguard their crops and future livelihood.

1.1.5 Cyclones

For people living in and near coastal areas cyclones pose a significant threat as it is a powerful and terrifying natural weather events that brings the strong dangerous winds and heavy rains^[25]. Cyclones forms over warm ocean waters, where temperature rises and atmospheric instability generates low pressure centres. Advancing toward land, they bring heavy wind and rains which further causes torrential rains and storms surges that leads to rapid flooding in vast areas suddenly^[28]. For farmers it is not only a weather conditions but a serious problem and threat which can destroy their efforts and years of hard work just in minutes^[1,25]. The coming heavy and strong winds and rains flattens the standing crops, also causes waterlogging and flooding in the field which leads to loss of soil quality^[1]. The salty water from sea may enters in the fields which damages the fertility of soil and in future causes difficulty in growing crops^[25,26]. It damages the orchards and plantations which takes many years of a farmer hard work and time in development are uprooted and damaged by cyclones leads to long-term loss^[5]. Beyond crops these extreme weather events also causes damage to livestock, forestry, and fisheries to a large extent^[25,28]. Creates loss of fodder, shelter, and burden on farmer families^[1]. With the help of weather forecasting these challenges can be managed by farmers and prepare better in future. Farmers can better withstand these problems and save their livelihood^[27].

2.1 Agrometeorological impacts on crop growth, productivity and yield stability

Agrometeorological factors like temperature, rainfall, humidity, sunlight, and wind have great impact on productivity, crop growth, and stability in yield^[29,30]. Many important processes in plants are affected by these elements such as water use efficiency, photosynthesis, and stages of growth^[29]. These extreme weather conditions cause disruption of environment by creating serious conditions of drought, floods, heatwaves, hailstorms, and cyclones further damages the crops and livelihood. Agrometeorological assessment plays an important role for managing these problems and helps in providing useful information on time to farmers and researchers through which

management practises can be opted and leads to sustainability.

2.1.1 Temperature

Temperature is one of the major factors in agro meteorology which influences crop growth and development at every stage such as germination, flowering, vegetative, and maturity stage and affects the plant processes includes photosynthesis. Every crop requires different temperature for growth. In low temperatures or cold stress, the metabolic activity of crops reduces and as in hot temperatures it leads to evapotranspiration and reduction in yield^[31,32]. Temperature is an important variable which is necessary for crop growth if provided as per requirement and can also be dangerous for plants if changes suddenly which leads to low productivity and sometimes death of plant^[33].

2.1.2 Rainfall

This is the source which provide adequate amount of water to plants and enough soil moisture for crop growth^[34]. Rainfall in required amount supports the plant health, growth, and provides good yield, if no proper rainfall or less rainfall it can lead to drought like conditions and disrupts the nutrient uptake in plants and further problems in yield productivity^[35]. If there is excessive rainfall it leads to flood and problems like waterlogging, loss of quality in soil and nutrients^[35]. Rainfall is an important part of crop growth required amount can lead to good yield formation and inadequate can severely damage the crops^[33].

2.1.3 Solar Radiation

Solar radiation is basically sunlight which is the major source of energy for plant growth and required by different stages of crop growth as plants makes their food by photosynthesis in which sunlight is major component^[34,36]. Proper sunlight can lead to healthy crop growth and development^[36]. Less or no solar radiation can cause poor yield and no proper healthy growth of plants, sunlight if excessive can cause heat stress and dryness in plant further yield reduction and poor grain quality. Variation in sunlight leads to different crop growth and yield results^[34].

2.1.4 Relative Humidity

This variable influences the moisture in air important for crop growth, production, and stability in yield^[34]. It impacts the plant processes and stomatal activity of crops^[37]. High relative humidity can lead to damage and rotting in plants due to conditions like flood and cyclones. Low humidity can lead to heat stress and affects the flowering, pollination, grain filling, and wilting of plant. Also influences the insect activity causes damage to plant health and loss in yield. If we talk about crop growth relative humidity is an important aspect which is important to maintain as per requirement of crop because different crops required different amount of moisture while growth processes.

2.1.5 Crop Phenology

Crop phenology is simply the observation and study of different stages of growth of plant which if from starting germination to maturity and influenced by changing weather and environmental conditions^[38]. Each and every stage of plant growth requires adequate amount of rainfall, temperature, sunlight and wind as they are highly sensitive to agrometeorological factors because it can reduce or increase the productivity of crop^[39].

Extreme weather conditions easily disrupt the normal required conditions and timings of growth stages of crop. Heat stress can

cause short flowering duration and floods are cause disease-pest infestations further leads to poor gain quality and lower produce of yield^[38].

By understanding the concept of crop phenology farmers and researchers can predict crop growth patterns according to weather changing conditions much better. It also helps in easy decision making for farmers and helps in selecting crop resistant and tolerant varieties which provides good yield formation^[40]. Concept of crop phenology has main role in developing the idea of climate-resilient agricultural strategies safeguarding stability in yield and sustainability in farming systems for future required for food security.

2.1.6 Yield Stability

Yield stability simply represents the ability of crops to produce same yield every year even under changing weather and environmental conditions over time^[27]. In agriculture these climate changing conditions are not predicted on time and accurate^[27]. On crop growth there is influence of major factors such as temperature, rainfall, humidity, and sunlight which determines their capability^[41]. Crop growth and development remain normal and leads to higher yield productivity if environmental conditions are favourable^[41]. But due to extreme weather events like floods, droughts, heatwaves, cyclones, and hailstorms can destroy and affect the different stages of crop growth^[14,42]. These weather conditions such as drought can cause limited water availability for crop growth, heatwaves lead to high temperature in which crops cannot survive. Such extreme weather events affect the different growth stages of crop include germination, flowering, and quality and quantity of the yield. In result farmers face challenges, financial instability, and loss of income, also threatens food security of population at large scale^[27,42].

To overcome these problems researchers and farmers utilizes agrometeorological technology and weather forecasting to manage the crop yield^[27]. With these modern tools it is easy to predict the weather conditions and helps farmer to make better decisions for their crop production^[27]. To reduce the weather changing impact and improving the yield stability. By selecting climate-resilient crop varieties, adjusting sowing dates, and planning irrigation effectively, farmers can reduce the impact of weather variability and improve the stability of their yields over time^[42].

2.1.7 Crop Growth Stages

Crop growth stages do not occur at once it is a slow and steady journey through which a crop develops. A crop passes through several different stages from until it's ready to get harvest^[43]. In each and every growth stage crop responds to its external environmental factors such as temperature, sunlight, humidity, rainfall, and winds which determines the major role in crop growth and its productivity^[44]. By understanding about all different growth stage of plants farmers can further make useful decisions at correct time^[11]. Future planning helps farmers to plan irrigation effectively, fertilizer application, pest and disease management, and protect the crops from climate changing conditions which can destroy the crops. By understanding and knowing the different crop stages it is easy to make farming more consistent.

- **Germination stage:** This stage is the initial stage of crop in which the seed is sown in soil and further grows by absorbing the water from soil. The temperature and moisture in soil are essential and important for better germination of seed. Germination rates get lower if

temperature is high and less moisture which further leads to slowdown enzyme activity of seed and takes longer time in sprouting. High moisture or waterlogging can decay the seed in soil. With the help of agrometeorological technology, the sowing and irrigation time can be increased.

- **Seedling establishment stage:** After germination stage, next stage is seedling establishment stage in which the plant starts to grow its roots, leaves and, shoots to establish themselves in soil properly. In this stage plants are very delicate and highly sensitive to outer environment conditions. They require a proper temperature and moisture to grow as young seedlings are highly sensitive. Changing weather conditions and extreme weather such as cold, high temperature, and frost can cause damage to these tender plants and increases risk of death of seedlings. So proper care and management is required by plants like drainage must be good, proper essential nutrients should be provided, proper spacing, protection from pests and diseases, and proper amount of sunlight. By this seedling will be stronger and healthier for upcoming growth.
- **Vegetative stage:** In this stage we can the shift in development of seedlings establishment in which leaves, stems, and plant canopy is developed strongly. In vegetative stage the plant mainly builds its structure and produces large leaves amount which is called foliage for future growth. Favourable weather conditions help in plant growth and increase its productivity. If temperature is high and low moisture can weaken the plant completely, further heavy winds can cause physical damage to plants. So, every factor influences the plant growth also in this stage. Management of nutrients is very necessary and crucial in vegetative stage.
- **Flowering stage:** This is the most essential and crucial stage of plants life which decides the future yield and productivity of crop. Crops are very much sensitive at this stage to environmental factors for example if temperature is much higher than required it will affect the flowers and reduces fruiting, if humidity is low, it will affect the pollen viability further makes difficult for fertilization and physical damages can occur as plants are highly sensitive at this stage. Careful management and plants requirement should be provided according to adequate amount which helps in crop protection and leads to higher productivity which is also useful in future.
- **Fruit or grain formation stage:** In fruiting stage, plants provide its essential nutrients and energy to its fruits and grains which are growing. In this stage yield of the crop can be determined. The nutrients and irrigation are required by plants in adequate amount to develop properly otherwise no proper management can cause poor grain filling and small size of fruits. Such extreme weather conditions can also cause nutrient loss due to high temperature. To ensure better quality and yield proper maintenance and care is provided to crops to get healthy plant and yield productivity.
- **Maturity Stage:** Last stage is the maturity stage in which the plants fruits are developed completely and they finish their physiological development and are ready to harvest. Optimal maturation is promoted by dry circumstances. High humidity and rainfall occurrence can cause rotting of fruits and grains. So, harvesting is done at proper time and in proper weather conditions which leads to prevent of postharvest losses. This stage is also very essential for crop yield and productivity because farmers invest their time and money to get the good amount of productivity from the

crops harvest.

2.1.8 Water Use Efficiency

WUE is an essential concept included in agro meteorology which tells about crops utilization of water under different weather changing conditions to get good produce^[27]. It basically provides the amount of water units is used to get better crop productivity^[11]. As we know farming system mainly depends on weather conditions as crops require proper environment condition to grow strong and healthy so, water use efficiency is majorly affected by environmental factors such as rainfall, sunlight, humidity, and temperature^[11,45].

Changing of weather and climatic conditions causing extreme events disturbs the balance with water use efficiency for example high temperatures like droughts and heatwaves causes moisture loss and damages the crop and increases evapotranspiration^[45]. Water use efficiency reduced by these extreme weather events as it causes evapotranspiration which further leave less water for growth and development of plant^[20]. Beyond this not only hot weather but also heavy rains can influence the WUE in which waterlogging in soil can decay the plants and reduce the oxygen level required by plants. This kind of condition damages the crops system up to high extent and also reduces the ability of crops to grow. Agrometeorological analysis has become vital for farmers and researchers to get information of unpredictable weather like cyclones, hailstorms before any major damage to crops which is helpful for normal growth of crops and can save the hard work and time of farmers. By utilizing modern tools and technology weather can be monitored carefully and helpful for farmer to adopt management practises like climate-resilient practises and also improves water use efficiency. By carefully using the techniques such as proper irrigation efficiently, resistant varieties, stress tolerant varieties of crops and other methods significantly it helps in maintaining the WUE ensuring sustainable agriculture which is required helpful in climate changing conditions^[46].

3.1 Implications of extreme weather events on allied agricultural sectors

The allied sectors of agriculture like poultry, livestock, fisheries, forestry, and beekeeping also influenced by extreme weather events^[5]. In livestock thermal stress is caused by heatwaves leads to high temperature which further causes health issues in animals such as feed intake reduction, low productivity of milk, meat, and egg^[47,48]. Another shortage due to drought in which there are food and water reduction leads to poor animal health and also affects the crop^[48]. High temperatures are not only the risks but rainfall, floods also destroy the fisheries, their food stock and other resources too. Also influences the apiculture in which it destroys the flowering and affects the all over activity of bees leads to lower honey yields^[49]. Beyond this unpredictable weather conditions such as storms and cyclone destroys and damages the shelters, fodder, infrastructure, and productivity. Extreme events also provide severe challenge to market access and put a burden on farmers income and includes risk of livelihood and food security^[5].

3.1.1 Livestock Sector

The extreme weather events have serious influence on livestock health and productivity^[5]. During high temperatures animals are affected by severe heat causes to reduction in feed intake, problems in health conditions and lowers the production as we know animals requires water in good amount^[47]. In changing

weather conditions fodder crops are also affected which leads to fodder shortages and because of this issue animals suffer from weakness and illness^[5]. Another problem is of diseases causes death of livestock the spread of diseases caused by floods damages overall health of animals and cannot be managed easily^[47]. Agro meteorology plays an important role by providing information with the help of modern tools and technology to reduce such risks in future and safeguards the lives of livestock.

3.1.2 Fisheries

Fisheries from inland and coastal areas are heavily sensitive to extreme weather changing conditions include factors like temperature, heavy rainfall, floods, and cyclones^[5]. By during the time of high temperatures or hot weather level of water lowers and salinity increases which causes stress to fishes and leads to problem in their growth and development^[49]. On the other side heavy floods, rainfalls lead to damage to shelters, infrastructure, and destroys the entire system of aquaculture^[5]. Overall, their health, reproductively, and metabolism disturbed and productions it also disturbs their life in many ways. To handle these challenges agrometeorological tools are very helpful and useful in many ways and provides early warnings to farmers^[50].

3.1.3 Horticulture and Plantation Crops

Plants are damaged highly by weather conditions as they require proper growing condition at different crop stages^[5]. Plants of fruits, vegetables, and plantation crops are seriously damaged by climate conditions and unseasonal changes^[29]. Hot weather causes heat stress to fruits growth leads to no proper flowering, fruit setting, and also causes physiological damages to plants further causes degradation of quality and productivity^[51]. By excessive rainfall there is risks of disease- pest infestations. With the help of microclimate management techniques and early weather-based warning there is resilience in horticultural systems^[27].

3.1.4 Poultry

Poultry includes birds which are sensitive to these changing weather conditions due to temperature and humidity changes^[5]. These extreme events cause reduction in feed intake, low production of eggs, meat and also decreases the reproduction and growth rate^[48]. It causes harm to birds up to great aspect and leads to problems like diseases and pest infestations, sometimes death of birds. As they are very sensitive to the temperature fluctuations^[47]. To reduce this stress modern technology is very useful and provides them proper conditions to live as per their requirement.

3.1.5 Forestry and Agroforestry

In forestry and agroforestry, these extreme weather events influence the trees and crops strongly which leads to reduction in growth, productivity, and their existence^[5]. Environmental problems such as droughts, floods, and storms further damage the plants and causes degradation of land, poor soil quality, and soil erosion. The risk of pest and diseases susceptibility and forest fires are created by these environmental conditions further damages the trees and crops^[52]. To control these conditions in future agrometeorological modern technologies and early warning systems are very helpful, it helps in providing proper guidance and decision to farmers which is used by them to choosing good crop resistant varieties and opting the sustainable practises helps to protect the ecosystem from any risks^[5].

4.1 Weather based risk planning assessment

WBRPA is an important concept used in agro meteorology for understanding and management of the risks of weather changing conditions which affects the agricultural systems and allied sectors [5]. It provides and monitors the extreme weather conditions like drought, heatwaves, floods, and unpredictable changes in climatic conditions and influence of these factors on agriculture and its allied sectors [27]. This method merges the weather data of past, present, and future observations and also provides information of crop growth, animals, and other practises. By collecting the important data, it helps into providing proper information of different time periods which can further used for opting proper management practises and reducing the damage effects, which leads to higher yield productivity.

Weather based risk planning assessment provides appropriate strategies and solutions to prevent the losses in crop productivity. This includes the adjustment in dates of crop sowing, contingency crop planning, irrigation efficiency, and improved drainage system by utilization of agrometeorological assessment analysis [53]. It also supports the insurance schemes for farmer at time of problematic challenges due to weather conditions and helps in managing the risk on time and reinforces the agriculture and allied sectors at the time of climate variability and extreme events [5].

4.1.1 Contingent Planning

Contingent planning is a systemic planning which involves the early planning and execution of alternative agricultural plans to counter the weather anomalies and climate extremes [5]. By examining meteorological data, weather predictions, and agro climatic indices, agro meteorology is very important in identifying the weather anomalies like failed or delayed monsoons, prolonged dry periods, droughts, floods, heat waves, cold waves, cyclones, and unseasonal rainfalls. Based on this assessment, contingency plans are developed to minimize the damage of crop, stabilize crop production, and reduce the financial risk of farmers [5]. These programs include flexible crop and variety choice, use of a short duration or stress resistant cultivar, changing sowing and transplanting date, intercropping, reshewing or replacing crops in case of early crop failure. Soil and water management practices include in-situ moisture conservation, mulching, ridge and furrow, rainwater, life-saving irrigation, and proper drainage systems among others, which are vital in contingency planning [27].

4.1.2 Crop Weather Indices

Agrometeorological indices serve as essential instruments for evaluating the integrated effects of multiple atmospheric factors on agricultural productivity and plant development. They facilitate the determination of crucial developmental phases in crops that exhibit heightened susceptibility to meteorological variations [53]. For instance, thermal conditions and precipitation patterns during reproductive and maturation periods substantially affect ultimate productivity [27]. Through the utilization of these metrics, scientists and policy developers can construct forecasting frameworks to project agricultural performance across varying environmental conditions [5]. Furthermore, crop weather indices contribute to strategic planning regarding water management schedules, planting timing modifications, and resource allocation decisions [27].

4.1.3 Growing Degree Days (GDD)

Growing Degree Days (GDD) is an agrometeorological scale to

quantify the heat cumulative needed to grow and develop crops. It is based on the fact that the growth of plants is directly proportional to temperature and that there is some temperature threshold in which some crops cannot grow [11]. The GDD is calculated as the mean of daily high and low and then the value is changed by the base temperature [11]. The index is used in predicting diverse phenological periods of crops such as germination, flowering and maturity [27]. An example is the number of units of accumulating heat that crops like wheat, maize and rice have in order to accomplish their life cycle [11]. GDD has particularly been useful to farmers and researchers when determining the ideal dates on which to plant the seeds, the appropriate period at which to irrigate the crops, and the actual period at which to apply the manure [27]. It can also be used in predicting pests and diseases since majority of the insects and pathogens are sensitive to temperature. The GDD in crop simulation models is applied in modern agricultural practices to predict crop yield in different climatic conditions. GDP provides a convincing method of tracking the growth of crops and provide a shift in the field of farming operations, which make the crop control more efficient and productive according to the altering and shifting climatic patterns.

4.1.4 Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) is a typical statistical tool of measuring and monitoring the presence of a drought utilizing the data of precipitation. It compares the historical averages of the long-term basing on the periods (1, 3, six or twelve months) against the actual rainfall of a specific period to determine the aberrations of normal expectations [54]. The values of SPI are standardized and they can be negative or positive with the mean of zero. The positive sign values of SPI depict that there is rain more than the average amount (wet season) and the negative depict the opposite (dry season or drought) [27]. The measurement of the value indicates the level of the problem. Its ability to be used in different climatic regions and periods means that SPI is a useful and reliable index that can be used to assess drought. In agriculture, it is an early warning and crop planning and water resources management in the use of SPI. It enables the farmers and policymakers to respond promptly to changing patterns of cropping, regulating irrigation or possessing measures capable of countering droughts. Since it is rather straightforward and efficient, SPI is used in weather variability studies and risk management in agricultural land [53].

4.1.5 Rainfall Variability

Rainfall variability can be defined as the variability by amount, timing, intensity and distribution of rainfall within a given period and information over an area [5]. It is one of the major constituents of climate variability and has enormous effect on the agricultural productivity of a given economy particularly the rain fed farming systems [53]. Irregular rainfall pattern may be experienced during a season (intra-seasonal) or annual (inter-annual), for example, delayed start of monsoon, early drained, extended dry season or sudden severe rainfall events. These anomalies give unpredictability in crop planting and control. Rainfall variability in agriculture impacts on such vital crop developmental processes as germination, flowering, and grain filling [53]. As an illustration, a lack of rainfall in initial stages may damage the seed germination and too much rainfall in maturity may destroy crops and lead to low quality yield [27]. There is also high variability that the variability raises the possibility of droughts and floods that contributes to crop failure and economic losses by the farmers [5].

The variability of rainfalls is critical to understanding to create climate-resilient agricultural methods^[27]. It assists in choosing the appropriate types of crops, changing the time to sow and determining the irrigation and water management units. Variability is usually addressed by adopting techniques like rainwater harvesting, crop diversification and planting of drought resistant crops. In general, the problem of rainfall variability and its management is critical to achieving constant agricultural yield and food security in the long run^[53].

5.1 Adaptation/ Mitigation Measures

Weather Forecasting

One of the key strategies of adapting to changes is weather forecasting which enables farmers to make the wise decision depending on the predicted weather condition^[5]. It entails meteorological information, satellites and computers modeling of 12 months and 6 months weather like rain, temperature, wind and humidity^[27]. The right weather predictors in agriculture aids farmers in planning such major practices as sowing, irrigation, application of fertilizers and harvesting. Using an example, in case of heavy rainfall forecast, farmers will be able to postpone irrigation or harvest to prevent damages of crops. Equally, prediction of dry spells is used in water conservation planning. Weather forecasting is also important in reducing losses incurred as a result of extreme weather conditions like droughts, floods and cyclones. The agrometeorological services offer a location-based forecast and advisory services to farmers over mobile application as well as SMS and radio in India^[53]. These services enhance efficiency of farms and decrease the risk in the changing climate conditions. All in all, weather forecasting proves to be a low-cost instrument which can be very effective in improving resilience in the agricultural sector as it improves the right time and right-way decision-making, hence contributing to the increase in productivity as well as sustainability^[5].

Crop Diversification

One of the mitigation strategies and adaptation practices is crop diversification, which entails the cultivation of diverse crops as opposed to the single crop (monoculture)^[5]. The practice assists in minimizing the risk posed by climate variability, pests, and changes in the market. Crops also differ in their water, nutrient as well as climate needs; hence, by diversifying, crops may survive in case of unfavorable weather conditions and generate income^[53]. As an example, the intercalation/interceding of cereals with pulses or oilseeds enhances the fertility of soils and lowers the reliance on external inputs. Diversity of crops also enriches biodiversity, increases the health of soil and reduces the proliferation of pests and diseases^[5]. In mitigation perspective, the greenhouse gas emission can be mitigated through diversified systems of cropping which is more efficient in the utilization of nutrients hence requiring less use of chemical fertilizers. It also enhances sustainable land use and improved management of resources. Farmers use mixed cropping, inter cropping or crop rotation to sustain the production in areas where rainfall is unpredictable^[27]. In general, crop diversification enhances stability and resilience of farms, incomes stability, and also leads to sustainability in agriculture in the long-term in the changing climatic conditions.

Climate-Resilient Varieties

Climate-resilient varieties refer to genetic varieties of crops that are produced to overcome deleterious climatic situations like drought, flood, heat and salinity as well as pest attacks^[53]. They

are bred through traditional breeding methods or advanced biotechnological methods to alleviate their resistance to environmental stress. An alternative adaptation approach that is feasible is the use of climate-resistant varieties, which helps to keep crop productivity intact even when there are poor weather conditions^[5]. Indicatively, drought-tolerant rice and wheat that are heat-resistant may work better when there is a scarce supply of water or when there is a high temperature stress. Some of the characteristics that come along with these varieties include deeper roots, early maturity and better water-use efficiency. Besides adaptation, they help mitigate by enhancing yield stability besides consuming less unnecessary inputs such as irrigation and fertilizers. These varieties are promoted by the governments and agricultural institutions with the use of seed distribution programs and extension services. Such varieties should also be adopted especially where there is high likelihood of variability of climatic conditions and occurrence of extreme weather conditions. In general, climate-resistant crops have a significant role in the climate change scenario in ensuring food security and sustainable agriculture^[8].

Agro Advisory Services

Agro-advisory services, as part of the weather prediction services, offer farmers advice in a timely and location-specific manner depending on the weather predictions and the state of the crops. These services are a combination of meteorological information and agricultural activities to assist the farmers to make decisions^[27]. Advisory messages can be provided with information on dates of sowing, irrigation timings, application of fertilizers, control of pests and diseases and harvesting techniques^[53]. The agro-advisories are spread in India by different means which include: mobile phones, radio, television, and agricultural extension centers. These services are useful to the farmers in cutting down losses due to the unpredictable weather and to enhance efficiency in use of resources^[55]. Indicatively, a forecast of a rainfall would allow farmers to delay the time of irrigation or application of fertilizer in order to prevent waste. Climate risk management is also facilitated through agro-advisory services educating early alerts on extreme events such as drought or storms. Also, adhering to such advisories, farmers will be able to maximize crop production, minimize the costs of inputs, and mitigate environmental effects^[8]. Altogether, agro-advisory services are an intermediary between science and practice in farming, which have a crucial role in promoting the agricultural resilience and sustainability in changing climate conditions^[5].

6.1 Policy and Institutional Framework

The policy and institutional framework are critical in the agrometeorological evaluation of extreme weather effects and subsequent impacts on agriculture and other related sectors. As more and more events like droughts, floods, heat waves, and unseasonal rainfalls take place, more and more solid policies and effective coordination of the institutions are required. In India, the government efforts aim at incorporating weather-based information into farming planning in order to reduce risks and promote resiliency. Meteorological departments, agricultural universities, and research organizations are some of the institutions collaborating to produce, interpret, and distribute data on weather in order to make improved decisions.

6.1.1 Weather-Based Agricultural Policies

The agricultural policies are centered on the weather-based policies aiming at incorporating the meteorological data in the

planning and management of farms to mitigate the risks associated with climatic conditions ^[27]. The following policies would advantage the application of seasonal forecasts, real-time weather and climate models to inform decisions like sowing dates, choice of crop, timing of irrigation and placing fertilizers ^[53]. Such policies help in encouraging climate-resistant and climate-sustainable agricultural systems in light of extreme weather conditions such as droughts, floods, and heatwaves ^[5]. Governments promote contingency crop planning where other crops or varieties are prescribed depending on the probable weather. These policies also stimulate the use of efficient water management techniques such as micro-irrigation and rain harvesting ^[56]. In India, agro-related schemes are also becoming more involved in weather-based advisories so that farmers can react positively to the alterations in climatic variations. In these policies, focus is given to the reduction of the losses of crops, by way of early warnings and adaptive strategies as well. In general, it is clear that the agricultural policies based on weather can objectively help to reduce the exposure to production risks, better using resources, and attracting the capabilities of farmers to withstand extreme weather situations to secure stable agricultural production ^[8].

6.1.2 Agrometeorological Services Supported by institutions.

Agrometeorological services cannot operate effectively without institutional support, particularly the evaluation and control of events of extreme weather ^[27]. The collection, analysis, and distribution of weather data are done by various institutions such as meteorological agencies, agricultural universities, and research institutions. Such institutes prepare place-based weather forecast and convert this to viable agro-advice to farmers ^[53]. Agrometeorological advisory services at the district level make farmers make wise decisions using timely information on rainfall, temperature, humidity and wind conditions. Farmers can also be notified about the recurrence of extreme weather patterns like cyclones, heatwaves, or heavy rain; hence they can adopt preventive measures, which is important particularly through early warning systems. The extension services also make sure that this information is extended to farmers using mobile messages, apps, radio, and field demonstrations. Institutional coordination promotes accuracy and reliability of the information about weather and increases the availability of the same too ^[5]. In general, effective institutional backing is able to fill the divide that exists between scientific information on one side, and implementing this knowledge at the field level so that farmers can minimize risks and enhance productivity in fluctuations in climatic conditions ^[8].

6.1.3 Crop Insurance and Disaster Risk Management.

Agricultural policies are essential in the management of a disaster risk and crop insurance to mitigate the effects of extreme weather ^[57]. These policies are concerned to be ready, mitigate and recover on climatic disasters like droughts, floods, cyclones and hailstorms. Crop insurance plans will offer farmers financial rewards in cases of a loss incurred as a result of such occurrence thus eliminating economic vulnerability ^[58]. When farmers have insurance cover, they will invest in agriculture knowing that they will not go bankrupt should they fail. Another disaster management approach is the planning of contingency, emergency handling and assistance. The weather forecasts and the early warning systems are relevant in reducing damage since they allow prompt action to be taken. Government-sponsored insurance plans allow stabilizing the income of the farmers, and creating resilience in the agricultural sector within India ^[59].

Further, awareness campaigns and institutional reinforcing also help make sure that farmers become familiar with and use these plans. All in all, it is possible to say that disaster risk management and crop insurance not only help the farmers to avoid losses in finances, but also enable the sustainability and stability of agricultural production systems in the face of the changing climate ^[5].

6.1.4 Allowance to Allied Sectors (Livestock, Fisheries, etc.).

Other sections of the economy like livestock, fisheries and poultry are very vulnerable to extreme weather conditions and they need special policy and institutional assistance ^[8]. The health, productivity and survival of animals may be adversely affected by climate related stresses such as heatwaves, cold waves, floods and droughts ^[5]. The policies targeted on the sectors are concerned with shelter management, proper water supply, feed availability and veterinary services during the bad weather conditions. An example of this is where the proper ventilation, shading and cooling of livestock is advised in times of heat stress to maintain livestock productivity. In the fisheries, extreme weather may destroy the breeding cycle, and damage the aquatic ecosystems necessitating adaptive management action plans ^[60]. The government and institutional support are in the form of timely advisories, control, and emergency support. Training also allows farmers to embrace allied sectors that have resistant measures towards climate changes. It is of essence to enhance these sectors since they offer extra revenue and a source of livelihood to farmers. On the whole, the increase of the allied industries increases the stability of the whole agricultural system and decreases the general effects of extreme weather on the rural economy.

6.1.5 P-P Partnerships and Technology Intervention

Technology integration and public-private partnership (PPP) have a major role in enhancing climate resilience and improving agrometeorological services in agriculture. Government agencies and private companies work together in coming up with and spreading superior technologies including remote sensing, Geographic Information Systems (GIS), industry mobile-based advisory systems ^[53]. With these technologies, there can be a precise prediction of weather, real-time observation of conditions of crops, and effective information delivery to the farmers. Innovation, development of infrastructure and service delivery is boosted by the involvement of the private sector which is complemented by the government so that accessibility and regulation are provided. Farmers receive weather updates, management advice in real-time via mobile applications and through two-way SMS-based advisory.

Conclusion

In conclusion it is clearly showing the effects of extreme weather conditions on agriculture and allied sectors which further causes loss in productivity. The increasing of weather change overtime and risks of floods, droughts, cyclones, and heatwaves are become serious problems for now. These events damage the normal growth of crops, reduction in productivity, and provide serious damage to animal's health, reduce their production also. It not only affects the food security but also lower farmers income and creates burden on rural farmers as they are mainly depending on agriculture. Crops are sensitive to changing weather because in different growth stages they depend on sunlight, moisture, and soil.

By understanding about these weather risks management practises can be implemented easily. For more accurate data

researchers collected and merged data from past few years with the help of modern tools and technology including current weather observations to identify the problems on time and reduce the productivity losses on time. This useful approach helps farmers and researchers to make good decisions. By adopting resistant varieties, climate resilient strategies, and integrated farming systems can strengthen agricultural systems. For long-term adaptation, agrometeorological analysis, farmer awareness, and adopting management practises are important to ensure sustainability.

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