QUANTIFICATION OF CLIMATE CHANGE IMPACTS ON PRODUCTION AGRICULTURE

ACCOMACK-NORTHAMPTON CLIMATE RESILIENCE STUDY

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November 2024

Accomack-Northampton Planning District Commission

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VIRGINIA DEPARTMENT OF CONSERVATION AND RECREATION VIRGINIA COMMUNITY FLOOD PREPAREDNESS FUND GRANT PROGRAM

FINAL REPORT

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Study Title: Quantification of Climate Change Impacts on Production Agriculture in Accomack and Northampton Counties of Virginia
Study Managed by: Accomack-Northampton Planning District Commission (A-NPDC)
Study Period: November 1, 2022 – November 1, 2024
Principal Investigator: Dr. Abhilash Chandel, Virginia Tech, Tidewater Agricultural Research and Extension Center
Funding: Virginia Department of Conservation and Recreation, Virginia Community Flood Preparedness Fund
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EXECUTIVE SUMMARY

The Accomack-Northampton Climate Resilience Study, managed by the Accomack-Northampton Planning District Commission (A-NPDC), was funded to address the impacts of climate change on agriculture in Virginia's Eastern Shore. A-NPDC provided administrative oversight and financial management for the grant, ensuring that the study goals aligned with regional climate resilience priorities. With a focus on primary crops like corn, cotton, soybean, and winter wheat, this study quantified climate impacts, examined water demands, and developed predictive tools to aid local farmers and policymakers. This study, funded in part by the Virginia Community Flood Preparedness Fund, aimed to quantify the effects of extreme weather, analyze crop water demand, and develop data-driven tools to support agricultural resilience and informed planning. Key findings demonstrate significant changes in extreme weather frequency, rising sea levels, and altered crop health due to climate factors. The study's results support climate adaptation and resilience planning in the region, benefiting farmers, policymakers, and other stakeholders.

The findings reveal significant increases in extreme weather events, a 1.31-foot rise in mean sea levels over 32 years, and altered crop health and yield due to climate stressors. The study also developed predictive models, achieving up to 85% accuracy in forecasting crop health based on climate variables, which enables more proactive agricultural management. These results provide actionable insights for farmers, policymakers, and stakeholders on strategies for improving crop resilience and mitigating climate risks.

For full details of the study's methodology, data, and recommendations, please refer to Dr. Abhilash Chandel's final report from Virginia Tech's Tidewater Agricultural Research and Extension Center, which is included in this report.

1. INTRODUCTION

BACKGROUND

The Eastern Shore region of Virginia, encompassing Accomack and Northampton counties, faces growing risks from climate change. This low-lying coastal area is particularly susceptible to climate-induced challenges, including a rising frequency of extreme weather events (e.g., hurricanes, severe storms, droughts), steadily rising sea levels, and shifting precipitation patterns. These challenges pose significant threats to the region's agricultural sector, which is not only a central part of the local economy but also a critical source of food security. The area's sandy, nutrient-limited soils and reliance on water-intensive crops make local agriculture particularly vulnerable to climate variability, as extreme weather and water scarcity can drastically reduce crop yields.

Recognizing the urgency of these climate challenges, the Accomack-Northampton Planning District Commission (A-NPDC) sought to develop a study that would assess the impacts of climate change on agriculture and support climate adaptation strategies. With funding from the Virginia Community Flood Preparedness Fund, A-NPDC managed the study grant, partnering with Virginia Tech to conduct a multi-year study aimed at enhancing the region's agricultural resilience. A-NPDC played a critical role in coordinating study objectives with Virginia Tech, ensuring that the research outcomes aligned with local agricultural and climate resilience needs. Through this collaborative effort, A-NPDC aimed to empower local farmers, agricultural stakeholders, and policymakers with data-driven insights to improve their capacity to adapt to evolving climate risks.

STUDY OBJECTIVES

The Accomack-Northampton Climate Resilience Study, managed by A-NPDC, was designed to address three core objectives critical to understanding and mitigating climate impacts on local agriculture:

- Analyze annual climate variations impacting local agriculture: This objective focused on examining year-to-year changes in the key climate variables, of air temperature, soil moisture levels, relative humidity, and wind speed. By assessing these parameters, the study aimed to establish a comprehensive understanding of how each climate factor has evolved over recent decades and the extent to which these changes affect crop growth cycles and resilience. This analysis provides a baseline for identifying trends and anticipating future climate-related risks to agriculture.

- Assess the effects of extreme weather events on crop health and yield: This objective involved a geospatial and data-driven assessment of extreme weather events, including droughts, heavy rainfall, high winds, and extreme temperatures. The goal was to measure how these events impact crop health, specifically focusing on corn, cotton, soybean, and winter wheat—crops that are economically and nutritionally significant to the region. By correlating extreme weather data with crop health metrics, the study sought to quantify the vulnerability of these crops to climate extremes, identifying which crops and growing conditions are most affected.

- Evaluate changes in crop water demand due to climate shifts: This objective focused on understanding how shifting climate patterns affect crop water demand, with an emphasis on evapotranspiration rates and water-use efficiency. Given that rising temperatures and altered precipitation patterns can increase crop water needs, this analysis was crucial for determining the viability of current water management practices. Findings from this objective are intended to guide farmers and local planners in adapting water-use strategies to optimize crop yield and resource sustainability under increasingly variable climatic conditions.

Through these objectives, A-NPDC and Virginia Tech worked to provide actionable insights into climate adaptation for Eastern Shore agriculture, aligning with regional priorities for sustainable, climate-resilient farming.

Stakeholders and Collaborators

The Accomack-Northampton Planning District Commission (A-NPDC) provided essential administrative oversight for the study, ensuring efficient use of grant funds, adherence to study milestones, and alignment of research activities with local agricultural needs. A-NPDC's role extended beyond grant management; they facilitated collaboration between Virginia Tech's research team and key regional stakeholders, including local farmers, agricultural advisors, and policymakers. By actively engaging these stakeholders throughout the study, A-NPDC helped ensure that the research findings would be directly relevant and useful to those most impacted by climate change in the region.

Virginia Tech's Tidewater Agricultural Research and Extension Center led the research, conducting rigorous analyses on climate data, crop health, and water demand across Accomack and Northampton counties. AREC's expertise in climate science and agricultural resilience was crucial in identifying trends and generating predictive models that could guide future planning. Additionally, local agricultural advisors and extension agents provided on-the-ground insights into crop management practices and regional farming challenges, allowing the research team to ground their analyses in practical, real-world considerations.

The collaborative nature of this study was instrumental in maximizing its practical impact. By aligning research activities with the specific needs of Eastern Shore farmers and policymakers, A-NPDC ensured that the study's findings would support realistic, actionable solutions for climate adaptation. Engagement with stakeholders also facilitated knowledge transfer, future equipping farmers and local authorities with the information and tools necessary to make informed decisions for long-term agricultural resilience.

2. METHODOLOGY

DATA COLLECTION

Historical weather and crop data spanning 33 years (1990–2023) were collected from the following: the National Oceanic and Atmospheric Administration (NOAA), National Aeronautics and Space Administration (NASA), United States Department of Agriculture (USDA), and Visual Crossing Corporation. These datasets, totaling approximately 50 terabytes, encompassed air and soil temperature, precipitation, soil moisture, relative humidity, and extreme weather event records. A web-based dashboard (Grafana) was developed to facilitate data visualization, allowing users to analyze information at daily, monthly, and annual levels.

Data Source	Parameter Collected
NASA Earth Data	Air and Soil Temperature, Solar Radiation
NOAA	Precipitation, Sea Level, Extreme Weather Events
USDA	Crop Yield, Planted vs. Harvested Acreage, Water Usage
Visual Crossing	Relative Humidity, Wind Speed

ANALYTICAL TECHNIQUES

ADVANCED GEOSPATIAL AND MACHINE LEARNING TOOLS WERE USED TO EVALUATE THE DATA:

GEOSPATIAL ANALYSIS: Using Google Earth Engine, historical NDVI and other vegetation indices were mapped to assess crop health and identify impacts from extreme weather.

MACHINE LEARNING MODELS: A Recurrent Neural Network (RNN) was implemented to predict crop health variations using time-series weather data. This model was selected for its ability to capture sequential data patterns, such as temperature and rainfall changes over time.

CORRELATION ANALYSIS

To evaluate the influence of climate factors on crop health, a Pearson correlation analysis was conducted, linking variables like air and soil temperature, soil moisture, and wind speed to crop yield indicators. Maximum wind speed and soil moisture showed moderate-to-strong correlations with negative impacts on crop health, particularly for corn and winter wheat.

3. Results and Findings

Key Climate Trends

The analysis identified a significant increase in extreme weather events in Accomack and Northampton counties, with records showing a total of 94 extreme weather incidents over the past 30 years. These events include a mix of severe storms, hurricanes, droughts, winter freezes, and instances of intense rainfall, each of which poses unique threats to agriculture. The region has also experienced a 1.31-foot rise in mean sea levels over the past 32 years. This sea-level rise, combined with increased storm frequency, amplifies the risk of coastal flooding, particularly for low-lying agricultural lands.

The implications of these climate trends are profound: frequent flooding and soil saturation can lead to root diseases, delayed planting seasons, and reduced soil quality. Moreover, higher sea levels can lead to saltwater intrusion into freshwater resources and coastal farmlands, potentially making certain areas unsuitable for traditional crops. The cumulative effect of these changes is an increase in both the intensity and unpredictability of climate-related risks to crop viability. For farmers in these counties, adapting to these shifting environmental pressures is essential for maintaining productivity and economic stability.

Impact on Crop Health

The study revealed that air temperature (both maximum and minimum) and soil moisture were among the most influential factors affecting crop health for corn, soybean, cotton, and winter wheat. High temperatures, particularly during the growing season, can lead to heat stress, which reduces photosynthesis rates, disrupts plant metabolism, and ultimately lowers crop yields. Soil moisture levels also play a critical role; excessive moisture can lead to waterlogged soil conditions, impeding root oxygen uptake and promoting root diseases, while insufficient moisture during dry spells can stress crops and inhibit growth. Additionally, strong winds—frequent in extreme weather events—were found to exacerbate crop stress by damaging plant structure and increasing evapotranspiration rates, further depleting soil moisture and raising water demand.

Together, these climate factors create a challenging environment for Eastern Shore agriculture, where variable weather patterns can lead to inconsistent crop performance from one season to the next. Understanding how each of these variables affects specific crops enables targeted recommendations for crop management practices under different climate scenarios.

Crop-Specific Impacts:

Each crop studied displayed a distinct response to climate stressors:

- Corn: The analysis showed that corn fields experienced up to a 19% reduction in harvested acreage compared to planted acreage. Extreme weather events, such as heatwaves and droughts, were identified as the primary drivers of these losses, as corn is highly sensitive to temperature fluctuations and soil moisture variations. Additionally, rising fertilizer prices contributed to these reductions, as some farmers reduced planted acreage to manage input costs. Corn's vulnerability to climate extremes suggests a need for protective measures or alternative crop options in high-risk areas.

- Winter Wheat: This crop was found to be the most vulnerable among those studied, with an average yield reduction of 28% in harvested acreage relative to planted acreage. Winter wheat is particularly susceptible to cold weather extremes, such as frost, as well as excessive moisture during early growth stages, which can impair germination and root development. The high sensitivity of winter wheat to both extreme cold and wet conditions indicates that farmers may need to consider alternative planting dates or different wheat varieties to mitigate yield losses.

- Soybeans: In contrast to corn and winter wheat, soybeans demonstrated significant resilience to climate stress, showing a yield impact of less than 5% over the past 14 years. This resilience is attributed to the crop's efficient water usage and adaptability to drought conditions, as soybeans can access deeper soil moisture and maintain productivity under water stress. The ability of soybeans to withstand varied environmental pressures makes it a promising option for farmers facing unpredictable climate conditions and water limitations.

Predictive Model Findings

The study developed a machine learning model using Recurrent Neural Networks (RNN) to forecast crop health and yield based on climate variables. The model achieved high predictive accuracy, with up to 85% accuracy for crop health predictions across the four primary crops. This level of accuracy suggests that the model could serve as a reliable tool for forecasting crop outcomes under studyed climate scenarios. By inputting anticipated weather conditions, farmers and policymakers can use the model to estimate yield outcomes and adjust crop planning, resource allocation, and risk management strategies proactively. The RNN model's success in predicting crop health based on historical climate data underscores its potential as a valuable decision-support tool for enhancing climate resilience in regional agriculture.

Water Use and Efficiency

Analysis of water demand and crop water use efficiency (WUE) revealed that:

The study's water demand analysis showed that soybeans maintained relatively stable Water Use Efficiency (WUE) under drought conditions, unlike corn and winter wheat, which experienced notable declines in WUE during dry years. Water Use Efficiency is a measure of a crop's yield relative to the amount of water used. Soybeans' ability to conserve water while maintaining yield makes them an efficient crop choice in water-scarce environments. In contrast, corn and winter wheat showed higher sensitivity to water availability, with significant drops in WUE when exposed to prolonged dry periods. This difference underscores soybeans' suitability for areas where water resources are constrained or where irrigation access is limited.

Rising Water Demand: The analysis also highlighted an overall increase in water demand across all crops, attributed primarily to higher ambient temperatures and greater atmospheric water demand due to increased evapotranspiration. Rising temperatures mean that crops lose more water to the atmosphere, requiring additional water to sustain growth and productivity. This trend places added pressure on regional water resources, making efficient water management a critical focus for sustaining agricultural productivity in the face of climate change.

In response to these findings, the study recommends adopting advanced water management practices such as precision irrigation, which uses soil moisture sensors and climate data to target water application based on actual crop needs. This approach can help optimize water usage, reduce waste, and maintain stable yields even under challenging climatic conditions. Enhanced water conservation strategies will be essential for adapting to rising water demands and for securing sustainable agricultural production in Virginia's Eastern Shore.

Key Takeaways

Soybean Resilience: Soybeans demonstrated consistently higher resilience to drought and other climate-related stressors throughout the study, suggesting they are a robust choice for farmers in regions with variable or limited water resources. Unlike other crops examined, such as corn and winter wheat, soybeans maintained stable yields even under conditions of fluctuating soil moisture and high temperatures. This resilience can be attributed to the crop's relatively efficient water use and its adaptability to dry conditions, where it showed lower yield losses than other evaluated crops. The soybean's deep-rooted structure allows it to access water from deeper soil layers, which may contribute to its ability to endure droughts and remain productive in periods of reduced rainfall. Given this advantage, soybeans represent a highly viable option for farmers aiming to secure stable yields in areas prone to water scarcity, offering a path toward more climate-resilient agricultural practices.

Increased Water Demand: The study revealed a clear trend of rising water demand across all crops, primarily driven by increasing ambient temperatures and higher atmospheric water demands. As temperatures rise, crops experience enhanced rates of evapotranspiration, the process by which water is transferred from the soil and plants into the atmosphere. This increase in evapotranspiration places additional strain on water resources, as crops now require greater volumes of water to sustain growth, maintain soil moisture, and avoid heat-induced stress. For water-intensive crops, such as corn and cotton, this trend may lead to notable decreases in yield if water needs are not adequately met.

These findings highlight the urgency for strategic water management approaches to maintain productivity under warmer conditions. Approaches such as precision irrigation—targeting specific crop water needs based on soil moisture sensors and climate data—can help optimize water usage and reduce waste. Additional techniques, like selecting drought-resistant crop varieties or employing mulching practices to retain soil moisture, could further support resilience in response to increased water demand. By prioritizing these adaptive strategies, farmers can help mitigate the impact of rising temperatures on crop health and productivity, safeguarding yields in the face of climate challenges.

Modeling Tool for Decision Support: The predictive model developed in this study has proven to be an effective decision-support tool, offering valuable insights for crop planning and climate adaptation. Utilizing historical and current climate data, this model applies machine learning algorithms to forecast crop yield and health under various climate scenarios, with prediction accuracies reaching up to 85% for select crops. For stakeholders—including farmers, agricultural advisors, and policymakers—this tool provides a data-driven approach to anticipate the impact of temperature, precipitation, soil moisture, and other climate variables on crop outcomes.

With this model, stakeholders can make informed decisions on crop selection, planting schedules, and resource allocation based on anticipated weather conditions. For instance, the model can guide farmers on the best-suited crop varieties for expected seasonal conditions, helping them minimize risks associated with climate extremes. Additionally, agricultural agencies and policymakers can use the tool to plan support and resources for regions expected to experience adverse conditions, such as drought or excessive rainfall. In the long term, expanding this modeling capability to other regions and crop types could further strengthen the resilience of Virginia's agricultural sector, equipping it to adapt to an evolving climate landscape.

4. Challenges and Limitations

Data Processing Constraints

The study's extensive dataset, totaling approximately 50 terabytes in raw data, introduced significant challenges related to storage, processing, and analytical capability. This large volume of data encompassed detailed, high-resolution information from various sources, including historical climate data, soil metrics, crop health indicators, and yield outcomes spanning multiple decades. Due to the sheer size and complexity of the data, each dataset required substantial computational resources to process effectively. High-performance computing (HPC) systems were necessary for tasks such as geospatial analysis, machine learning model training, and integration of climate and crop datasets into a cohesive structure.

However, these HPC resources were limited, which led to extended processing times and necessitated adjustments in the study timeline. Analytical tasks that would typically take hours often extended to days or weeks, especially for complex operations such as multi-layered geospatial mapping and long-term climate trend analysis. This constraint forced the research team to prioritize certain datasets over others and sometimes led to delays in analyzing seasonal trends and extreme weather impacts. Addressing these constraints in future studies would require investment in additional computing power or cloud-based processing capabilities to facilitate faster and more efficient data handling and to enable even broader analyses.

Funding and Resource Limitations

The study was impacted by funding and resource limitations, which restricted the scope of analysis and the depth of regional data insights. The study's budgetary constraints limited resources for advanced computational infrastructure, additional staffing for data processing, and the ability to collect high-frequency, localized data. As a result, while the study successfully covered key climate impacts on primary crops, the restricted funding prevented a more granular analysis that could have included smaller or niche crops and more frequent climate data updates.

With additional funding, the study could have expanded to conduct more detailed studies at the micro-regional level, incorporating specific areas within Accomack and Northampton counties. This would enable more precise mapping of climate impacts and tailored resilience strategies for different sub-regions. Additionally, a larger budget would allow for expanding predictive modeling to include a broader array of crops and climate variables, offering a more comprehensive tool for climate adaptation planning. Enhanced funding would also support longer-term monitoring, helping researchers observe climate patterns over time to detect emerging risks and trends.

Data Gaps

Certain historical datasets lacked the level of precision needed for highly detailed, crop-specific analyses, particularly for factors like nutrient uptake, water-use efficiency, and fine-scale soil health metrics. Many of the available datasets provided valuable, broad insights but were limited in their granularity. For instance, while soil moisture and temperature data were available at relatively high temporal resolutions, data on specific nutrient availability, crop response to micro-climate conditions, and small-scale water dynamics were either unavailable or inconsistent.

These gaps in crop-specific data prevented the research team from exploring finer resilience traits that would be useful for precision agriculture. More granular data on factors such as nutrient and water uptake rates, pest resistance, and localized soil composition could offer additional insights into how different crop varieties respond to climate stressors and could support the development of even more refined, targeted recommendations. Closing these data gaps in future studies would require increased investment in field-level monitoring, specialized sensors, and advanced data-gathering technologies to capture real-time crop performance metrics at a local scale. This data enhancement would enable researchers to make more precise recommendations for climate-resilient farming practices tailored to specific environmental conditions and crop needs.

5. Recommendations for Future Action

1. Adopt Climate-Resilient Crop Varieties

Based on the resilience observed in soybean yields under climate stress, it is recommended that farmers consider expanding soybean cultivation in areas prone to extreme weather. This crop's stability under varied conditions makes it a reliable option for maintaining yields amid fluctuating weather patterns.

2. Expand Predictive Modeling Tools

The predictive models developed in this study could further be developed for specific areas and crops grown on the Eastern Shore or scaled to support other regions and crop types across Virginia. By enhancing model accuracy with additional crop and climate data, the model could serve as a statewide agricultural planning tool or expand regional crops of interest. This would support farmers in making data-informed decisions and boost resilience across a more specific or wider geographic area.

3. Supportive Policy Initiatives

Future resilience efforts would benefit from increased funding and policy support at both the local and state levels. With dedicated resources, additional research and development can be conducted to address climate resilience in Virginia’s agriculture. Policymakers should consider funding grants that enable more extensive data collection, predictive modeling, and climate adaptation research for agriculture.

4. Enhance Water Management Practices

Given the rise in water demand observed across all crops, it is recommended to implement advanced water management practices. Strategies such as precision irrigation and soil moisture monitoring can optimize water use, ensuring that crops maintain yield without unnecessary water expenditure.

5. Inform and Train Regional Stakeholder

To maximize the practical impact of the study’s findings and tools, it is essential to inform and train regional stakeholders, including farmers, policymakers, extension agents, and agricultural organizations, on how to effectively use the Grafana dashboard and the study's data. Providing targeted workshops and training sessions will ensure that stakeholders understand the dashboard’s functionality and its value in decision-making processes. These sessions should cover how to navigate the dashboard, interpret key visualizations, and apply insights to optimize crop selection, irrigation planning, and resilience strategies against climate stressors.

Additionally, creating user guides and on-demand video tutorials will allow stakeholders to access training materials at their convenience, enhancing long-term adoption. By equipping stakeholders with the skills to utilize these tools, the region can better leverage the predictive models and climate insights to proactively address climate challenges, improve agricultural planning, and ensure that decision-makers at all levels are empowered to act on evidence-based recommendations. This collaborative effort can significantly amplify the region's overall climate resilience.

6. Additional Resources

To support the findings and facilitate ongoing research and decision-making, a web-based data visualization dashboard was developed. This dashboard, created with Grafana, allows users to interact with the comprehensive climate and crop data analyzed in this study. Users can access visualizations of historical data on air temperature, soil moisture, precipitation, crop health indices, and more, with options to view data at daily, monthly, and annual levels. This resource is intended to aid stakeholders—including farmers, researchers, and policymakers—in making informed decisions based on historical climate patterns and crop performance.

Grafana Dashboard Access

Northampton County Dashboard: https://sathishraymondemmanuel.grafana.net/goto/IQG15yrSg?orgId=1

Accomack County Dashboard: https://sathishraymondemmanuel.grafana.net/goto/5sUJ5yrIR?orgId=1

For additional study documentation and technical support regarding the dashboard, please contact the Accomack-Northampton Planning District Commission (A-NPDC) or Virginia Tech's Tidewater Agricultural Research and Extension Center.

7. Conclusion

The Accomack-Northampton Climate Resilience Study has provided critical insights into the effects of climate change on Virginia's Eastern Shore agriculture, highlighting both vulnerabilities and opportunities for adaptation. Key findings include the identification of climate-sensitive crops (corn and winter wheat), the resilience of soybean, and the essential role of predictive models in preparing for climate impacts.

This study lays the groundwork for future agricultural planning in Virginia, emphasizing the importance of data-driven decision-making to safeguard crop yields and promote resilience. By expanding predictive models and supporting climate-smart agriculture, Virginia's agricultural sector can better withstand the uncertainties of a changing climate.

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Project title: **Quantification of climate change impacts on production agriculture of Accomack and Northampton Counties of Virginia**

Project report period: Aug 19, 2022–May 31, 2024

Total funding received: $ 42,848

Principal Investigator: Abhilash Chandel, Virginia Tech Tidewater Agricultural Research and Extension center, Suffolk, VA 23437.

1. Summary

Climate change poses significant challenges to agricultural production worldwide, and the coastal regions of Virginia are no exception. Accomack and Northampton counties, located on the Eastern Shore of Virginia, are areas with rich agricultural heritage. Northampton and Accomack Counties are characterized by a humid subtropical climate which experience hot and humid summers, and mild winters, with average summer temperatures ranging from 75°F to 85°F (24°C to 29°C) and winter temperatures from 35°F to 45°F (2°C to 7°C). Annual precipitation averages around 45 inches (1143 mm), evenly distributed throughout the year, these regions are also susceptible to tropical storms, hurricanes, and coastal flooding due to its proximity to the Atlantic. These counties predominantly have sandy loam soils that support major crops like soybeans, corn, wheat, cotton and vegetables, alongside aquaculture. These regions are highly vulnerable to the impacts of climate change due to their geographical location, agroclimatic situations, and reliance on specific crops. Therefore, a project study was conducted to quantify variations in climatic conditions, crop health situations, and yields towards devising strategies for climate-smart crop production management and agricultural sustainability.

2. Objectives: Specific study objectives pertaining to this project were

1) To develop the understanding of annual variations in climate change parameters for Accomack and Northampton counties.
2) Data-driven geospatial impact assessment of extreme weather events (rainfall, storms, and heatwaves) on seasonal crop phenology and final yield.
3) Evaluation of crop water demand (or transpiration) dynamics because of climate change.

3. Methods and findings

Obj. 2.1. Understanding of annual variations in climate change parameters for Accomack and Northampton counties: To achieve this historical weather data was collected for the past 33 years (1990 to 2023) from various government and private web sources (Table 1). Most of these data were in geospatial format ranging in size of about 20 TB. These data were extracted at county level for both the counties and then extracted in point data format for a highest resolution of 1-h. Extracted data was then processed to compute average, minimum, and maximum values for different temporal resolutions of hourly, daily, monthly, and annual. Given the size of data and number of variables to be assessed, one of the major bottlenecks was to effectively and comprehensively present all the extracted information. For this, a web-based interactive data dashboard was created (Grafana.com) which enables the user to select the resolution of data to be studied (Hourly, daily, monthly, or annual) as well as the parameter (weather or crop). A sample graph from the developed dashboard is presented in figure 1. Complete access link will be provided based on requests. This dashboard also presents temporal depiction of extreme weather events that have occurred in the assessment period.

Table 1: Summary of weather and crop data harnessed for Northampton and Accomack Counties of Eastern Shore.

Sr.	Parameter	Source
1	Air Temperature	NASA Earth Data, NASA Power - DAV and Visual Crossing Corporation
2	Soil Temperature	NASA Earth Data, NASA Power - DAV and Visual Crossing Corporation
3	Cumulative Precipitation	NASA Earth Data, NASA Power - DAV and Visual Crossing Corporation
4	Solar Surface Net Radiation	NASA Earth Data, NASA Power - DAV and Visual Crossing Corporation
5	Relative Humidity	NASA Earth Data, NASA Power - DAV and Visual Crossing Corporation
6	Wind Speed	NASA Earth Data, NASA Power - DAV and Visual Crossing Corporation
7	Soil Moisture	NASA Earth Data, NASA Power - DAV and Visual Crossing Corporation
8	Relative Mean Sea Level	NOAA - Tides & Currents
9	Extreme Weather Events	NOAA – National Weather Service
10	Actual Evapotranspiration or crop water use	Google Earth Engine Data Catalogue (Modis Series) and USDA - Crop Data Layer (CDL)
11	Crop NDVI	Google Earth Engine Data Catalogue (Landsat & Sentinel Series) and USDA - Crop Data Layer (CDL)
12	Crop Surface Temperature	Google Earth Engine Data Catalogue (Landsat & Sentinel Series) and USDA - Crop Data Layer (CDL)
13	Crop Actual Evapotranspiration	Google Earth Engine Data Catalogue (Modis Series) and USDA - Crop Data Layer (CDL)
14	Crop Water Use Efficiency	Actual evapotranspiration and USDA – National Agricultural Statistics Service
15	Crop Planted vs Harvested	USDA – National Agricultural Statistics Service
16	Crop Loss Ratio	USDA – National Agricultural Statistics Service
17	Crop Yield	USDA – National Agricultural Statistics Service
18	Crop Net Production	USDA – National Agricultural Statistics Service

19	Crop Fertilizer Expense	USDA – National Agricultural Statistics Service

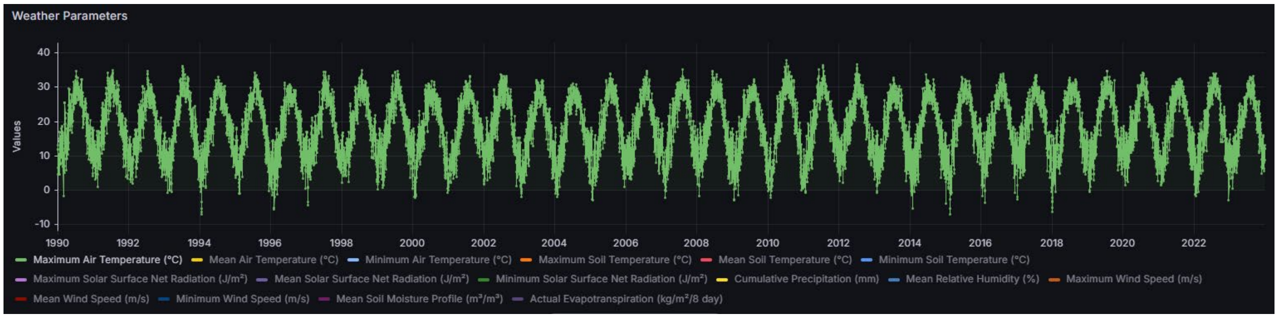

Fig 1: A sample graphical representation of weather parameters on developed data dashboard (Grafana).

<u>Objective 2.2. Data-driven geospatial impact assessment of extreme weather events (rainfall, storms, and heatwaves) on seasonal crop phenology and final yield:</u> For the two counties, we selected corn, cotton, soybean, and double crop of soybean and winter wheat for analyses as those crops accounted for significant size of farms in the region. These crops experienced about 80% variation during the growing seasons. As the first part of this objective, satellite imagery at spatial resolutions of 10 m (Sentinel 2) and 30 m (Landsat 8) were accessed using google earth engine. These imageries consisted of lands's (crop's) light reflectance maps and temperature maps. Next, crop data layers (CDL) for selected crops were accessed from USDA-CDL (USDA-NASS) onto the same google earth engine platform. These CDL are available from years 2008 until now which allowed us to obtain specific crop information for those 15 years. Normalized Difference Vegetation Index feature and all the weather parameters were computed from satellite imagery and weather data sources for all selected crops using CDL (Figs. 2 and 3).

Next, a correlation analysis was conducted between the crop health (NDVI) and weather parameters to quantify the influence of weather on crop health. Pearson's correlation coefficient was computed and is presented in figure 4 for all the crops selected in both counties. The higher the magnitude of coefficient, higher is the influence of that weather parameter on crop health. The results indicated that including maximum, mean, and minimum air and soil temperatures exhibited moderate to strong influence of crop health, while mean solar radiation showed weak to moderate correlations, underscoring its essential role in influencing crop health, although relatively lesser than temperatures. Cumulative precipitation and mean relative humidity displayed weak positive and negative correlations, indicating a relatively lower impact on NDVI compared to other weather parameters. Conversely, Maximum wind speed and soil moisture demonstrated weak to moderate negative correlations with NDVI, suggesting that excessive wind speed and soil moisture might negatively impact crop health. Such insights provide a comprehensive understanding of how specific weather parameters affect crop health. In addition to these assessments, crop surface temperature, crop water use efficiency, planted versus harvested acreage, crop loss ratio, yield, and net production parameters were also computed and included in the interactive data dashboard. These parameters further depict the influence of weather on crop productivity, water use, and potentially the economics of crop production over the past 15 years.

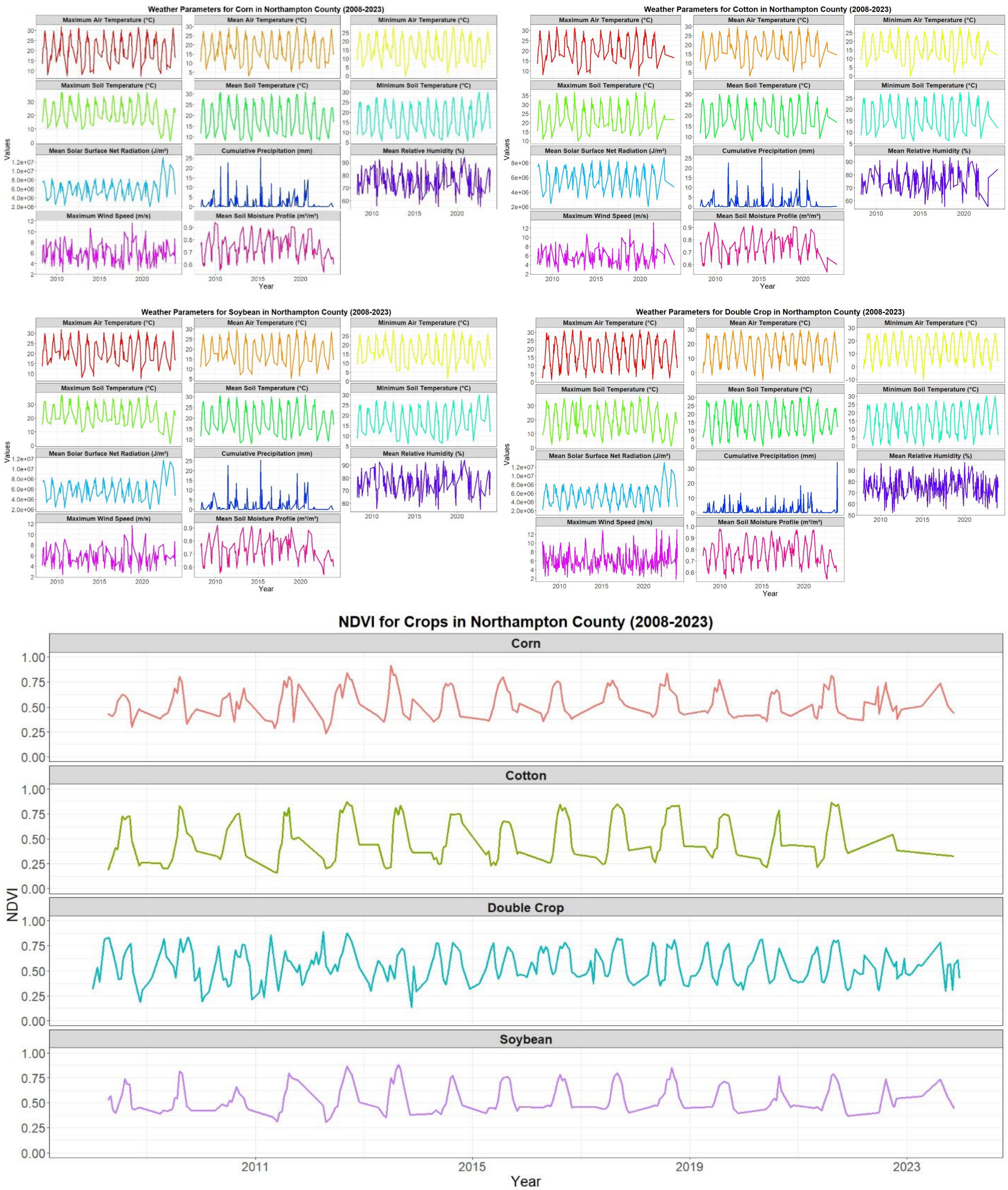

Fig. 2. Weather parameters and crop health (NDVI) for different crops observed in the Northampton County from 2008-2023.

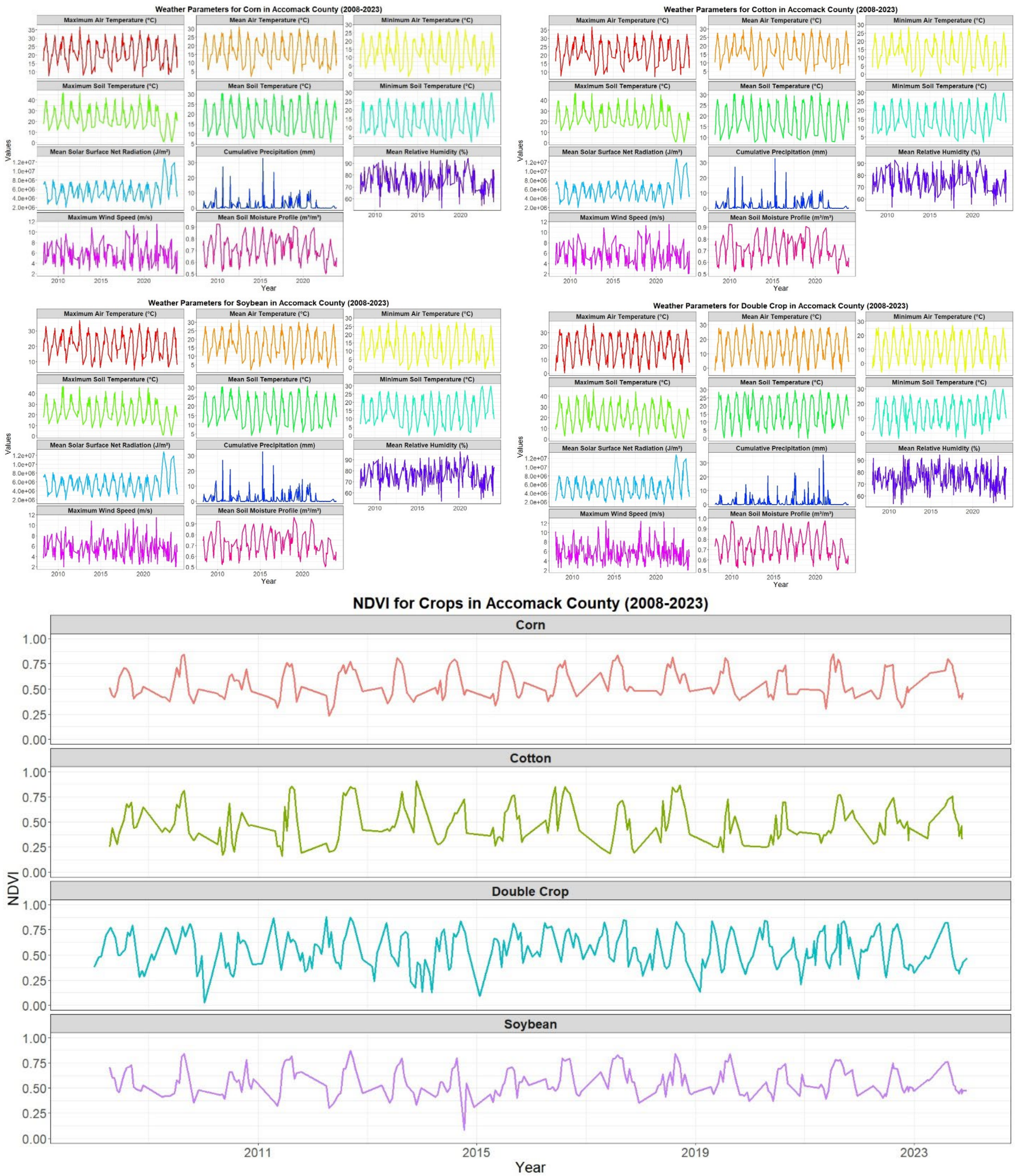

Fig. 3. Weather parameters for different crops observed in the Accomack County from 2008-2023.

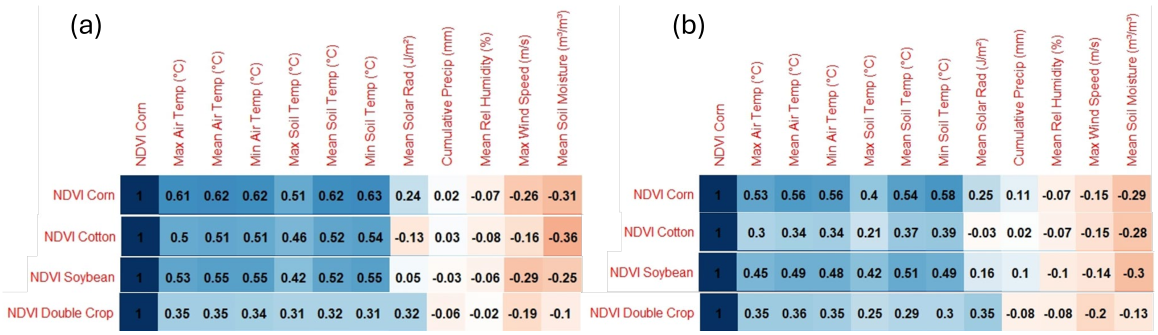

Fig. 4. Influence of weather parameters on crop health observed in the (a) Northampton and (b) Accomack counties from 2008-2023 using Pearson correlation analyses.

Crop health prediction using machine learning and agroclimatic data: A recurrent neural network model (RNN) was formulated to predict crop health as a result of weather parameters. The RNN model was chosen for its strengths in handling sequential and time-series data. Additionally, RNNs perform well in recognizing complex patterns in various time-series applications, making them a powerful tool for agricultural data analysis. Figures 5 and 6 show actual versus machine learning-predicted values of crop health. The results for Northampton County revealed moderately strong predictive power for all four crops. For corn, R^2 values ranged from 0.52 to 0.57 while prediction errors between 16.87% to 17.78%. For cotton, R^2 values ranged from 0.53 to 0.55 and prediction error values from 26.90% to 29.24%. For the double crop, crop health predictions R^2 values ranged from 0.50 to 0.59 and errors between 21.18% and 23.33%. For soybean, crop health prediction R^2 values between 0.53 to 0.57 and error values between 16.15% to 17.03% were observed.

Crop health prediction accuracies improved for the Accomack County where for corn, R^2 values ranged from 0.61 to 0.78 and prediction errors ranged between 12.58% and 15.75%. For cotton, R^2 values ranged from 0.60 to 0.73 and error from 15.84% to 22.20%. Crop health predictions for double crop showed R^2 values from 0.55 to 0.61 and errors between 22.18% and 22.63%. While for soybean, the model showed strong predictive power, with R^2 values from 0.56 to 0.66 and error values between 11.03% and 14.28%.

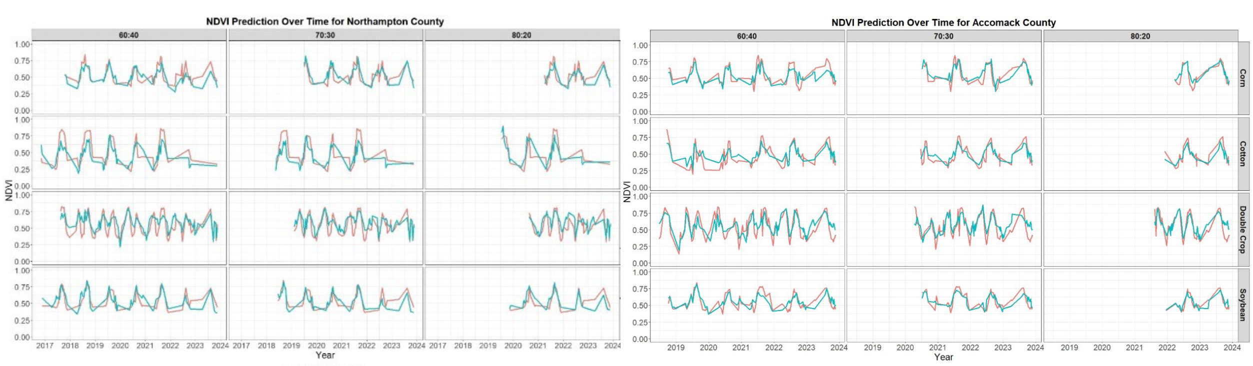

Fig. 5. Comparison of actual and predicted crop health status over different testing dataset sizes using machine learning for (a) Northampton and (b) Accomack counties.

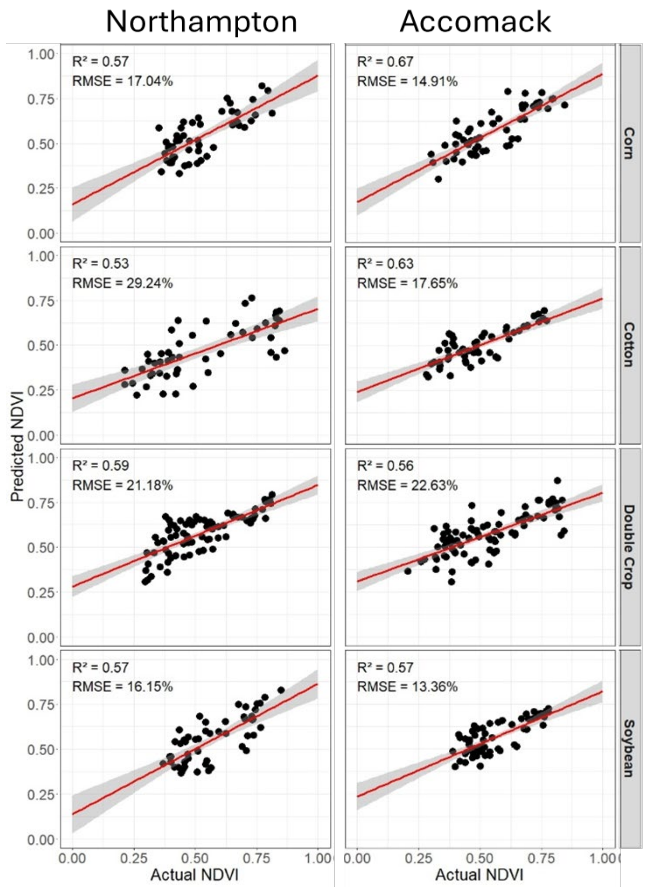

Fig. 6. Comparison of actual and predicted crop health status over different testing dataset sizes using machine learning for (a) Northampton and (b) Accomack counties.

Objective 3. Evaluation of crop water demand (or transpiration) dynamics from climate change:

As temperatures rise and precipitation patterns shift, understanding the dynamics of crop water demand, or transpiration, becomes crucial for effective water resource management for cropping systems. In this objective, we extracted actual evapotranspiration (ETa) from four crops in the two counties. Next, we also computed water-use efficiency (WUE) or crop water productivity for the four crops. These extracted and computed features have been included in the user dashboard, Grafana. Actual Evapotranspiration (ETa) were collected from 2008 to 2023 using MODIS satellite data and filtered for each crop using CDL information in those years (Fig 7). Actual evapotranspiration is the rate at which plants are using/losing water to the atmosphere. This is also the rate at which plants would require water i.e., irrigation. Next, crop water use efficiency was calculated (Fig. 8) as the ratio of crop yield to the total crop water use. It must be noted that crop yield information was available only for corn, soybean, and winter wheat crops for the two counties. From the observations, it was evident that crop water use has increased over the years for all crops, most probably due to increase in ambient temperatures and rise in atmospheric water demand (invariable shifts in climate). The peak of crop water use was observed for the 2016 growing season and as a result the crop water use efficiencies dropped in that period as well as later. It was also observed that for soybeans, the drop in crop water use efficiency was relatively lower than for corn and winter wheat showing its resilient nature towards water stress conditions.

These insights will eventually help growers plan to select and plant crops and cultivars that offer higher water use efficiency even in water stressed conditions.

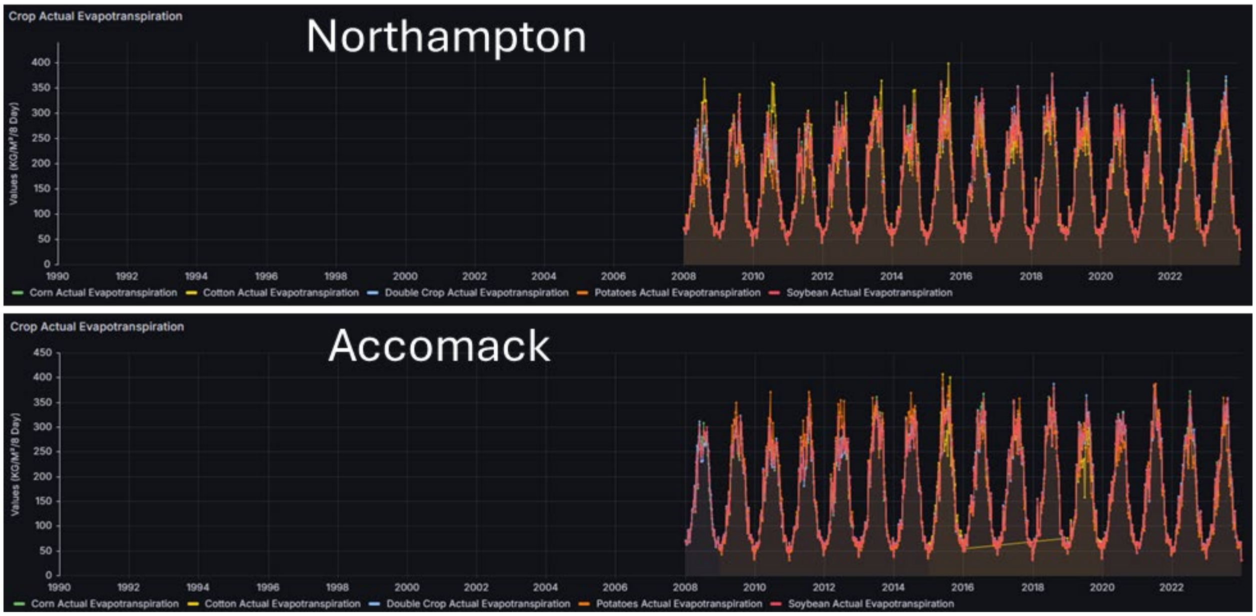

Fig. 7. Actual evapotranspiration for crops in Northampton and Accomack counties.

Fig. 8. Actual evapotranspiration for crops in Northampton and Accomack counties.

5. Conclusion

This project aimed to comprehensively assess the impacts of climate change on agricultural production in Accomack and Northampton counties by addressing three key objectives. First, by developing an understanding of the annual variations in climate change parameters for both counties, we quantified in detail of how temperature, precipitation, humidity, and other critical weather variables evolved or shifted over time. This baseline is crucial for identifying long-term trends and predicting future climatic shifts that could affect agricultural productivity. Secondly, we conducted a data-driven geospatial impact assessment of extreme weather events on seasonal crop phenology/health (NDVI). The analysis revealed significant correlations between the weather parameters and crop health, highlighting vulnerabilities and resilience of different crops to climatic stresses. This information is valuable for farmers and policymakers, enabling them to implement targeted strategies to mitigate the adverse effects of extreme weather on crop yield. In this objective we also attempted to predict crop health variations as a result of agroclimatic parameters and prediction accuracies were as desired (R^2 up to 0.78, r up to 0.9, and errors down to 12.6%). These findings establish that machine learning is capable of processing big time series data to predict crop health. Thirdly, the evaluation of crop water usage and water use efficiency against climate change were also evaluated that provided insights about the influence of rising temperatures, shifting precipitation patterns, and other climatic factors. All these insights form a critical outcome to support selection of climate smart crops for enhanced yield and productivity in the two assessed counties. Some of the biggest challenges encountered in this project were (1) finding reliable sources of data for entirety of the project, (2) extraction, processing, and storage of big data that was about 50TB (processing and extraction), and most importantly (3) presenting the data and trends comprehensively. Finding tangible solutions to these challenges was among the highest effort-consuming tasks that were able to accomplish. We eventually developed a data dashboard that comprehensively summarizes all the processed/extracted data. The future potential of this project outcome is developing a decision support system/software tool that will implement the machine learning models as in this project to identify best fit crops to be grown as per weather/climate forecasts as well as farming operation costs.

6. Annexure

The Grafana dashboard prepared for this project for both Northampton and Accomack County can be accessed via these two URL's.

Northampton County – https://sathishraymondemmanuel.grafana.net/goto/IQG15yrSg?orgId=1

Accomack County - https://sathishraymondemmanuel.grafana.net/goto/5sUJ5yrIR?orgId=1