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WEBINAR

Extensive Climate Hazards and Vulnerabilities Assessment of the Tree Crop Sector in Ghana

3rd December 2024 |14:00–16:00 CET | Virtual

Extensive climate hazards and vulnerabilities assessment of the tree crop sub-sector in Ghana

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Drought, ecophysiological response of plants and Ecosystem Services

Prof. Fausto Manes
Dr. Alessandro Sebastiani

Ghanaian's tree crops

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The Government of Ghana is pushing towards the enforcement of the tree crops subsector, which currently employs 1.6 million Ghanaian families. **Beside increasing the total income**, tree crops also have the capability of **enhancing its stability** over time.

Nevertheless, the **agricultural expansion**, including the plantation of new tree crops, has also played a negative environmental role in Ghana. Indeed, it has largely occurred **at expense of the natural forest**, with cocoa production being one of the major drivers of the alarming deforestation trends.

Table 1. Production, export and harvested area of tree crop production. Data obtained from FAOSTAT (2022). Values for Palm oil refer to year 2021.

Tree Crops	Production Volume, 2022 (1000 tons) (Global ranking in 2022)	Export Value, 2022 (1000 USD)	Area harvested (ha)
Cocoa beans	1108.6 (2°)	1,140,154	2,007,417
Cashew nuts, in shell	107.67 (12°)	262,385	202,056
Coconuts, in shell	504.36 (12°)	2,453	77,962
Palm oil	272.3	80,421	
Natural rubber in primary forms	117.6 (14°)	168,302	134,868
Sheanuts (karite nuts)	33.63 (5°)	-	32,868
Mangoes, guavas and mangosteens	102.99	46,624	7,184

Ecosystem Services in tropical forests

The tropical forests provide important Ecosystem Services at local and global scales, like climate regulation, carbon and water cycling, food and materials.

The expansion and intensification of agriculture at expenses of the tropical forest determine the loss of biodiversity and Ecosystem Services, deforestation and forest degradation, greenhouse gasses emissions, and local species extinctions (modified from Villa et al., 2021)

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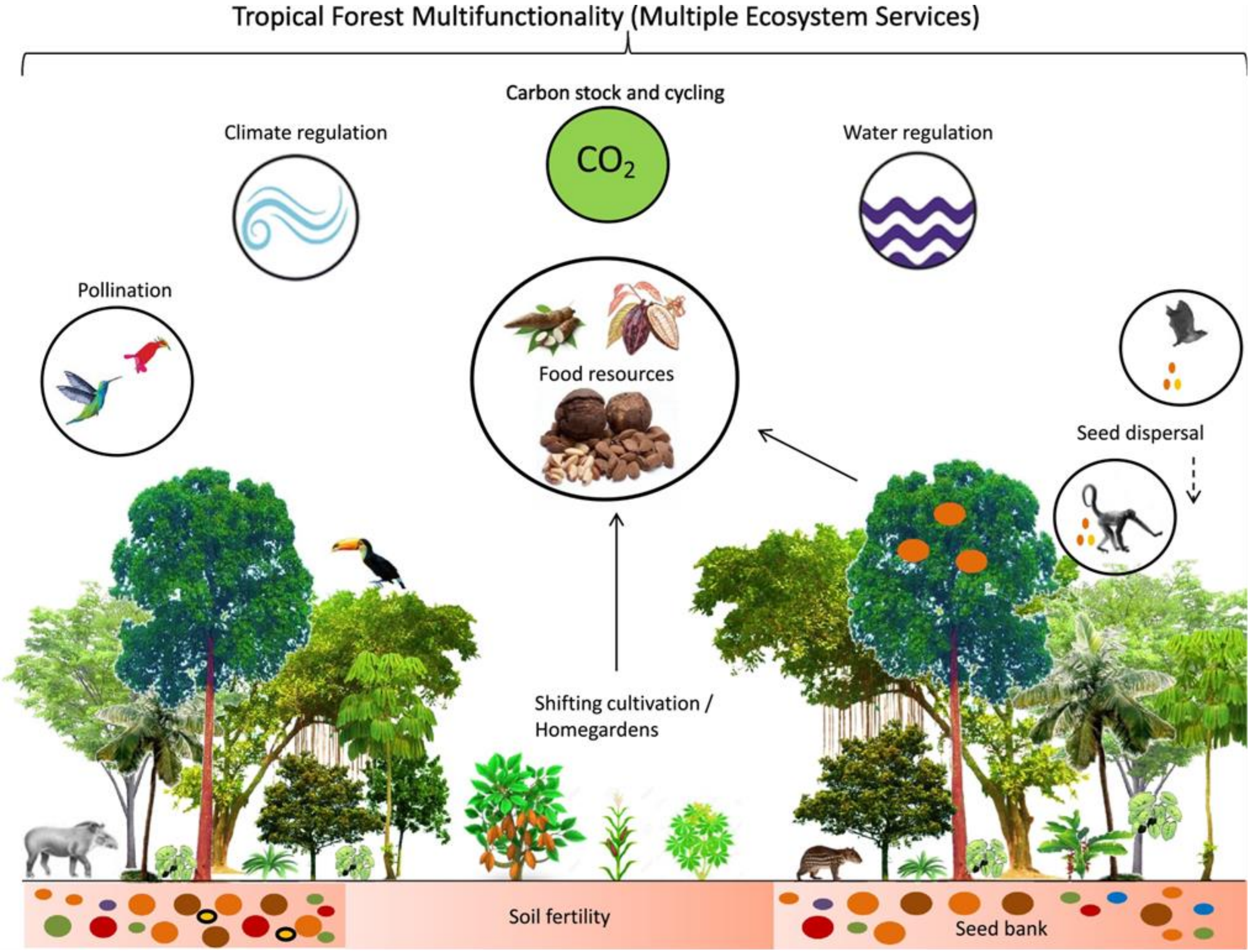

From: Villa, P. M., Rodrigues, A. C., Martins, S. V., de Oliveira Neto, S. N., Laverde, A. G., & Riera-Seijas, A. (2021). Reducing intensification by shifting cultivation through sustainable climate-smart practices in tropical forests: A review in the context of UN Decade on Ecosystem Restoration. *Current Research in Environmental Sustainability*, *3*, 100058.

Agricultural expansion and deforestation

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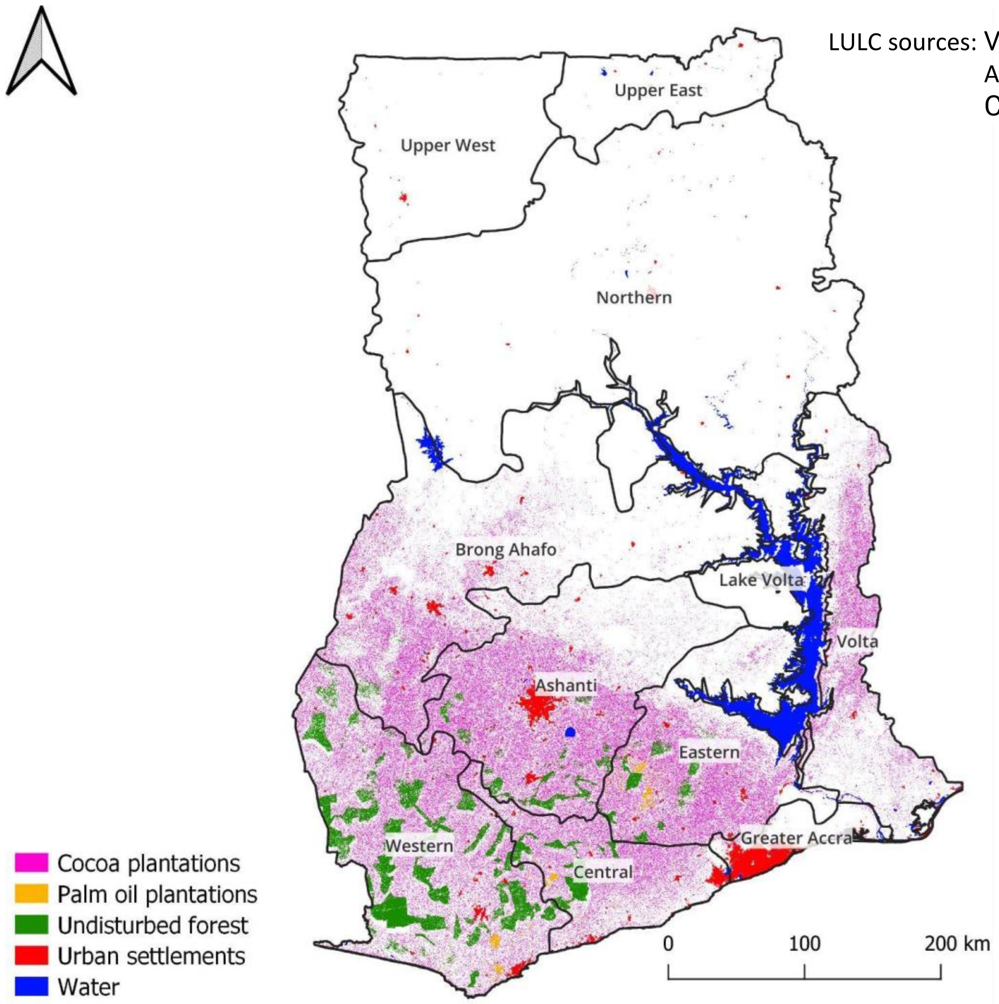
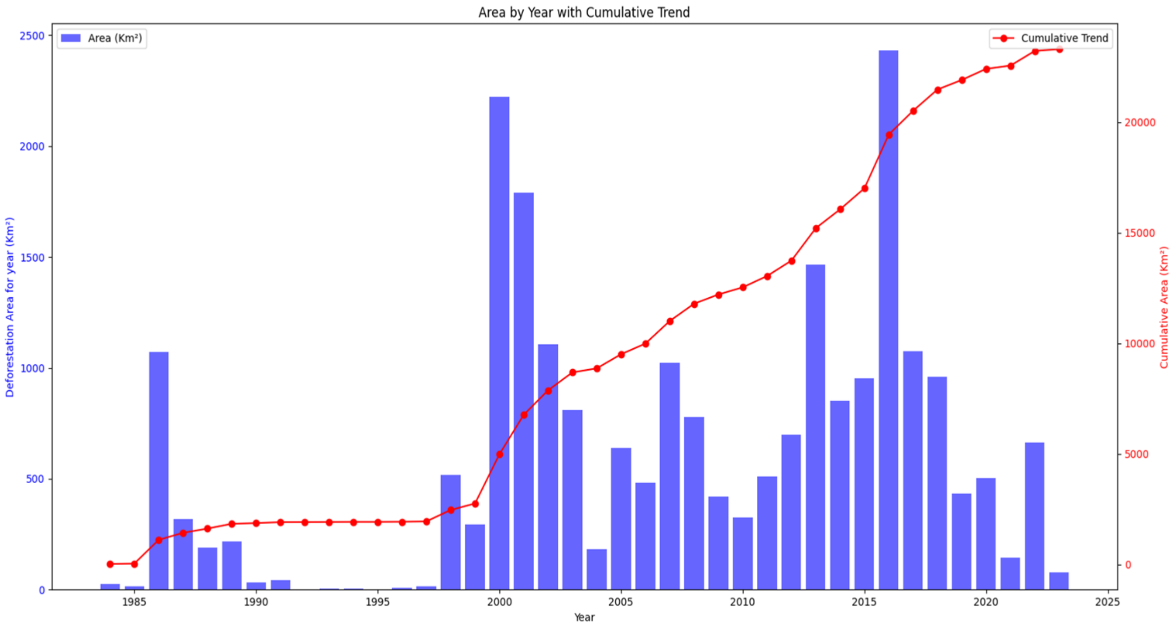


LULC sources: Vancutsem et al.
Abu et al.
CCI Land Cover (LC) team - ESA

	ha	%
Cocoa plantations	2,027,299	8.5
Palm oil plantations	45,216	0.19
Undisturbed forest	777,047	3.17
Urban settlements	347,985	1.46
Water	683,473	2.87



In the TMF domain, deforestation is decreasing. (from EC, Tropical forest status and dynamics of deforestation and forest degradation)

- Abu, I. O., Szantoi, Z., Brink, A., Robuchon, M., & Thiel, M. (2021). Detecting cocoa plantations in Côte d'Ivoire and Ghana and their implications on protected areas. *Ecological indicators*, *129*, 107863.
- Vancutsem, C., Achard, F., Pekel, J. F., Vieilledent, G., Carboni, S., Simonetti, D., ... & Nasi, R. (2021). Long-term (1990–2019) monitoring of forest cover changes in the humid tropics. *Science advances*, *7*(10), eabe1603.

Ghana REDD+ Strategy (2016-2035)

To halt the loss and degradation of forests, Ghana has joined the REDD+ framework, which seeks to reduce emissions from deforestation and forest degradation by promoting sustainable forest management. Nonetheless, the loss of forest has continued, with **agricultural expansion**, and especially cocoa production, being the main driver of degradation, followed by **wood harvesting and population development** (Ghana REDD+ Strategy).

The first program developed under the REDD+ framework was the **Ghana Cocoa Forest REDD+ Programme**, which incentivized farmers to adopt shaded cocoa production as well as to protect forests. The goal of this Programme is to cover 800,000 ha of cocoa plantations.

To realize this vision and goals, actions in line with Ghana's Strategy should maintain a focus on **five key criteria** for REDD+:

➢ Economic development
➢ Environmental sustainability
➢ Measurable
➢ Inclusive
➢ Marketable

Figure 1: Ghana's strategic options for addressing drivers of deforestation and degradation

Figure 4: The components of REDD+ in Ghana

Cocoa & Forest Initiative

The Cocoa & Forests Initiative (CFI) is an active commitment of top cocoa-producing countries with leading chocolate and cocoa companies to end deforestation and restore forest areas, through no further conversion of any forest land for cocoa production. In Côte d'Ivoire and Ghana, these Frameworks for Action have been translated into National Implementation Plans.

The first phase ran from 2018-2021 based on specified timelines, roles and responsibilities, monitoring and evaluation, and governance.

The implementation plans for the second phase, from 2022-2025 have also been shaped by public, private and civil society stakeholders, through a series of strategic and technical discussions.

Asunafo-Asutifi Hotspot Intervention Area (HIA), From Plans to Action

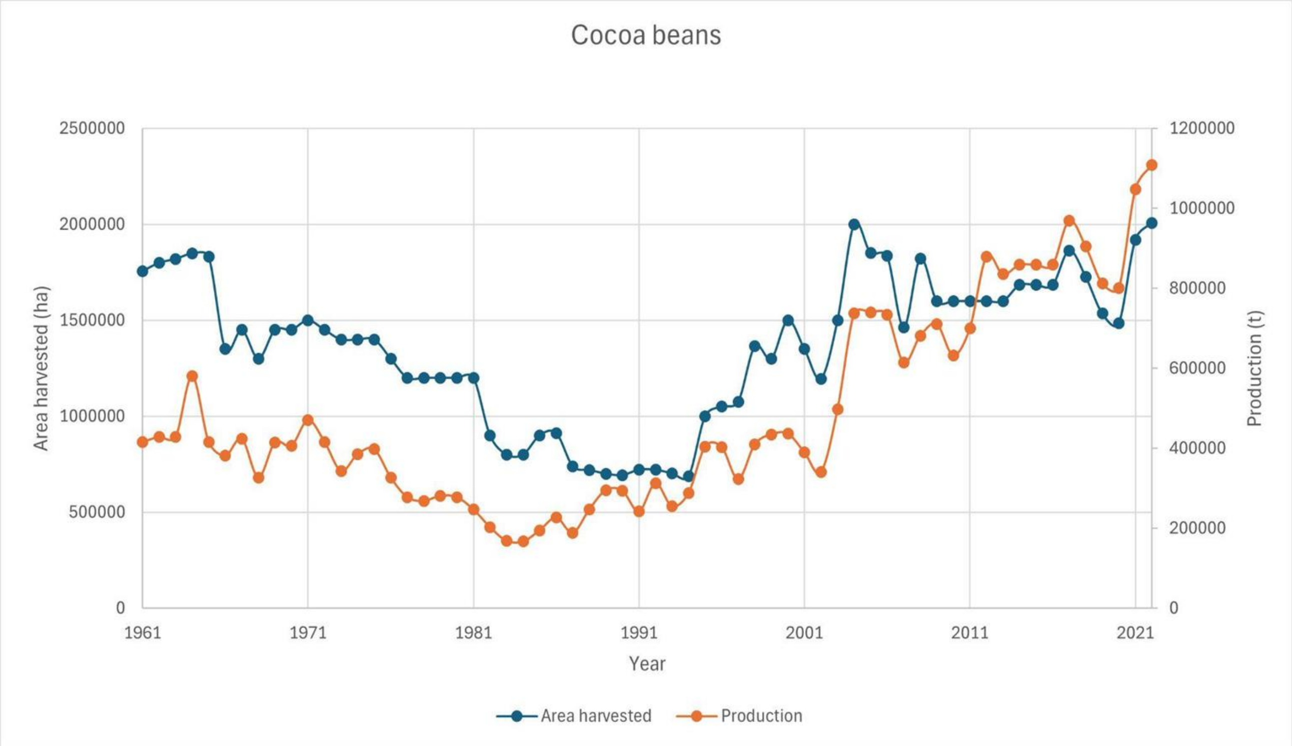
Spans a total area of 365,550 ha, with 125,731.17 ha as forest cover.
HIA has experienced a total forest loss of 12,028.95 ha. Despite efforts to manage and mitigate loss due to food crop cultivation which is the primary driver of deforestation, the enhance forest cover have resulted in 3,995.09 ha.

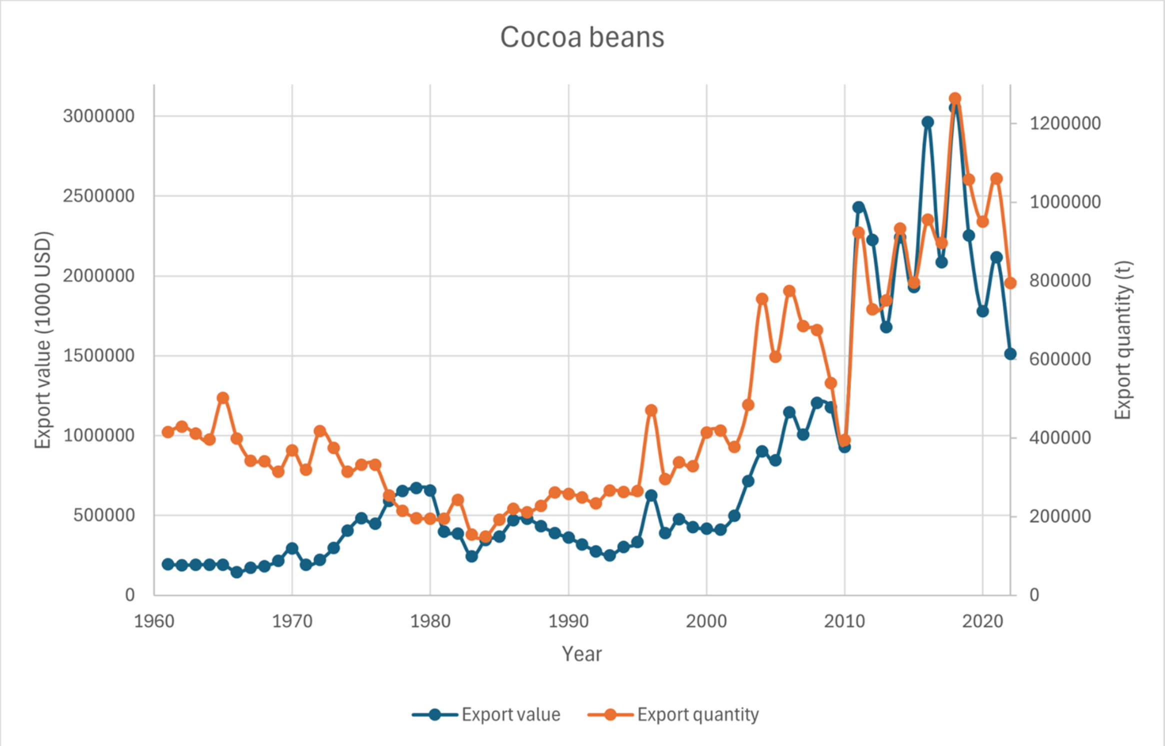
The objectives of the management plan are:

1. reduce deforestation on and off reserve
2. rehabilitate degraded land and forests
3. increase climate smart cocoa production with a focus on cocoa agroforestry
4. improve land and tree tenure
5. improve livelihoods
6. improve governance.

(Annual report Ghana 2023)

Cocoa overview

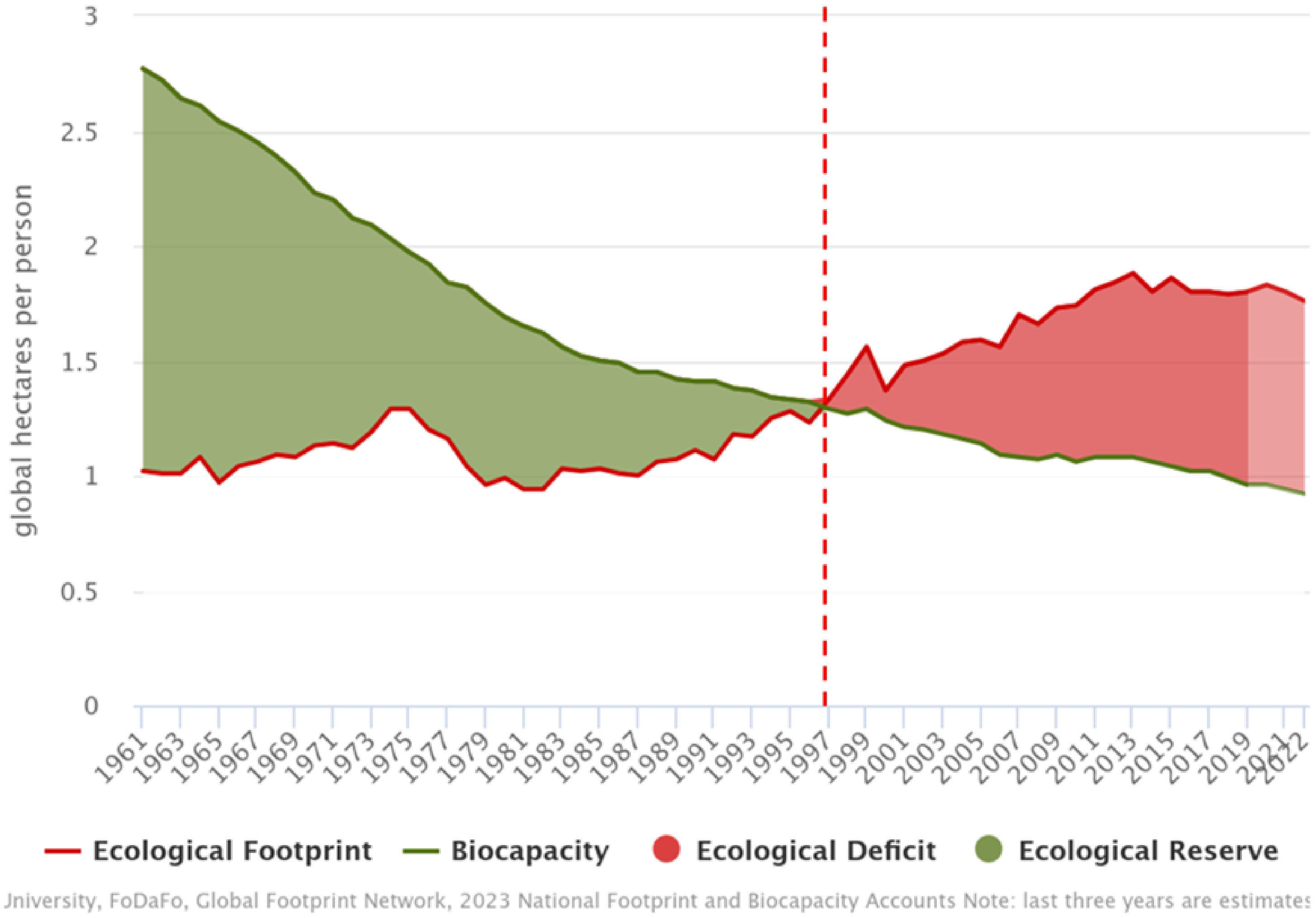




(source: FAOSTAT)

According to FAOSTAT, Ghana produced 1,1 million tons of cocoa beans in 2022, using more than 2 million hectares of land. Ghana has a crucial role in the world's cocoa production, being the second largest producer and exporter behind Ivory Coast; in 2022, Ghanaian cocoa beans export was equal to 0.8 million tons, generating roughly 1.5 billion USD.

Ecological Footprint

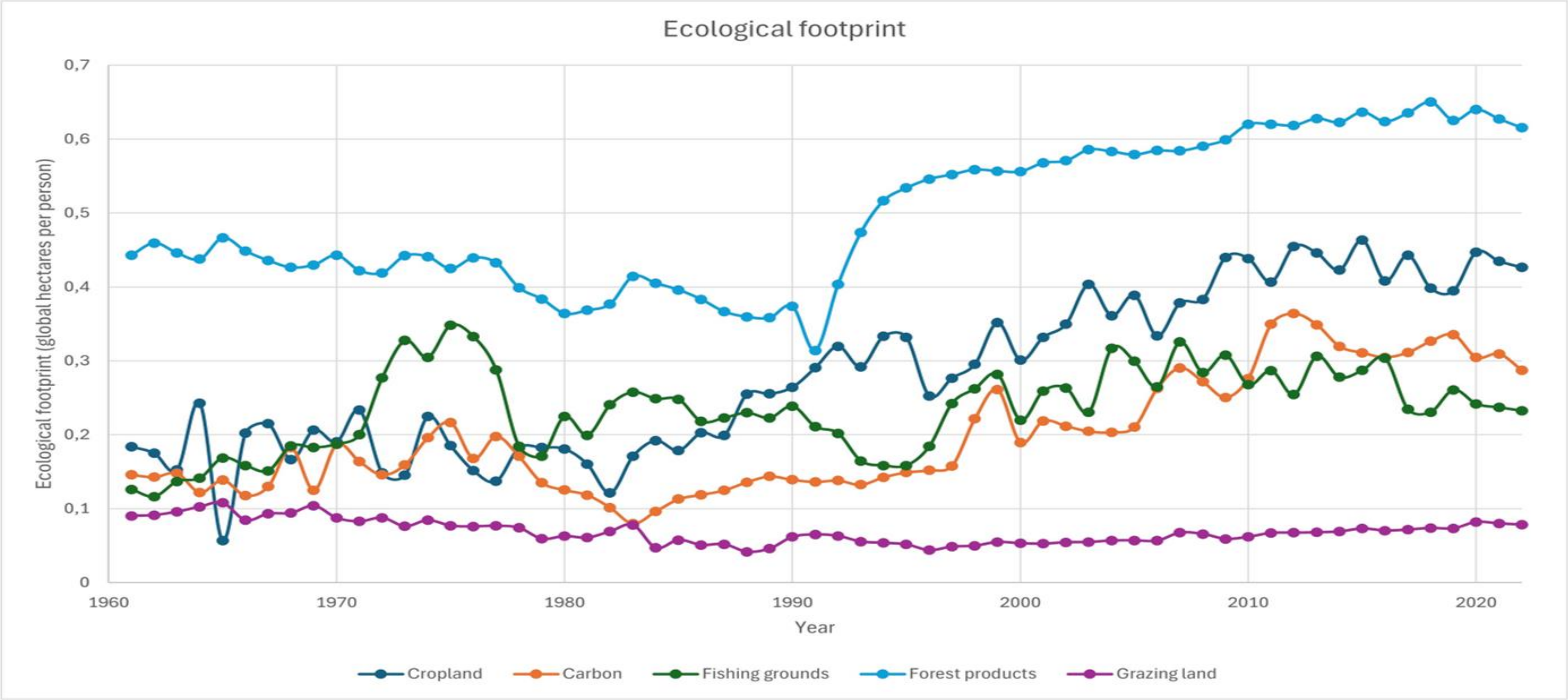


The **Ecological footprint** is a measure of the amount of biologically productive land and water required to support the demands of a population or productive activity. Ecological footprints can be calculated at any scale: for an activity, a person, a community, a city, a region, a nation or humanity as a whole. (IPBES). **Biocapacity** is the capacity of a Country, a region, or the world, to produce useful biological materials for its human population and to absorb waste materials (IPBES).

According to the data, **Ghana has been in overshoot**, the condition in which the demand for resources (ecological footprint) exceeds the regenerative capacity of ecosystems (biocapacity), **since 1997**.

Source: Global Footprint Network, at https://data.footprintnetwork.org/?_ga=2.230280860.1005423486.1733323786-984644610.1733323786#/

Ecological Footprint

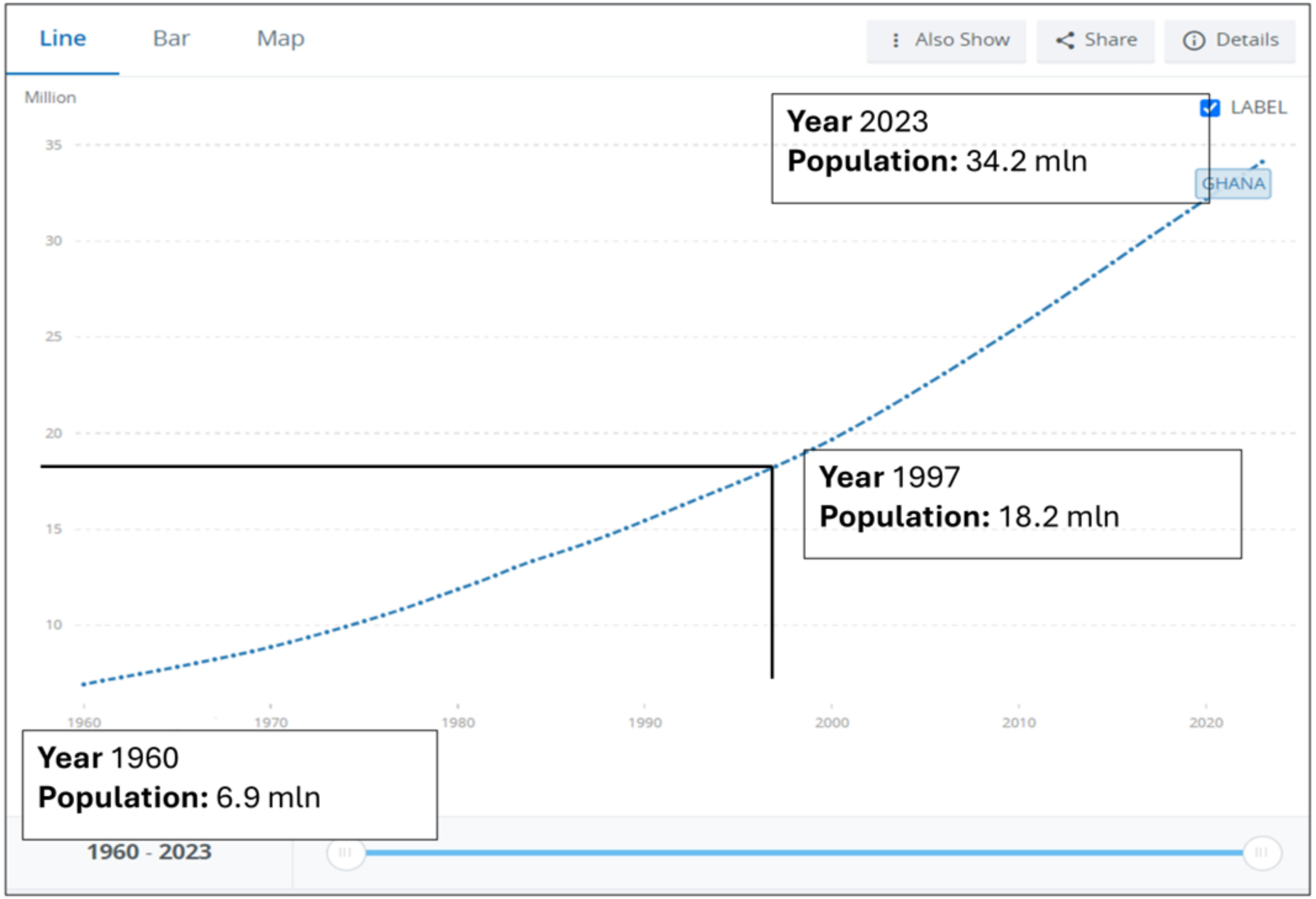


By breaking down the EF into its main components, it is evident that agriculture and the use of forest products are pushing it at unprecedented levels. The uncontrolled exploitation of the tropical forest has been one of the cornerstones leading to the Ecological Deficit. [Global Footprint Network 2023]

Source: Global Footprint Network, at https://data.footprintnetwork.org/?_ga=2.230280860.1005423486.1733323786-984644610.1733323786#/

Ecological footprint

Population growth of Ghana



Source: World Bank

In this framework, the constant growth of population, which went from about 7 million in 1960 to 34 million in 2023, has certainly played a primary role in determining the increase in the use of natural resources and in demand for food.

Human Development Index

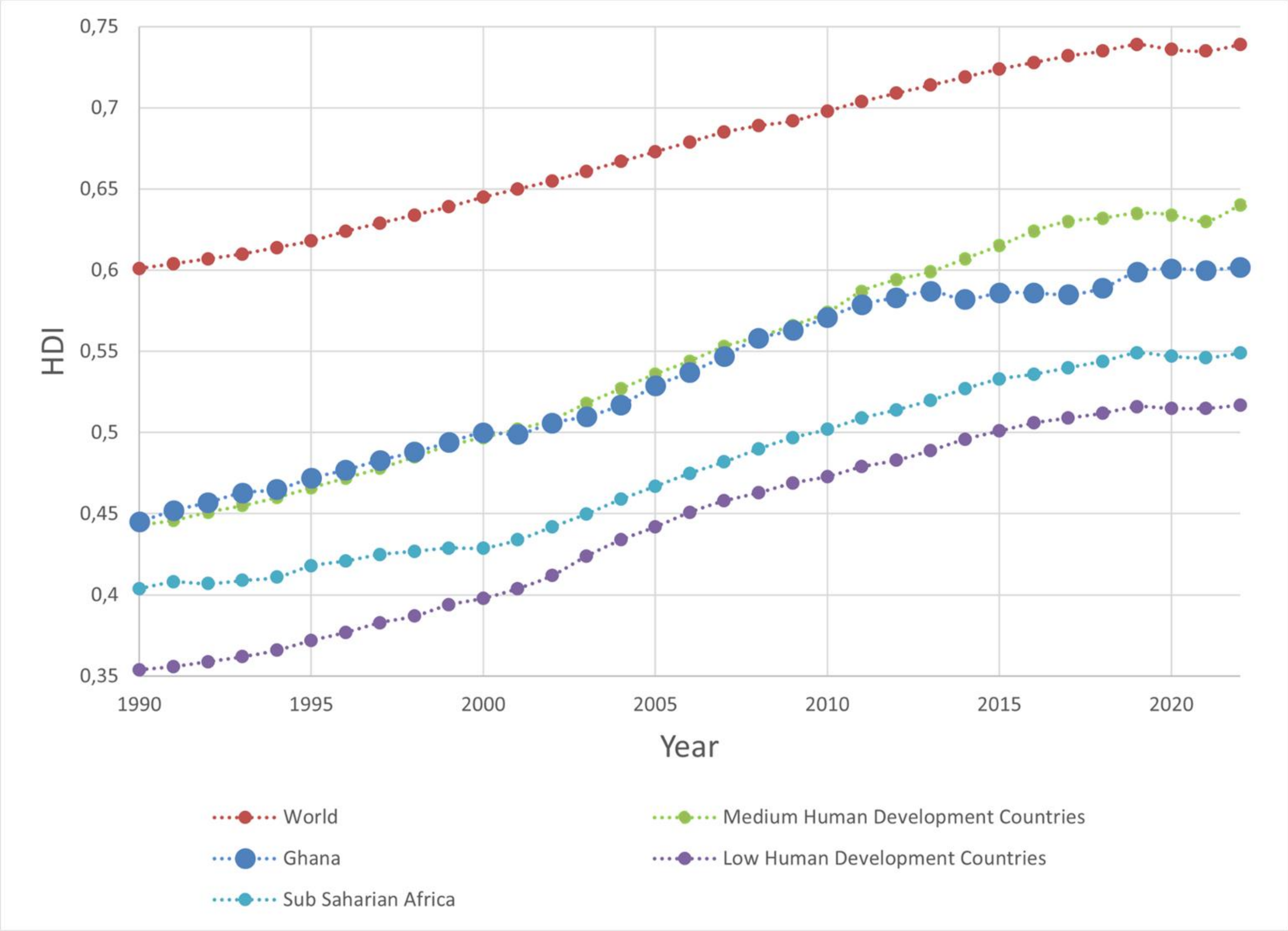
The Human Development Index (HDI) is a summary measure of average achievement in key dimensions of human development:

a long and healthy life (being knowledgeable), and having a decent standard of living.

The HDI is the geometric mean of normalized indices for each of the three dimensions. **The health dimension is assessed by life expectancy at birth, the education dimension** is measured by mean of years of schooling for adults aged 25 years and more and expected years of schooling for children of school entering age. **The standard of living dimension** is measured by gross national income per capita.

The HDI uses the logarithm of income, to reflect the diminishing importance of income with increasing GNI. The scores for the three HDI dimension indices are then aggregated into a composite index using geometric mean.

Ghana currently performs better than low human development countries, as well as the other sub saharian countries



Source: UN Development Programme

Tree crops vulnerability

Drought and heat stress are considered to be the most threatening factors for crop yields. Draught inhibit photosynthesis in a variety of ways, including early stomatal closure and Rubisco enzyme degradation; high temperatures limit the net photosynthesis process by increasing photorespiration and mitochondrial respiration, inactivating the Rubisco and damaging the photosystem II. However, the impact of Climate Change goes beyond those two factors. Stressed crops are more likely to be infested by **pests**; increased **flood disaster** and **wildfires**, which have reportedly yet become more frequent, will destroy farmlands and erode the soil, causing a decline in food production; **extreme weather events** will also speed up the erosion of soil nutrients, thus reducing its fertility.

Drought

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In Western Africa, climate change is leading to a **temperature increase, with a modification of the precipitation patterns** (Nakicenovic et al., 2000). Therefore, the total evaporative demand of plants is expected to rise over the next years; it will result into **increased frequency, severity and duration of water stress at the plant level.**

Plants often have both long and short term responses to drought and water deficit.
Short-term responses include, ad the leaf level, stomatal closure, root signal recognition, decrease in C assimilation, multi-stress sensing, gene responses with consequent reduction of growth**. At bud level,** amongst the others, inhibition of growth. **At the stem level**, among the others signal transport and xylem hydraulic changes. At root level, cell drought signaling, gene responses and osmotic adjustments. **Long-term responses** include shoot growth inhibition, reduced transpiration area, and metabolic acclimatation. At root level, these include increased root/shoot ratio, increased absorption area.
There are **two main response strategies to drought stress**, analyzed using leaf water potential at midday. In particular, anisohydric species lower their water potential with the increasing evaporative demand, thus being more effective in drawing water from the soil; isohydric species keep instead a constant water potential, independent of the soil water content. Interestingly, studies (Perera-Castro et al. 2023) have shown that polyploid cultivars might shift Mango from an anisohydric to isohydric behavior in response to water stress. Therefore, **selecting resilient cultivars**, which are capable of adapting to varying precipitation and temperature regimes, and more in general to drought, will be pivotal in order to enhance tree crops productivity over the next years.

Tree crops environmental extremes

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	Extremes		
Tree crop	**Water**	**Temperature**	**Flood**
Cocoa	no more than three months with prec. < **100mm**	the impact of **39 °C** is quite severe on photosynthesis compared to a control at 36 °C	Cacao can tolerate floods with appropriate growing techniques and flood resistant genetic material
Cashew	not less than 500 mm/y	above 45 °C	
Rubber	Taken together, these results suggested that rubber tree seedling was susceptible to drought stress, and the protection role of physiological and molecular responses only lasted for 3–5 days after withholding water.	rubber tree clones investigated are sensitive to thermal amplitudes characterized by temperatures higher than 40 °C and/or near to 10 °C	rubber tree is a flooding intolerant species,
Coconut	not less than **150 mm/month**	not >33°C during reproductive phase	coconut roots do not tolerate water logging for any length of time.
Mango	not less than **635 mm/year**		Mango is considered to be moderately flood tolerant species, and many mango-growing areas experience periodic waterlogging and flooding
Oil Palm	no month with precipitation <100mm	Very little is known about the effects of extreme high and low temperatures on oil palm development. However, brief exposures to **temperatures exceeding 38°C and below 8°C are not lethal.**	Oil palm does not tolerate continuous waterlogging and its roots are unable to respire under submerged conditions. The roots may die under prolonged flooding conditions.
Shea	400-1500 mm/y; shea can tolerate up to eight months of drought	24-38°C	

The table summarizes the survival extremes for water availability, temperature and flood exposition of all of the considered tree crops.

Data was gathered from literature (please see at the end of the presentation).

However, it must be borne in mind that extremes might come from field and controlled-conditions experiments.

Therefore, establishing clear and precise thresholds is not possible.

Drought and Ecophysiological response of plants

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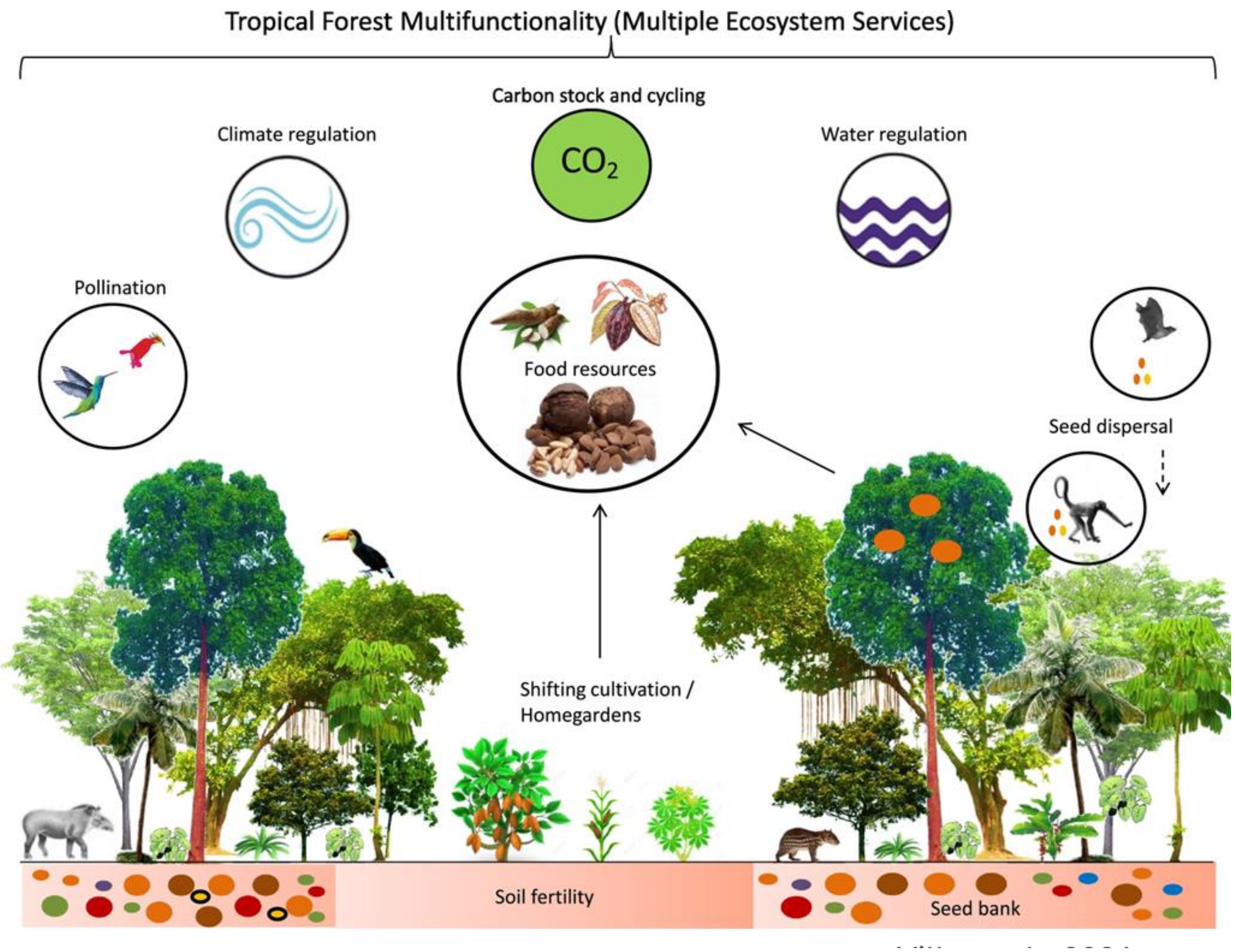
For most of the main tree crops (including cocoa, coconut, cashew and mango) the projected temperature increase of the worst-case scenario may exceeds the optimal values for growth. Indeed, **temperature above 36 °C are likely causing heat stress to generic cultivars** of all of the tree crops.

For almost all tree crops, the worst scenario (modeled by Prof. Cioffi and Collaborators) reports a **huge increase of precipitations during October, November and December** compared the 1999 – 2014 time frame. Such a phenomena may **alters the length and intensity of the dry season**; **It could also favor flooding events** in soils with limited drainage.

Even though analyzing the combined effect of the temperature increase and alteration of the precipitation patterns is not trivial, **an increase in the evaporative demand of plants is likely going to occurr**. Therefore, projections suggest that tree crops are probably going to face both water and heat stress.

Ecosystem Services in tropical forests

The tropical forests provide important Ecosystem Services at local and global scales, like climate regulation, carbon and water cycling, food and materials.
The expansion and intensification of agriculture at expenses of the tropical forest determine the loss of biodiversity and Ecosystem Services, deforestation and forest degradation, greenhouse gasses emissions, and local species extinctions (modified from Villa et al., 2024)



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Ecosystem Services in tropical forests

Carbon dioxide sequestration and emission:

The image highlights that carbon dioxide (CO_2) is continually sequestered (absorbed) and emitted (released) by the Earth's atmosphere through the forest ecosystem.

On the right side of the image, an arrow points downwards towards the trees with the text "As trees grow, they sequester CO_2." This indicates that growing trees absorb carbon dioxide from the atmosphere throught photosynthesis, which helps in reducing greenhouse gases.

(text modified from the Canadian's Government website, at https://natural-resources.canada.ca/climate-change/climate-change-impacts-forests/forest-carbon/13085)

InVEST Carbon storage

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InVEST
Integrated Valuation of Ecosystem Services and Tradeoffs

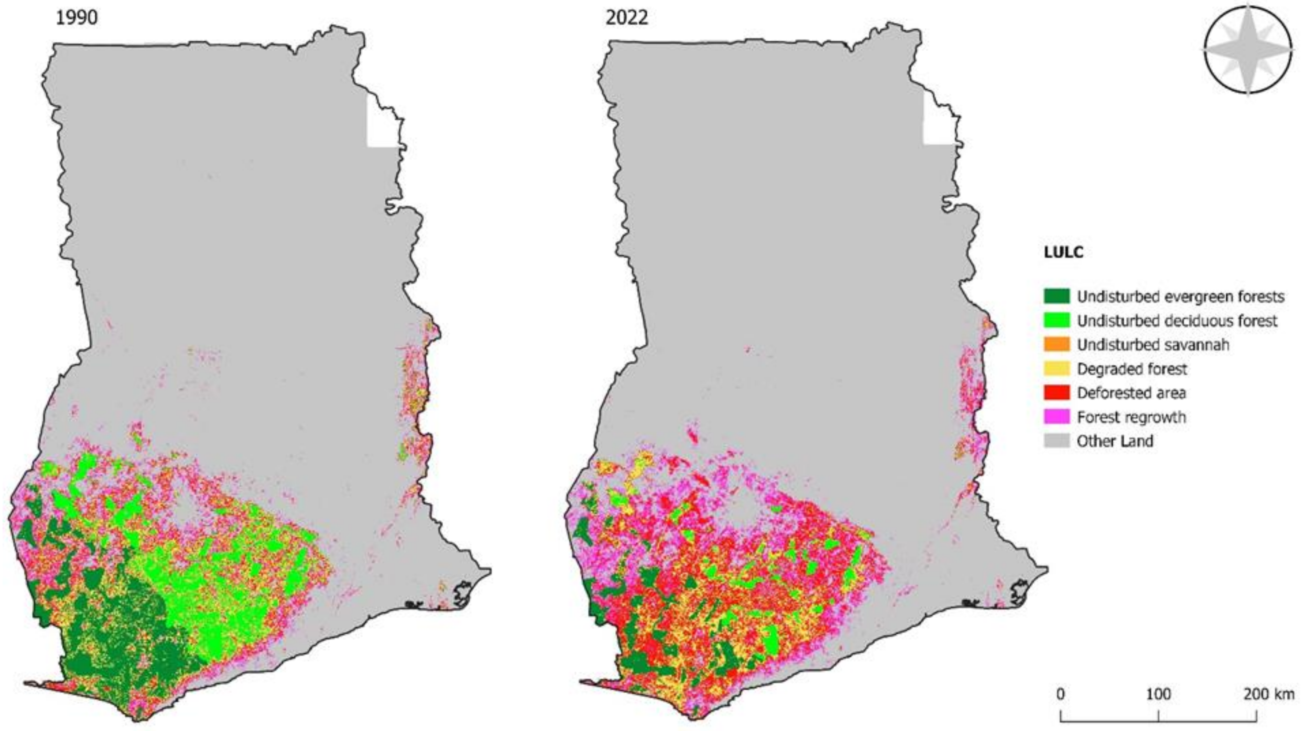
lu-code	LULC_name	C_above	C_below	C_soil	C_dead
1	Forest	140	70	35	12
2	Coffee	65	40	25	6
3	Pasture/grass	15	35	30	4
4	Shrub/undergrowth	30	30	30	13
5	Open/urban	5	5	15	2

Figure, Table and text from InVEST user manual

The InVEST Carbon Storage and Sequestration model **estimates the current amount of carbon stored in a landscape and values the amount of sequestered carbon over time.** First it aggregates the biophysical amount of carbon stored in four carbon pools (aboveground living biomass, belowground living biomass, soil, and dead organic matter) based on land use/land cover (LULC) maps provided by users. If the user provides a future LULC map, the carbon sequestration component of the model estimates expected change in carbon stocks over time.

Carbon stock of the tropical moist forest

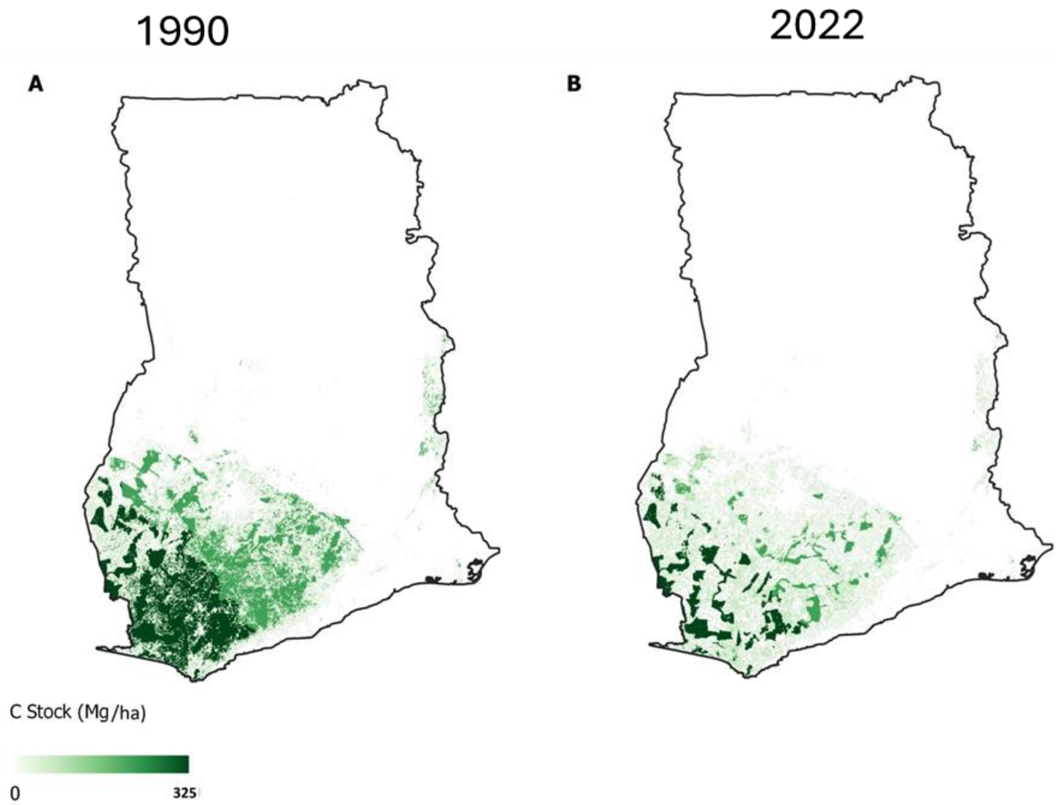
The extension of undisturbed forests (both evergreen and deciduous) has dropped significantly over the 1990-2022 period, as they went from 9.93 % to 3.26 % of the total area. The class of degraded forests had a slight decrease, whereas deforested areas rose from 3.8 % to 7.38 % of the total area. Interestingly, forest regrowth areas also increased, rising from 3.21 % to 5.14 % of the national territory.



Land use and land cover classification of the High Forest Zone of Ghana for years 1990 and 2022. Modified from JRC (TMF), https://forobs.jrc.ec.europa.eu/TMF/explorer

Carbon stock of the tropical moist forest

In this figure, the darker the green, the higher the C stock. According to literature, undisturbed evergreen forests store more carbon than deciduous undisturbed forests. Overall, C stock decreased from 830 Tg to 407 Tg. Undisturbed forests show the most substantial loss in C stock. Plus, the result do not take into account CO2 emission associated with the disruption of the natural forest (e.g. logging, wildfires) and other activities related to food production.



C stock of different LULC classes of High Forest Zone of Ghana in 1990 and 2022, in Tg.

LULC	1990	2022
Undisturbed evergreen forests	419,58	167,78
Undisturbed deciduous forests	228,58	55,26
Degraded forest	136,57	108,03
Evergreen forest regrowth	16,13	30,77
Deciduous forest regrowth	29,55	45,83
Total	830,41	407,67

Carbon stock of the tropical moist forest

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Carbon stock has clearly declined in south-western regions of Ghana. Most of the loss can be attributed to land cover change from undisturbed forest to disturbed forest or deforested land; some occasional gains (represented in blue) are due to forest regrowth over deforested areas.

According the Ghanaian REDD+ strategy, the principal drivers of deforestation and forest degradation are agricultural expansion (50%), wood harvesting (35%), population and development pressures (10%), mining and mineral exploitation (5%).

Interestingly, according to Asubonteng et al (2018), cocoa plantation has not only caused deforestation, but also caused a massive loss of food crop dominated areas, with negative implications for food security.

The table shows the stock variation over years 1990 and 2022 expressed in Tg.

LULC	Δ (2022 - 1990)	Δ % (2022 - 1990)
Undisturbed evergreen forests	-251,8	-60,01
Undisturbed deciduous forests	-173,32	-75,82
Degraded forest	-28,54	-20,90
Evergreen forest regrowth	+14,64	+ 90,76
Deciduous forest regrowth	+16,28	+ 55,09
Total	-422,74	-50,91

Carbon stock of the tropical moist forest

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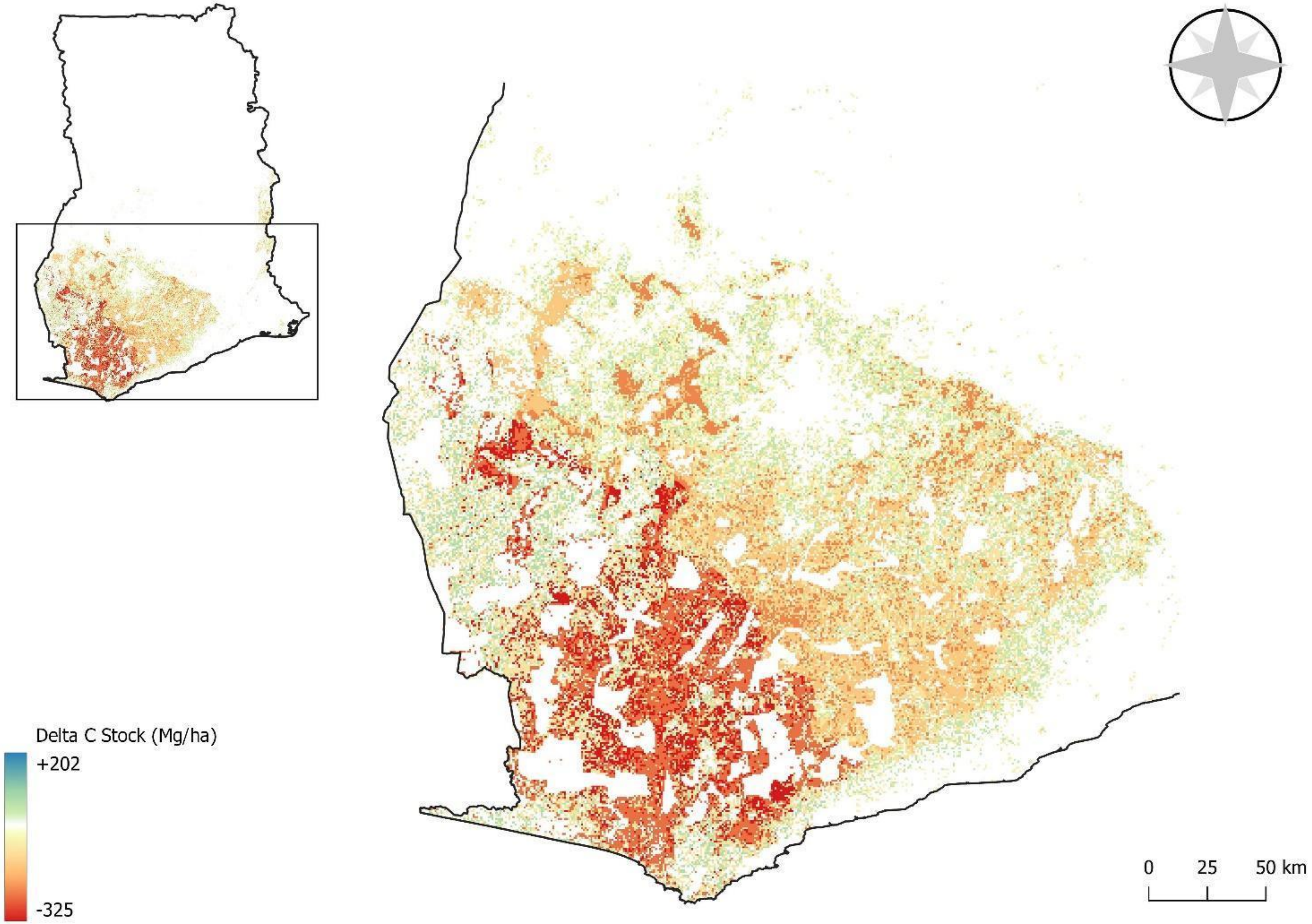

Carbon stock of the tropical moist forest - Pra river basin

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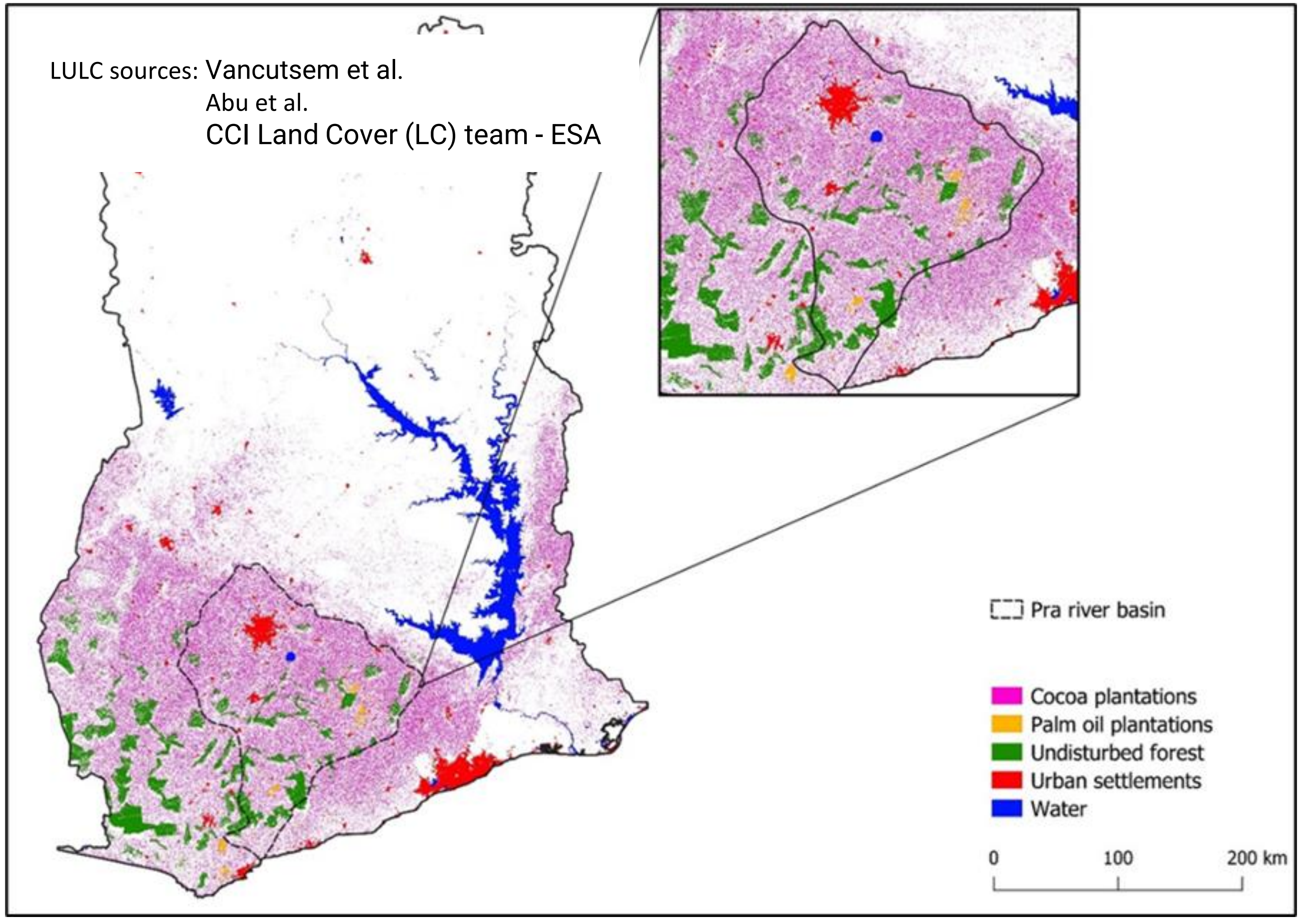

According to the classification, the Pra river basin is covered for **27.1 %** of its area by cocoa plantations (for a total of 644,000 hectares); oil palm covers **1.2 %** of the total area (roughly 28,000 hectares); undisturbed forest covers **9.04 %** of the total area (roughly 211,000 hectares)

LULC	C stock (Mg/ha)	C stock (Tg)
cocoa plantations	108	69.56
oil palm plantations	69	1.9
Tropical moist forest	up to 300	

- Abu, I. O., Szantoi, Z., Brink, A., Robuchon, M., & Thiel, M. (2021). Detecting cocoa plantations in Côte d'Ivoire and Ghana and their implications on protected areas. *Ecological indicators*, *129*, 107863.
- Vancutsem, C., Achard, F., Pekel, J. F., Vieilledent, G., Carboni, S., Simonetti, D., ... & Nasi, R. (2021). Long-term (1990–2019) monitoring of forest cover changes in the humid tropics. *Science advances*, *7*(10), eabe1603.

Relevant literature

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Tree crop	Reference
COCOA	https://www.icco.org/growing-cocoa/#:~:text=Cocoa%20plants%20respond%20well%20to,minimum%20average%20of%2018%20%E2%80%93%2021%C2%BAC. Hebbar, K. B., Apshara, E., Chandran, K. P., & Prasad, P. V. (2020). Effect of elevated CO 2, high temperature, and water deficit on growth, photosynthesis, and whole plant water use efficiency of cocoa (Theobroma cacao L.). International journal of biometeorology, 64, 47-57. Quaye, A. K., Doe, E. K., Attua, E. M., Yiran, G., Arthur, A., Dogbatse, J. A., ... & Addo, D. (2021). Geospatial distribution of soil organic carbon and soil pH within the cocoa agroecological zones of Ghana. Geoderma, 386, 114921 Sena Gomes, A. R., & Kozlowski, T. T. (1986). The effects of flooding on water relations and growth of Theobroma cacao var. catongo seedlings. Journal of horticultural science, 61(2), 265-276 https://www.gvsu.edu/cms4/asset/43276A40-0D8F-A887-4E4B2E0B509EA609/pennstatusofcacao.pdf
CASHEW	Predicting the Impact of Climate Change on Cashew Growing Regions in Ghana and Cote d'Ivoire Final report September, 2011; REPUBLIC OF GHANA CASHEW DEVELOPMENT PROJECT APPRAISAL REPORT Dedzoe, C. D., Senayah, J. K., & Asiamah, R. D. (2001). Suitable agro-ecologies for cashew (Anacardium occidetale L) production in Ghana. West African Journal of Applied Ecology, 2(1). Paull RE and Duarte O. 2011. Tropical Fruits. Volume 1. Centre for Agriculture and Bioscience International.
RUBBER	https://krishi.icar.gov.in/jspui/bitstream/123456789/24327/1/Chapter%206%20Cashew%20-%20Impact%20of%20climate%20change%20on%20plantation%20crops.pdf https://doi.org/10.1155/2021/3240686 Karumamkandathil, R., Jayasree, P. K., Radha, J., Uthup, T. K., Mathew, S. A., & Sathik, M. B. M. (2022). Genetics and Genomics of Abiotic Stress in Rubber Tree (Hevea Brasiliensis). In Genomic Designing for Abiotic Stress Resistant Technical Crops (pp. 245-298). Cham: Springer International Publishing Nóia Júnior, R. D. S., Pezzopane, J. E. M., Vinco, J. S., Xavier, T. M. T., Cecílio, R. A., & Pezzopane, J. R. M. (2018). Characterization of photosynthesis and transpiration in two rubber tree clones exposed to thermal stress. Brazilian Journal of Botany, 41, 785-794.
SHEA	https://gaez.fao.org/pages/ecocrop-find-plant Choungo Nguekeng PB, Hendre P, Tchoundjeu Z, Kalousová M, Tchanou Tchapda AV, Kyereh D, Masters E, Lojka B. The Current State of Knowledge of Shea Butter Tree (Vitellaria paradoxa C.F.Gaertner.) for Nutritional Value and Tree Improvement in West and Central Africa. Forests. 2021; 12(12):1740.

Relevant literature

COCONUT	Adkins, S., Biddle, J., Bazrafshan, A., & Kalaipandian, S. (Eds.). (2024). The Coconut: Botany, Production and Uses. CABI. Alvim, P. D. T., & Kozlowski, T. T. (Eds.). (2013). Ecophysiology of tropical crops. Elsevier. Selvamani, V., Maheswarappa, H. P., & Chowdappa, P. (2017). Soil Health Management in Coconut. Today & Tomorrow's Printers and Publishers, New Delhi.. Rao, N. S., Shivashankara, K. S., & Laxman, R. H. (Eds.). (2016). Abiotic stress physiology of horticultural crops (Vol. 311). India: Springer.
MANGO	https://www.mango.org/wp-content/uploads/2020/02/Nutrition_Fertilization_ENG.pdf pH: Bally, I. S. (2006). Mangifera indica (mango). Species profiles for pacific island agroforestry, 1-25. Rao, N. S., Shivashankara, K. S., & Laxman, R. H. (Eds.). (2016). Abiotic stress physiology of horticultural crops (Vol. 311). India: Springer. Gomes, F. P., & Prado, C. H. (2007). Ecophysiology of coconut palm under water stress. Brazilian Journal of Plant Physiology, 19, 377-391.
OIL PALM	Rao, N. S., Shivashankara, K. S., & Laxman, R. H. (Eds.). (2016). Abiotic stress physiology of horticultural crops (Vol. 311). India: Springer. https://www.ks-asiapacific.com/shared/data/kali-fertiliser-broschures-pdf/broschures-en-int/en-int-oil-palm-A4.pdf (Tiemann et al., 2018 and Corley et al., 2015) Satriawan, H., Fuady, Z., & Fitri, R. (2021, May). Physical and chemical properties of oil palm land which overgrown with weeds at different plant age. In IOP Conference Series: Earth and Environmental Science (Vol. 749, No. 1, p. 012014). IOP Publishing. Lim, K.H. & Goh, Kahjoo & Kee, K.K. & Henson, I.E.. (2011). Climatic requirements of oil palm. Agronomic principles and practices of oil palm cultivation. 1-46

Thank you for your attention

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Extensive climate hazards and vulnerabilities assessment of the tree crop sub-sector in Ghana

Part I: Understanding Climate Risks in Tree Crop Sector

Historical and projected climate & hydrological features in tree crop regions

Speaker:Prof. Francesco Cioffi
Team: Prof. Davide Luciano De Luca,Dr. Qin Jiang, Dr. Mario Giannini, Loretta Pearl Poku, Omar Boumarouane

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Presentation Outline

Historical Spatial and Temporal Structures of Hydrological and Climate Variables (Precipitation and Temperature)

Severity and Occurrence of Droughts in Ghana

Severity and Occurrence of Extreme precipitation and Flood Prone Zones

Development of Future Climate Scenarios

Impact of future climate change on tree crops

Historical and projected climate & hydrological features in tree crop regions

Issues

a) In recent decades, are there significant trends in annual and seasonal rainfall amounts, drought severity and frequency, as well as the magnitude and frequency of extreme precipitation?

b) Are there significant trends in maximum, minimum, and mean temperatures?

c) If so, what are the possible driving factors behind these trends?

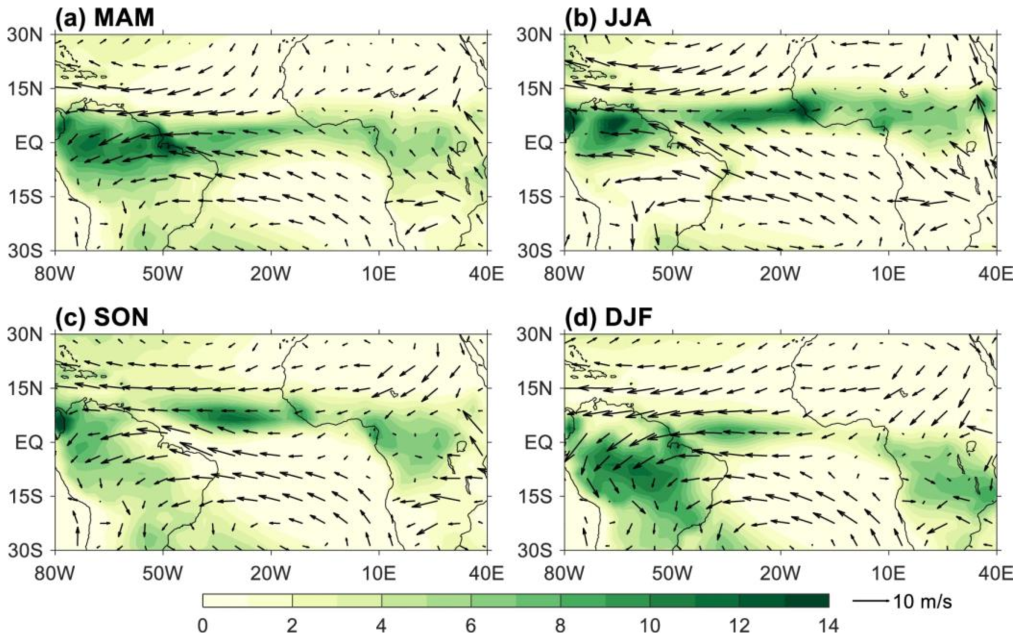
a) How will precipitation and temperature change in the future, and how will these changes affect tree crop regions?

The analysis covers all of Ghana, with a specific focus on southern Ghana (Coastal region, deciduous forest, rainforest, and transitional region), where tree crops are predominantly cultivated

Historical Spatial and Temporal Structures of Hydrological and Climate Variables: West African Moonson an rainfall patterns

- **Rainfall patterns in Ghana** are primarily influenced by **the West African Monsoon system**, which dictates the seasonal timing and intensity of precipitation. This monsoon is driven by the **temperature contrast between the warm Sahara Desert and the cooler Atlantic Ocean,** creating a pressure gradient that pushes moist air northward. The Intertropical Convergence Zone (ITCZ) plays a critical role, as its seasonal migration facilitates the convergence of trade winds, leading to upward air movement and rainfall.

- **In southern Ghana, monsoon rains typically begin in March, peaking between May and June**, as noted by Owusu and Waylen (2009). The **West African climate system exhibits variability across multiple time** scales—ranging from intraseasonal to interdecadal—due to complex **interactions of heat, moisture, and momentum in the atmosphere. Anthropogenic activities,** including greenhouse gas emissions (e.g., CO_2), deforestation also contribute to these climate variations.



Xing, W., Wang, C., Zhang, L. et al. Influences of Central and Eastern Atlantic Niño on the West African and South American summer monsoons. npj Clim Atmos Sci 7, 214 (2024). https://doi.org/10.1038/s41612-024-00762-7

Historical Spatial and Temporal Structures of Hydrological and Climate Variables

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Literature Review

- Numerous studies have examined spatio-temporal variations in rainfall and temperature trends in Ghana. Many rely on station-level data with limited geographical coverage, sparse sampling, and inconsistencies over time. Others utilize reanalysis datasets, which provide broader spatial and temporal coverage but require validation against ground observations, often hindered by a lack of consistent, long-term rainfall data, particularly in southern Ghana

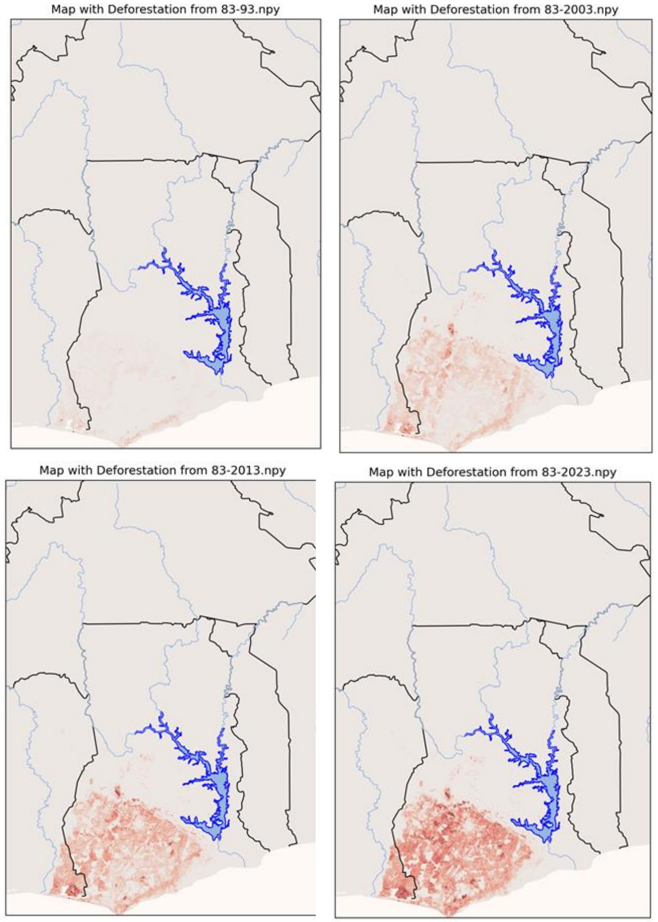
- The literature consistently shows a significant rise in temperatures across Ghana, with the most pronounced warming observed in the cooler southern regions compared to smaller increases in the warmer northern areas. This warming trend disproportionately affects southern Ghana

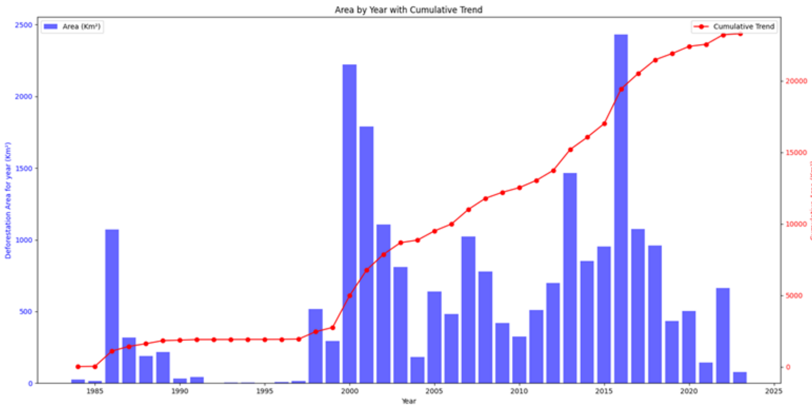
- Rainfall trends show more variability. In northern and central Ghana, annual, seasonal, and extreme rainfall trends are generally significant. In contrast, southern Ghana exhibits highly uncertain rainfall trends, varying by dataset and time period. Studies report these trends as insignificant, declining, or increasing, depending on the authors and methodologies used

Data Analysis

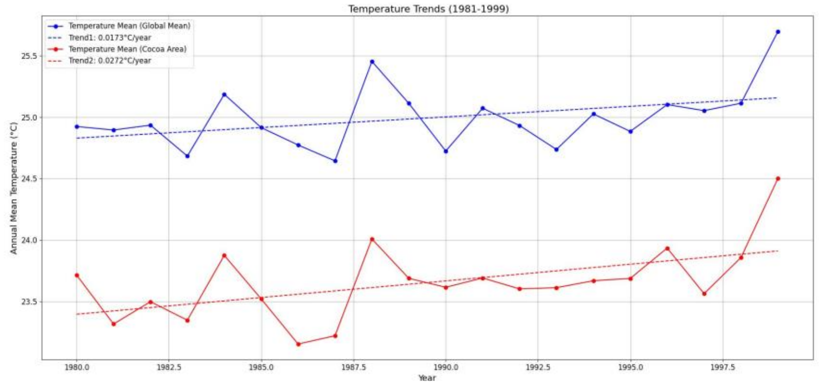
To address these uncertainties, we conducted additional analyses of rainfall and temperature time series using data from meteorological gauges and reanalysis datasets, with a specific focus on Southern and Coastal Ghana.

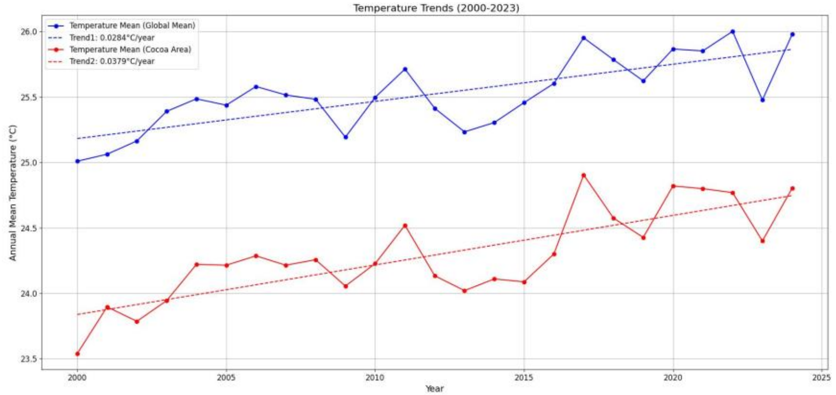
Historical Spatial and Temporal Structures of Hydrological and Climate Variables: Data Analysis Periods





Deforestation rate from 1981 to 2023



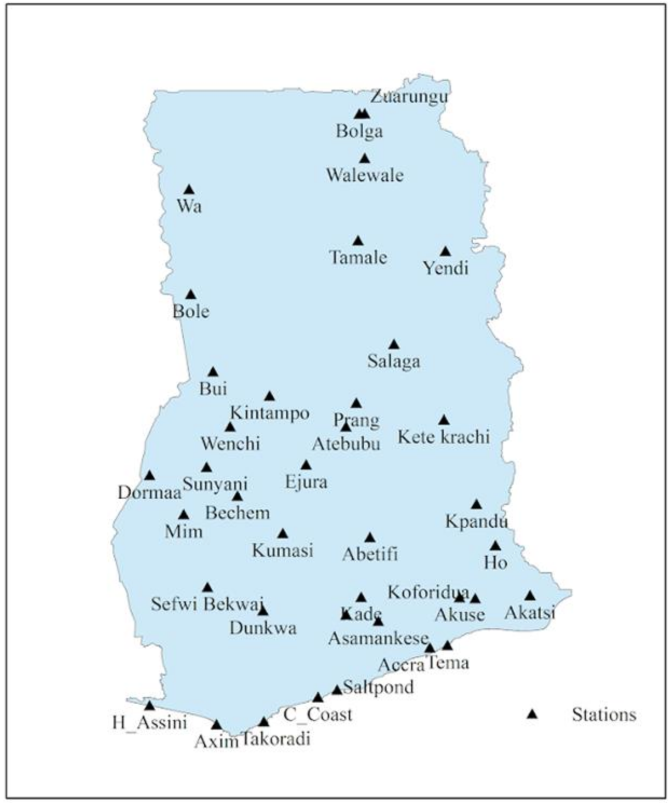


Mean Temperature trends: Entire Ghana (bleu), Sourthern Ghana (red)

A notable shift in the deforestation rate is observed from the year 2000 onward, prompting analyses to focus on two distinct periods: before and after 2000. In Southern Ghana, the second period (2000–2023) shows an increase in the mean temperature rate

https://forobs.jrc.ec.europa.eu/TMF/data
https://cds.climate.copernicus.eu/datasets/reanalysis-era5-single-levels-monthly-means?tab=overview

Historical Spatial and Temporal Structures of Hydrological and Climate Variables: rainfall and temperature collected by meteorological gauges



Spatial maps of ground stations in Ghana

Number	Name	Latitude (°)	Longitude (°)	Variable
1	Abetifi	6.408	-0.448	Pr, Tmax, Tmin
2	Accra	5.366	-0.101	Pr, Tmax, Tmin
3	Akatsi	6.070	0.480	Pr, Tmax, Tmin
4	Akim Oda	5.558	-0.587	Pr, Tmax, Tmin
5	Akuse	6.057	0.0716	Pr, Tmax, Tmin
6	Asamankese	5.520	-0.400	Pr
7	Atebubu	7.450	-0.588	Pr
8	Axim	4.520	-2.140	Pr, Tmax, Tmin
9	Bechem	7.048	-2.018	Pr
10	Bole	9.020	-2.290	Pr, Tmax, Tmin
11	Bolga	10.468	-0.510	Pr
12	Bui	8.170	-2.160	Pr
13	C_Coast	5.078	-1.150	Pr
14	Dormaa	7.168	-2.528	Pr
15	Dunkwa	5.580	-1.470	Pr
16	Ejura	7.230	-1.220	Pr
17	Goaso	6.850	-2.517	Tmax, Tmin
18	H_Assini	5.030	-2.528	Pr
19	Ho	6.360	0.280	Pr, Tmax, Tmin
20	Kade	6.060	-0.500	Pr
21	Kete krachi	7.490	-0.020	Pr, Tmax, Tmin
22	Kintampo	8.030	-1.432	Pr
23	Koforidua	6.052	0.162	Pr
24	Kpandu	7.010	0.170	Pr
25	Kumasi	6.430	-1.355	Pr, Tmax, Tmin
26	Mim	6.540	-2.330	Pr
27	Navrongo	-1.083	10.536	Tmax, Tmin
28	Prang	7.588	-0.528	Pr
29	Salaga	8.330	-0.310	Pr
30	Saltpond	5.120	-1.040	Pr, Tmax, Tmin
31	Sefwi Bekwai	6.118	-2.193	Pr, Tmax, Tmin
32	Sunyani	7.216	-2.198	Pr, Tmax, Tmin
33	Takoradi	4.536	-1.465	Pr, Tmax, Tmin
34	Tamale	9.332	-0.517	Pr, Tmax, Tmin
35	Tema	5.379	0.001	Pr, Tmax, Tmin
36	Wa	10.030	-2.300	Pr, Tmax, Tmin
37	Walewale	10.210	-0.480	Pr
38	Wenchi	7.450	-2.060	Pr, Tmax, Tmin
39	Yendi	9.270	-0.010	Pr, Tmax, Tmin
40	Zuarungu	10.470	-0.480	Pr

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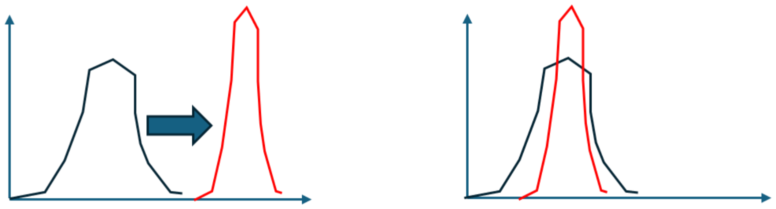
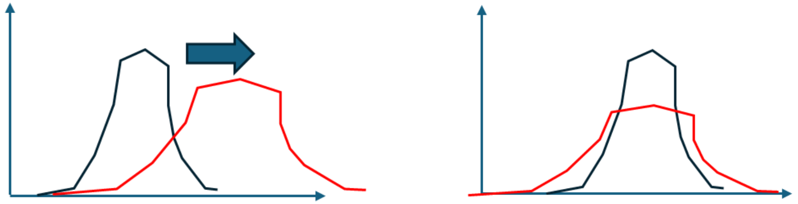
Historical Spatial and Temporal Structures of Hydrological and Climate Variables: annual precipitation



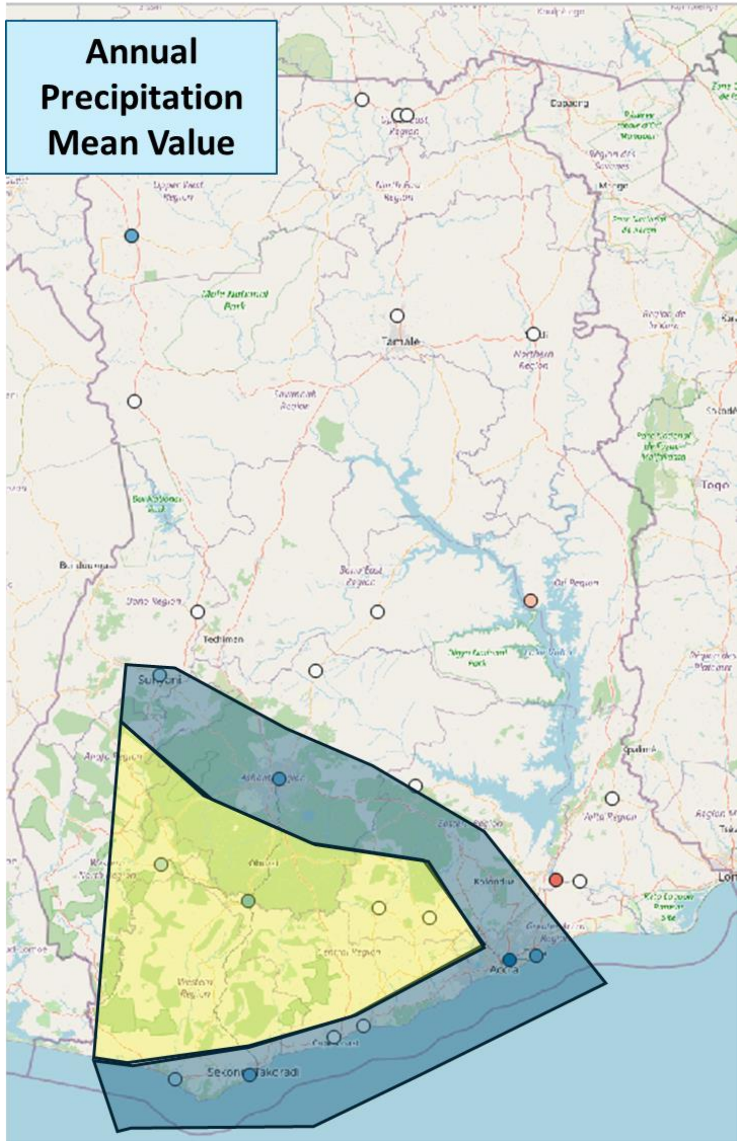
In the blue region, the probability distributions for 2001-2023 present higher (or not so different with respect to 1981-2000) mean values, and the shapes are less dispersed

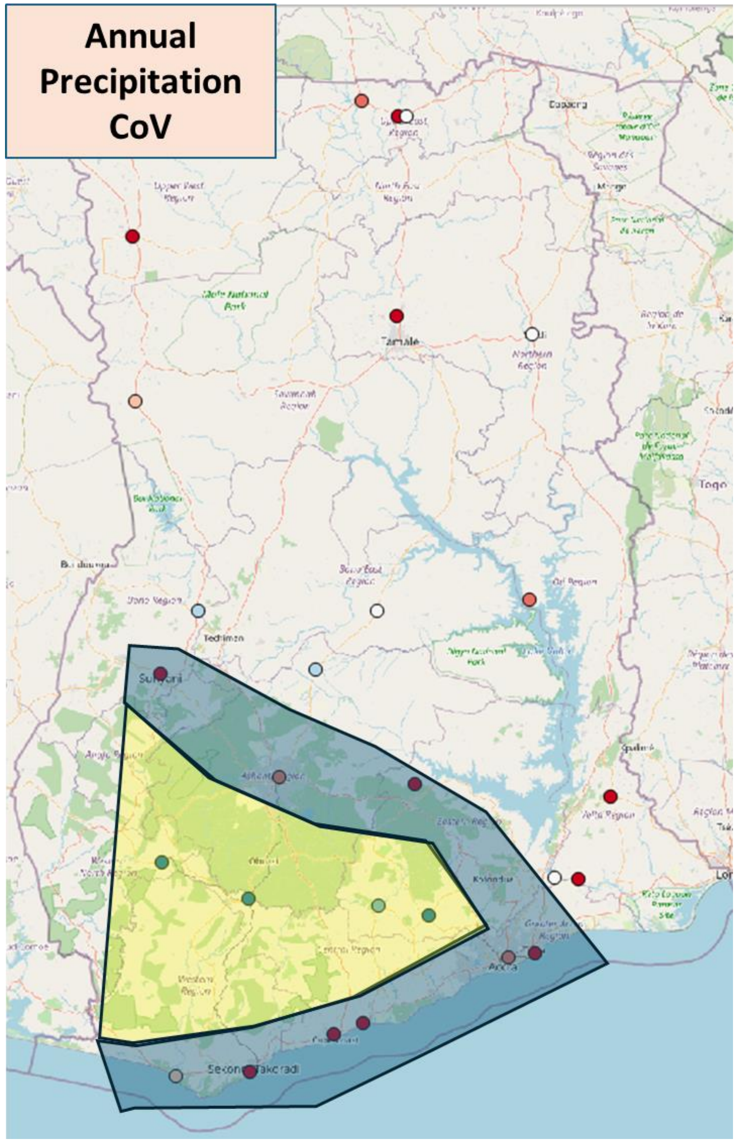


In the yellow region, the probability distributions for 2001-2023 present higher (or not so different with respect to 1981-2000) mean values, and the shapes are more dispersed

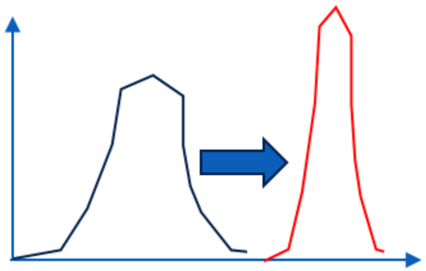
Cov= Stardard deviation/mean

- < -20.0 %
- -20.0 % - -10.0 %
- -10.0 % - -5.0 %
- -5.0 % - 5.0 %
- 5.0 % - 10.0 %
- 10.0 % - 20.0 %
- > 20%



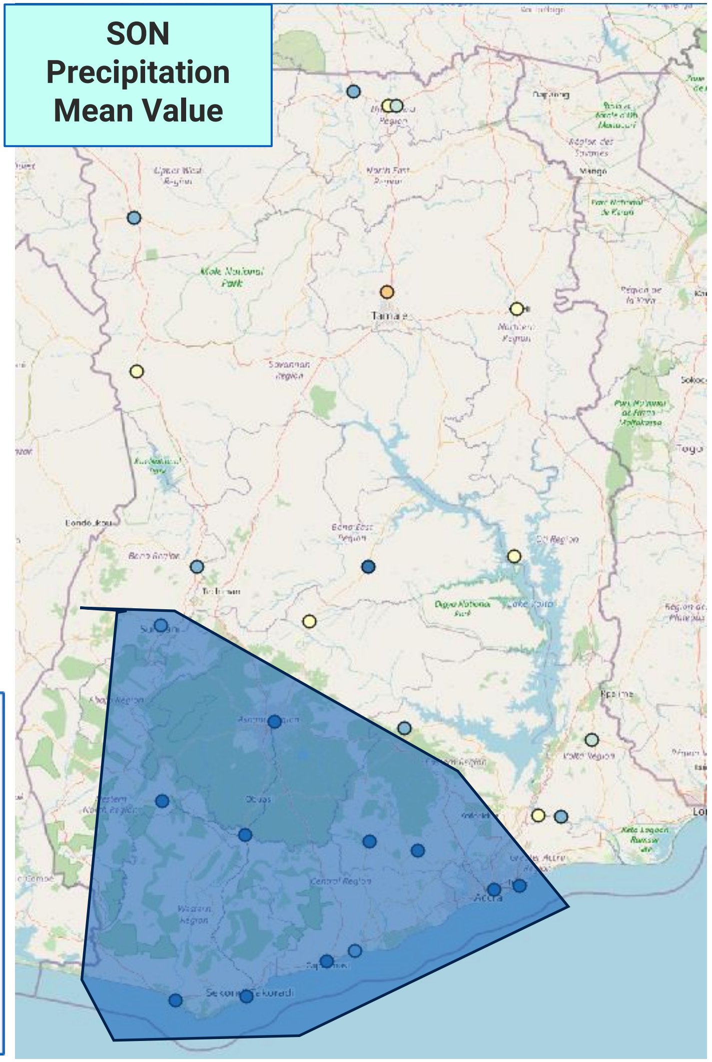


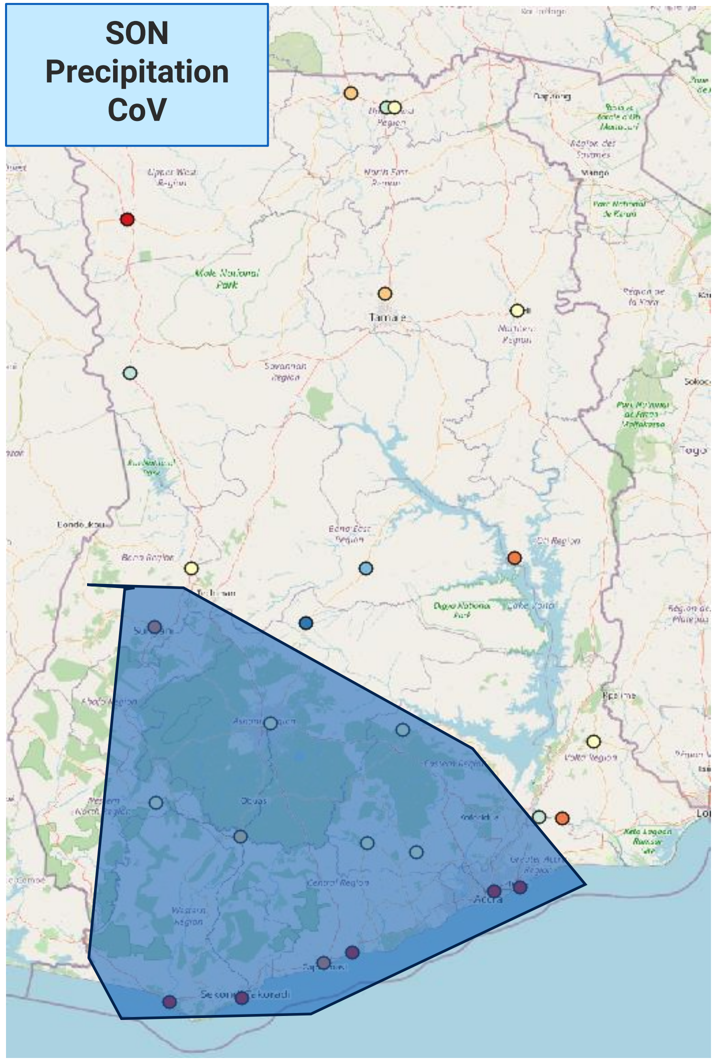
Historical Spatial and Temporal Structures of Hydrological and Climate Variables: Seasonal Precipitation



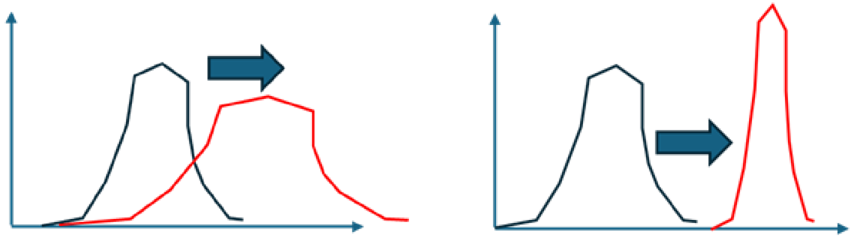
In the blue region, the probability distributions for 2001-2023 present higher mean values, and the shapes are less dispersed

< -20.0 %
-20.0 % - -10.0 %
-10.0 % - -5.0 %
-5.0 % - 5.0 %
5.0 % - 10.0 %
10.0 % - 20.0 %
> 20%

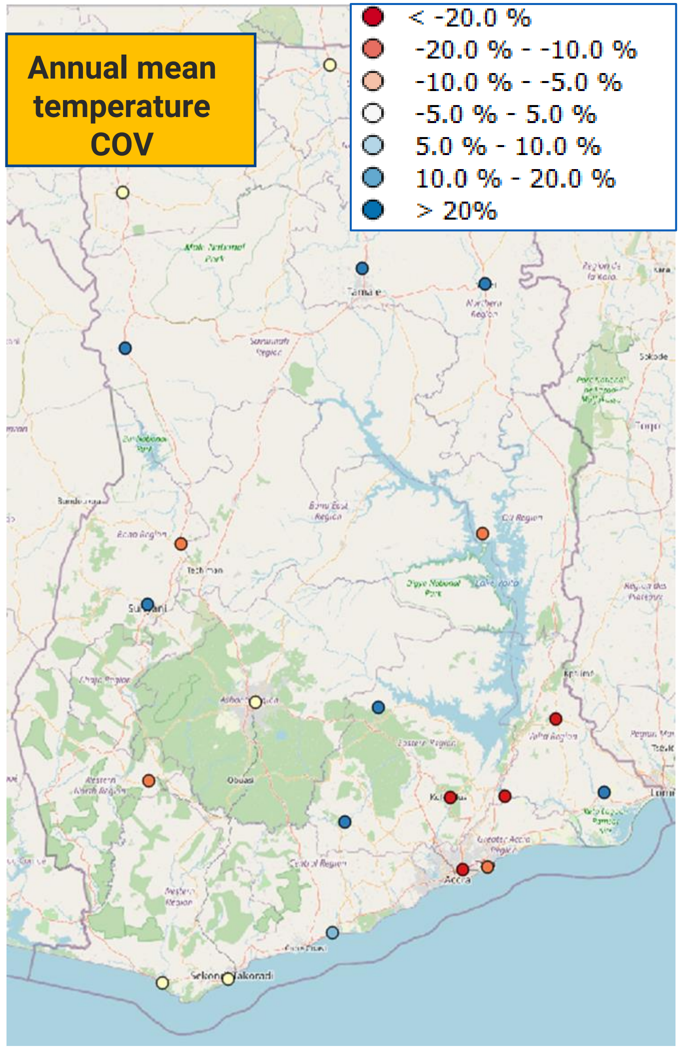




Historical Spatial and Temporal Structures of Hydrological and Climate Variables: Annual Mean Temperature

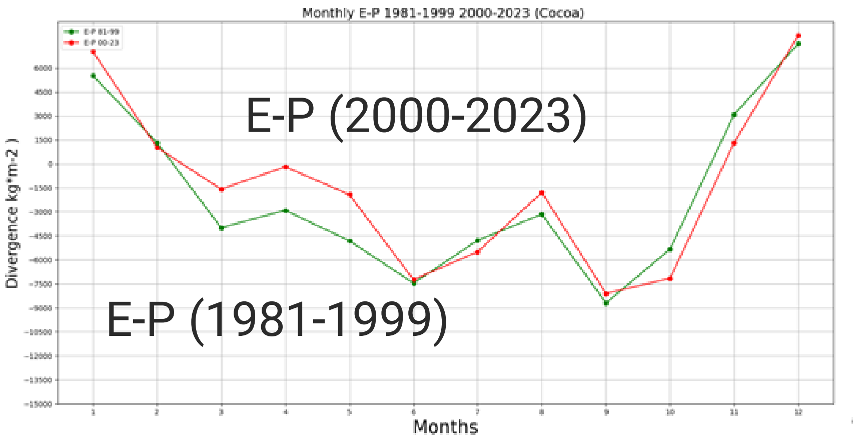


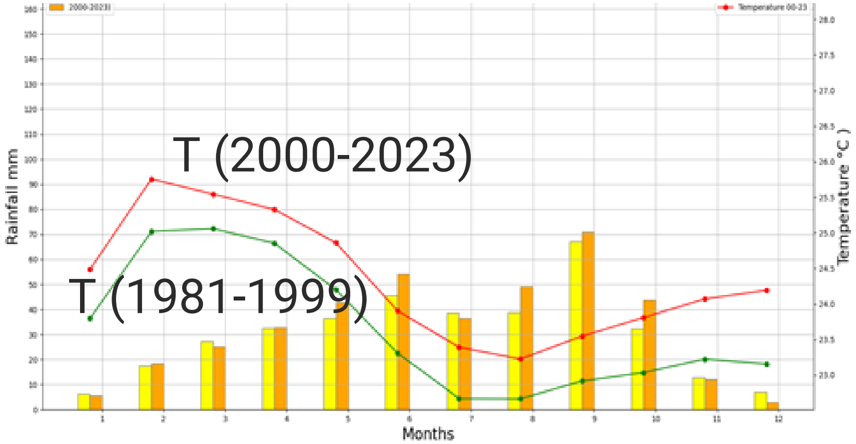
In the whole region, the probability distributions for 2001-2023 present higher mean values, and the shapes are more or less dispersed without any specific geographic connection



Historical Spatial and Temporal Structures of Hydrological and Climate Variables: Seasonal trends in monthly P,T, E-P,NDVI

For cocoa region we observe a significant change in E-P in MAMJ season mainly due to the increase of temperature.



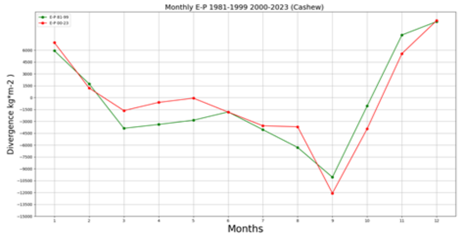


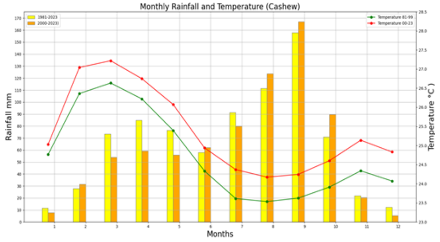
Significant changes are observed in NDVI (Normalized Difference Vegetation Index) specially during the MAMJ season

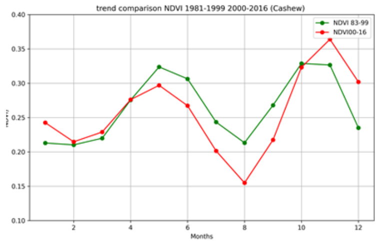
Divergence (E-P) –ERA5T – hourly– spatial resolution 0.25° X 0.25° https://cds.climate.copernicus.eu/datasets/reanalysis-era5-single-levels?tab=download
Temperature/precipitation –ERA5T – monthly–spatial resolution 0.25° X 0.25° https://cds.climate.copernicus.eu/datasets/reanalysis-era5-single-levels-monthly-means?tab=overview
NDVI NOA monthly, spatial resolution 0.05° https://www.ncei.noaa.gov/products/climate-data-records/normalized-difference-vegetation-index

Historical Spatial and Temporal Structures of Hydrological and Climate Variables: Seasonal trends in monthly P,T, E-P,NDVI

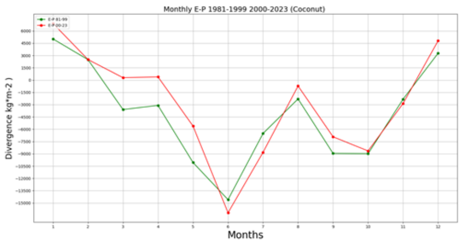
Cashew

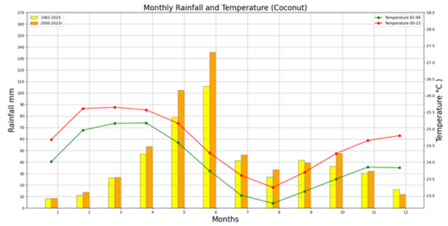


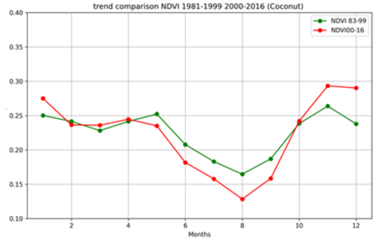




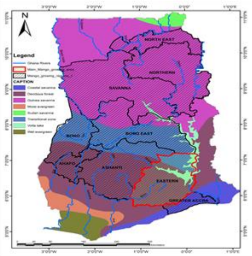
Coconut

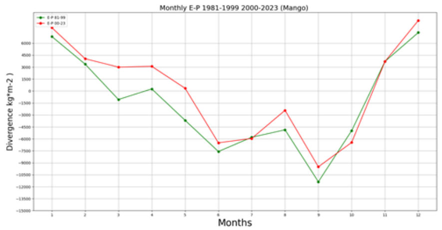


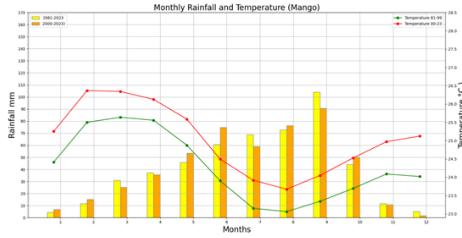


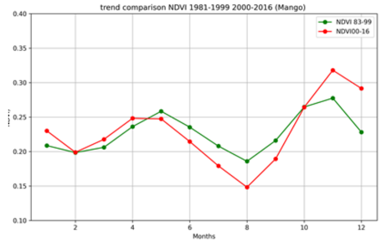


Mango

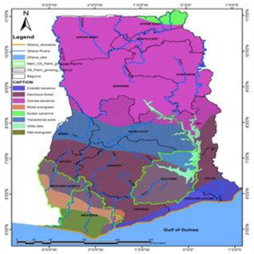


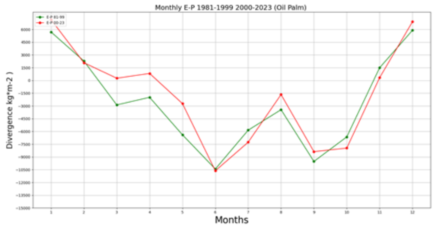


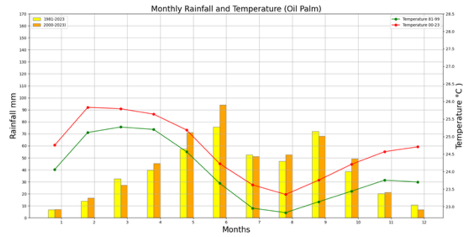


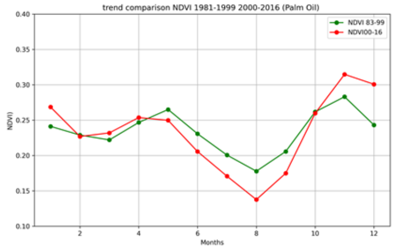


Oil palm









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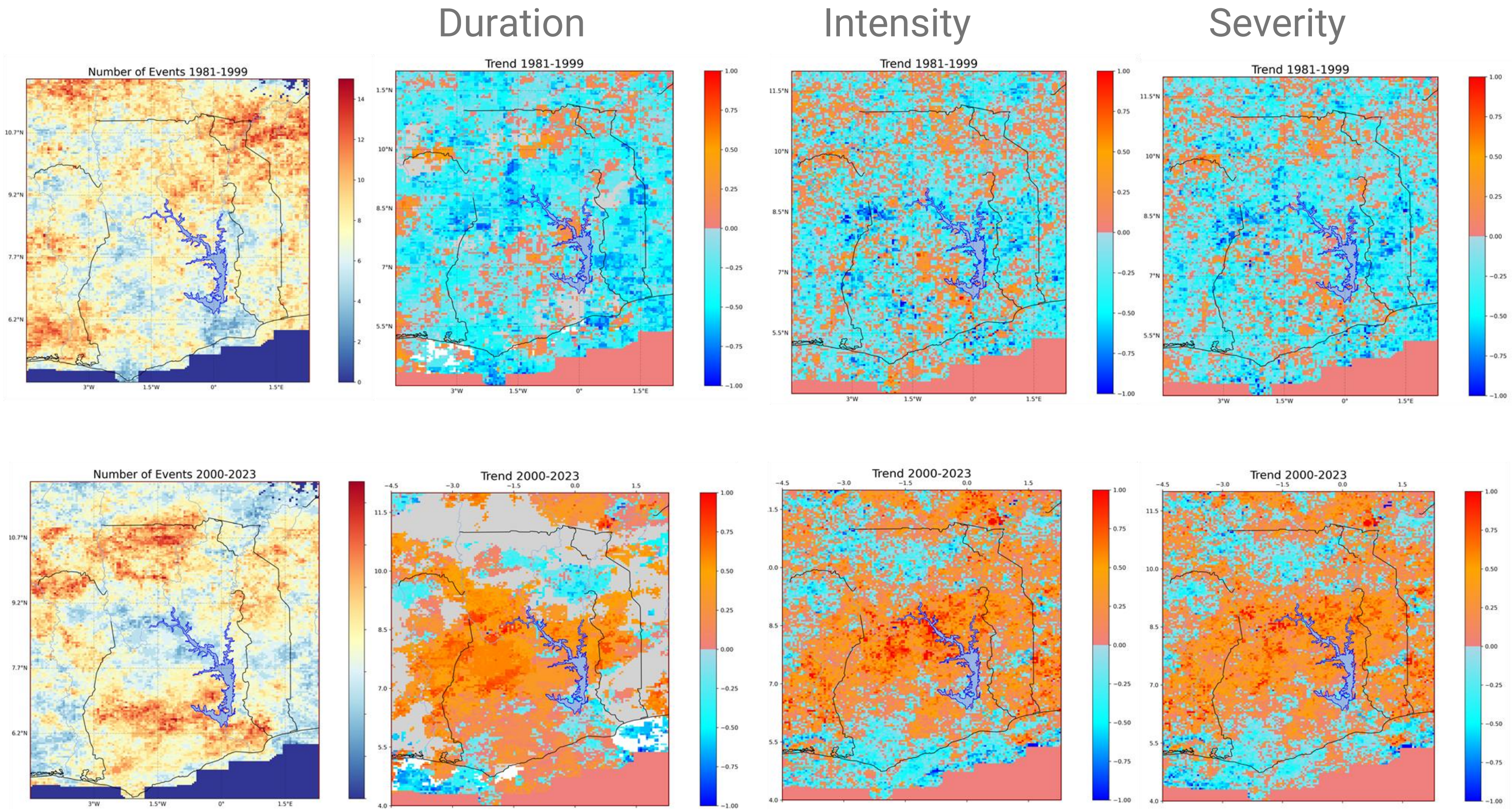
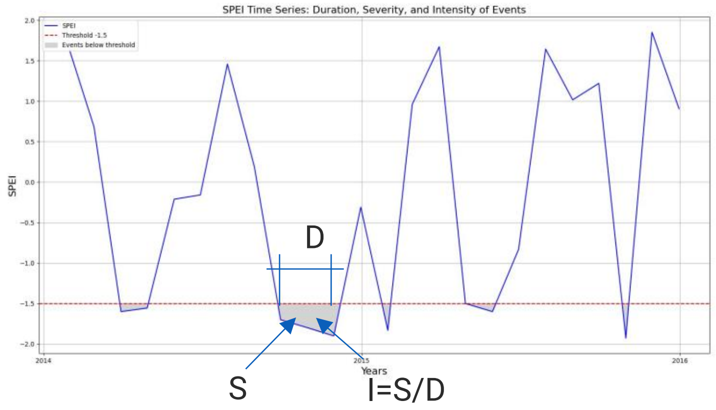
Severity and Occurrence of Droughts in Ghana: Comparison SPEI 3<-1.5 indices between 2000-2023 and 1981-1999





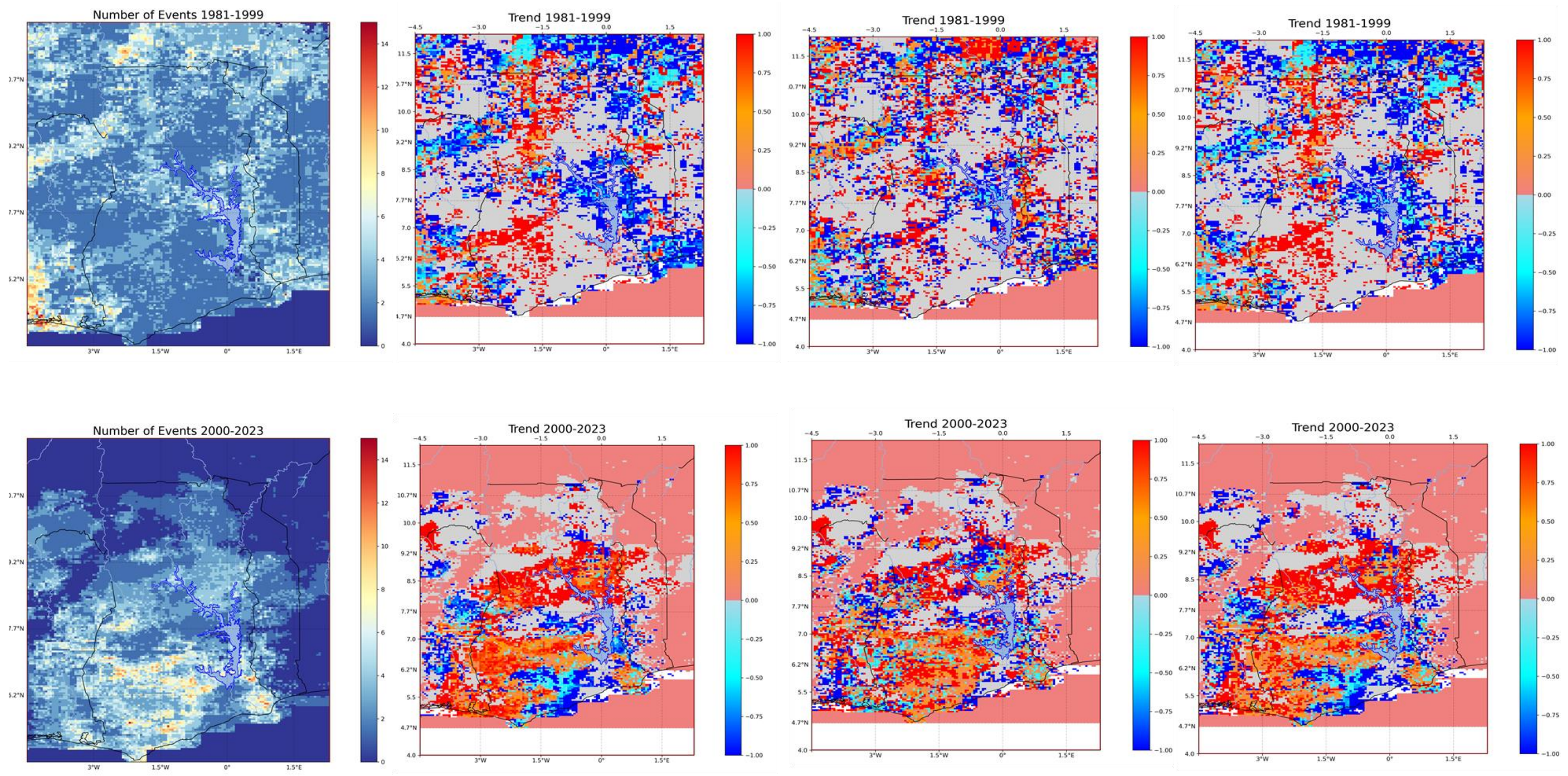
The Mann-Kendall Test is used to determine whether time series of the drought indices SPEI3,6,12,24 have a significant monotonic upward or downward trend

During the second period, in most of Southern Ghana, SPEI 3 droughts become more frequent, severe, intense, and prolonged

https://data.ceda.ac.uk/neodc/spei_africa/data

Severity and Occurrence of Droughts in Ghana: Comparison SPEI 24<-1.5 indices between 2000-2023 and 1981-1999

Duration | Intensity | Severity



During the second period, in most of Southern Ghana, SPEI 24<-1.5 (representative of hydrological droughts) shows that droughts are more frequent, severe, intense, and prolonged.

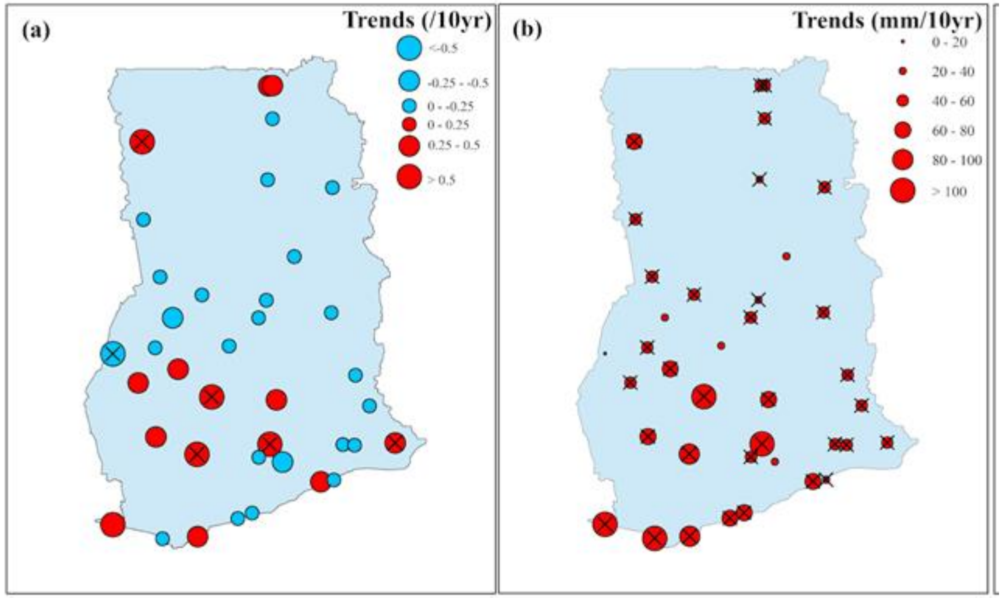
Drought index trends show a significant spatial coherence in southern Ghana

https://data.ceda.ac.uk/neodc/spei_africa/data

Severity and Occurrence of Droughts in Sourthern Ghana: Comparison SPEI 3,6,12,24<-1.5 indices between 2000-2023 and 1981-1999

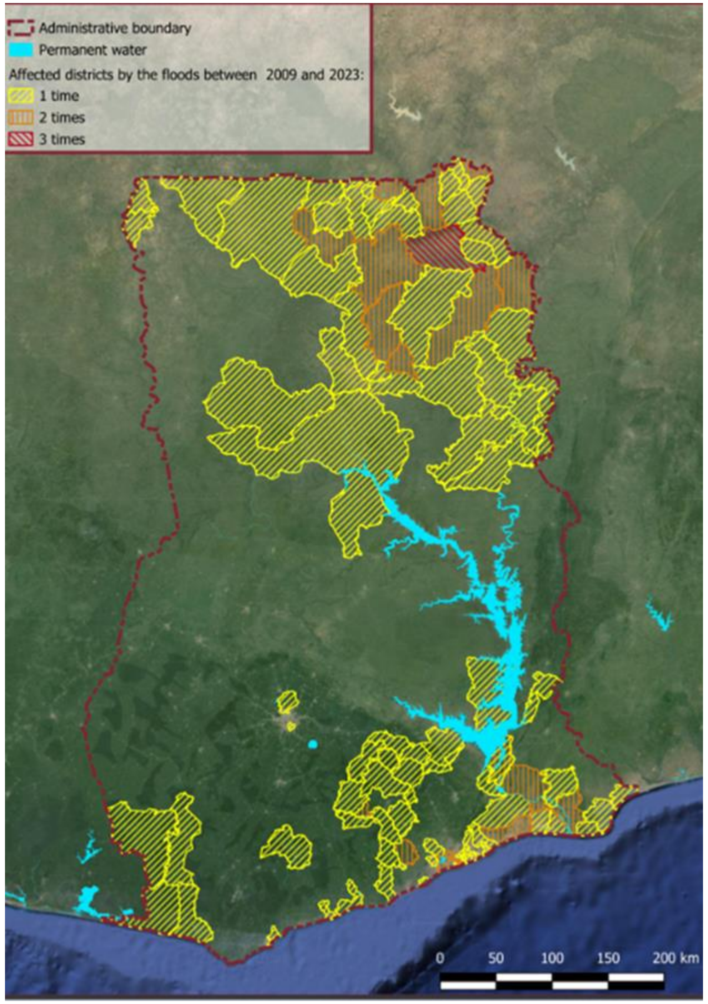
Drought Index	SPEI 3		Spei 6		Spei 12		Spei 24	
	1981-1999	2000-2023	1981-1999	2000-2023	1981-1999	2000-2023	1981-1999	2000-2023
Numbers of events	↑		↑		↑		↑	
Duration	o	+	o	+	-	+	o	+
Intensity	o	+	o	+	+	+	o	+
Severity	o	+	o	+	-	+	o	+

Severity and Occurrence of Floods and Flood Prone Zones



Change trends for total frequency and amount of annual extreme precipitation from 1981 to 2023. Red (blue) circles indicate positive (negative) trends, circle with x icons indicate the trends at 95% significance level.

Extreme precipitation refers to daily rainfall amount exceeding the 95th percentile of wet days



Flood Affected Districts
https://global-flood-database.cloudtostreet.ai/

Future Projections of Climate variables

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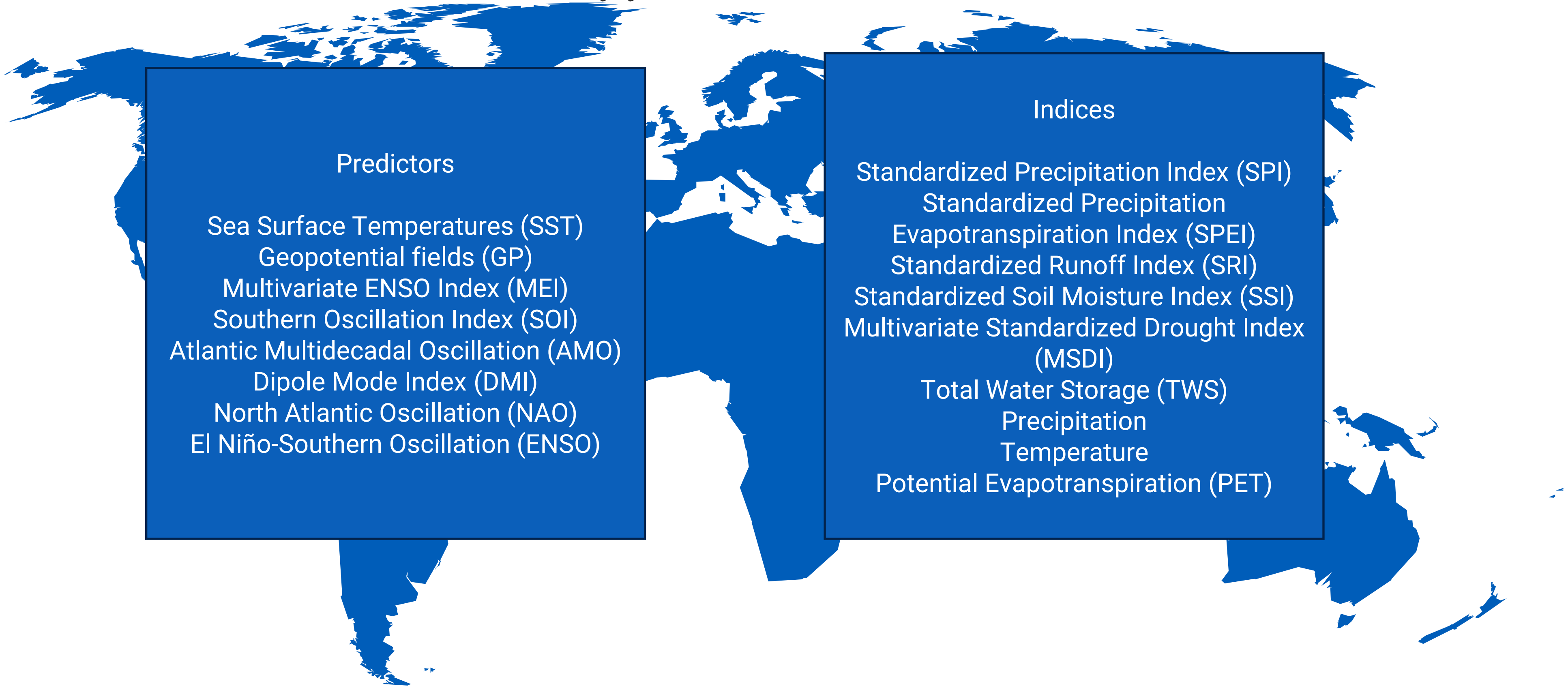
The analysis highlighted the increasing severity and frequency of droughts and extreme heavy precipitation in Ghana. These trends are driven by complex interactions between large-scale climate indices, regional climatic conditions, and local changes in land cover and use (e.g., deforestation). There is a clear latitudinal and altitudinal dependence across the region. In Southern Ghana, significant increasing trends in droughts and extreme rainfall events have been observed over the last twenty years.



Predictors

Sea Surface Temperatures (SST)
Geopotential fields (GP)
Multivariate ENSO Index (MEI)
Southern Oscillation Index (SOI)
Atlantic Multidecadal Oscillation (AMO)
Dipole Mode Index (DMI)
North Atlantic Oscillation (NAO)
El Niño-Southern Oscillation (ENSO)

Indices

Standardized Precipitation Index (SPI)
Standardized Precipitation Evapotranspiration Index (SPEI)
Standardized Runoff Index (SRI)
Standardized Soil Moisture Index (SSI)
Multivariate Standardized Drought Index (MSDI)
Total Water Storage (TWS)
Precipitation
Temperature
Potential Evapotranspiration (PET)

To carry out future projections, it is essential to establish the link between large-scale atmospheric circulation features and local spatiotemporal temperature and precipitation characteristics.

Future Projections of Climate variables: methodology

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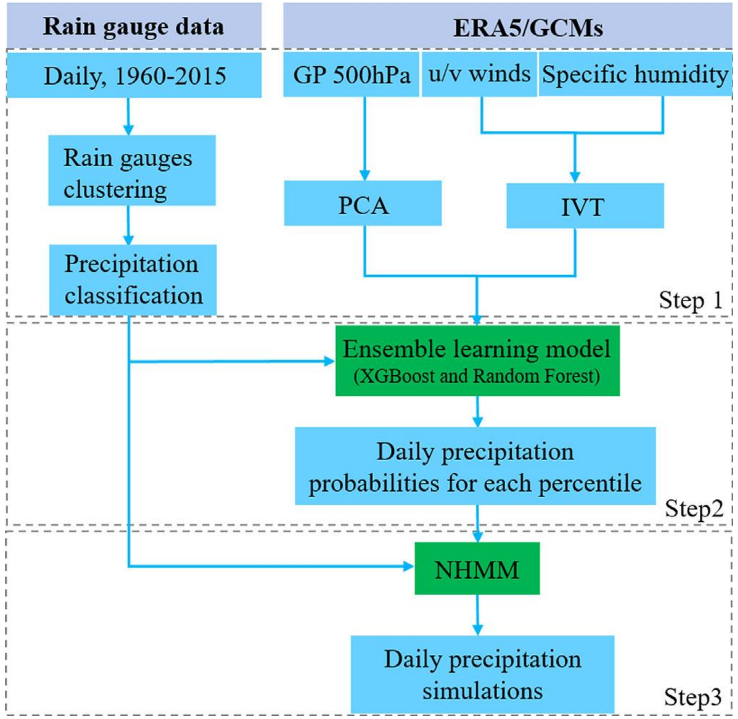
Event synchronization for the identification of atmospherical predictors linking large scale atmospheric circulation to rainfall extreme

Originally introduced by Quiroga et al. (2002) and later adapted by Conticello et al. (2018), this method quantifies the degree of synchronization and the time delay between two binary time series.

In Ghana project, this approach was applied to evaluate the simultaneities of extreme rainfall occurrences among the various rain gauges deployed throughout Ghana and the driving atmospheric patterns as represented by IVT and geopotential 500 hPa fields

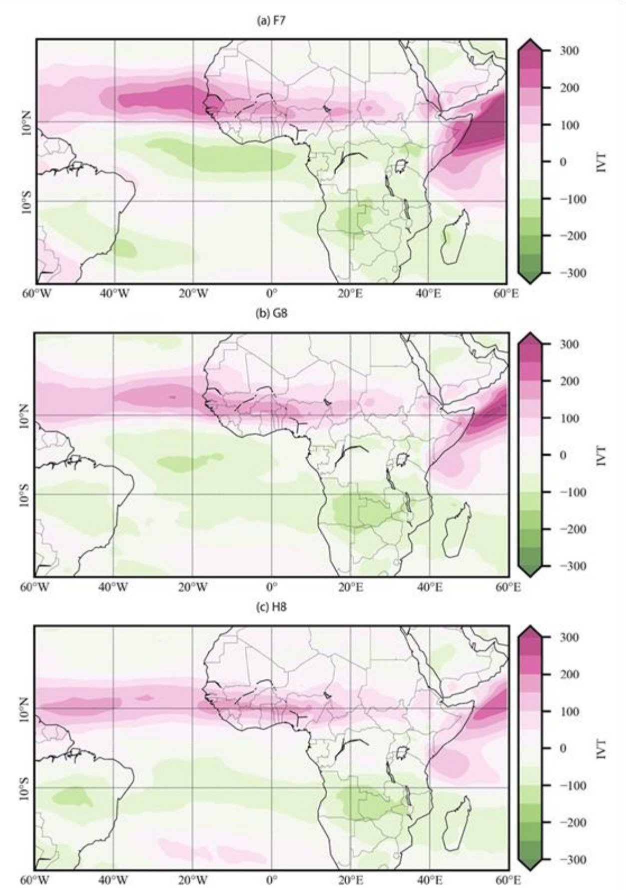
Downscaling model for high spatial resolution projections of rainfall and temperature features under different future climate scenarios (SSPs) from the CMIP6

A novel approach was used called "Ensemble-NHMM" that combines stacked ensemble learning and nonhomogeneous hidden Markov models for precipitation downscaling.

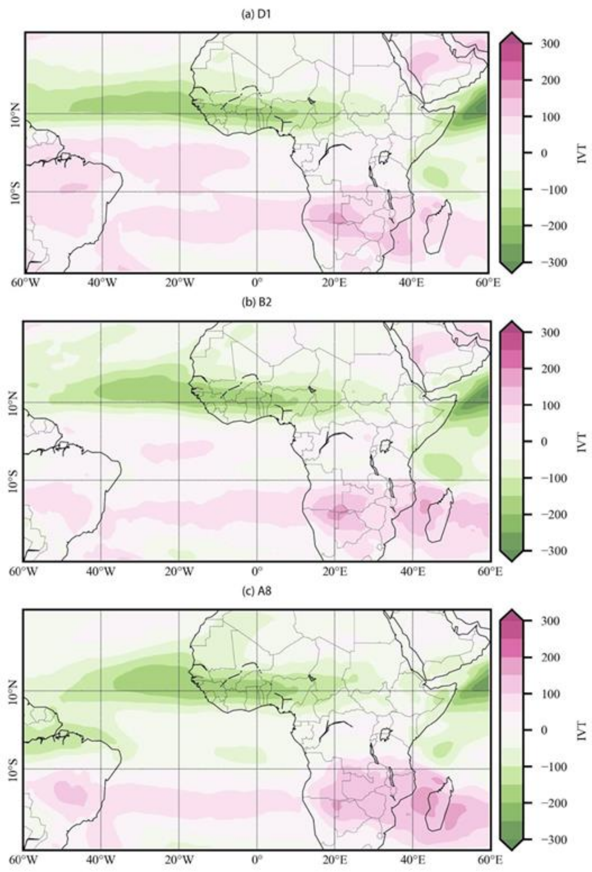


MSWX-Past and ERA5 dataset were used: Multi-Source Weather (MSWX) is an operational, high-resolution meteorological product (3-hourly 0.1°) that synthesizes data from diverse sources to provide comprehensive global coverage of weather variables

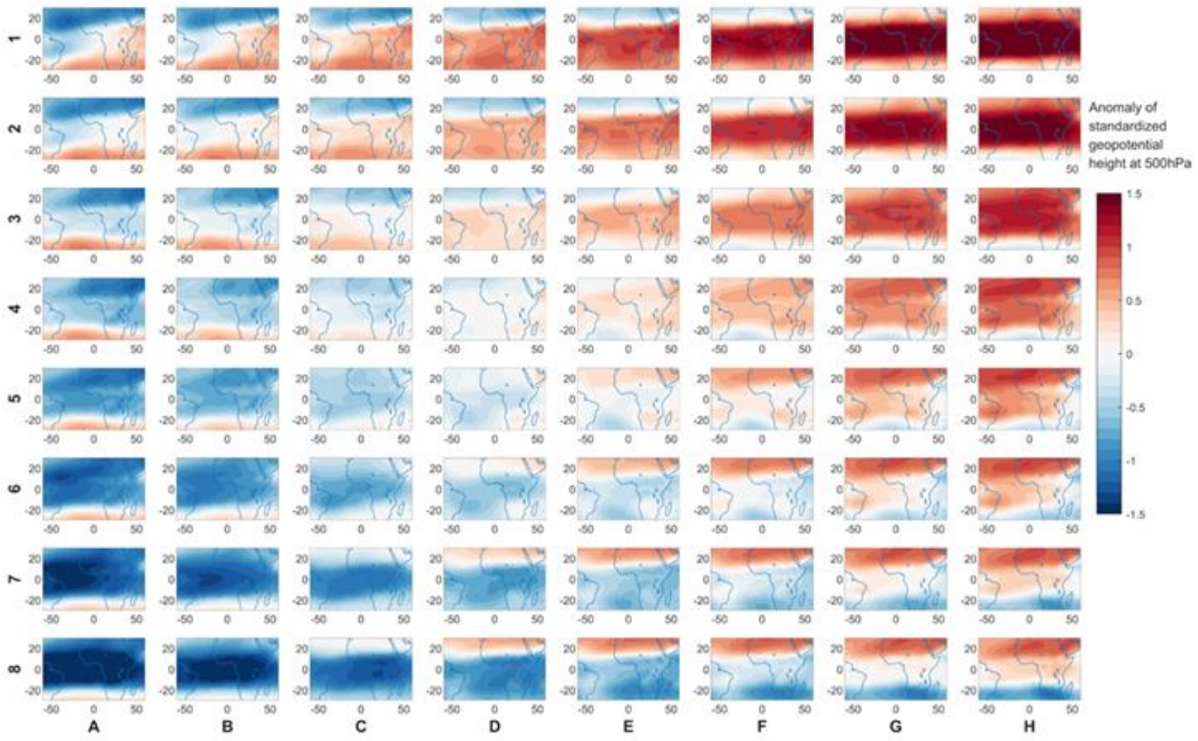
Link between large scale atmospheric circulation features and local spatial temporal temperature and precipitation characteristics



Anomalous fields (unit: kg m-1 s-1) of IVT for the circulation patterns driving **heavy/extreme precipitation**



Anomalous fields (unit: kg m-1 s-1) of IVT for the circulation patterns driving **droughts**

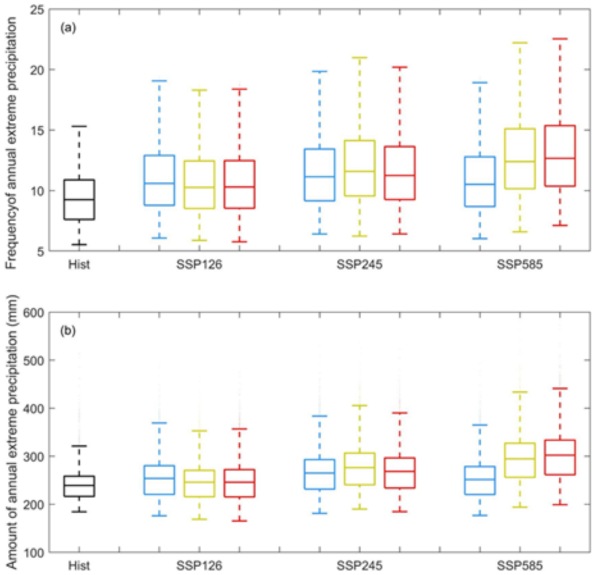


The propagation path and temporal variations in atmospheric moisture transport play a critical role in shaping the spatial distribution and intensity of extreme precipitation events across different regions of Ghana. This highlights the importance of accurately capturing and representing these synoptic-scale features in atmospheric models to enhance the prediction and understanding of extreme rainfall patterns in this climatically sensitive region.

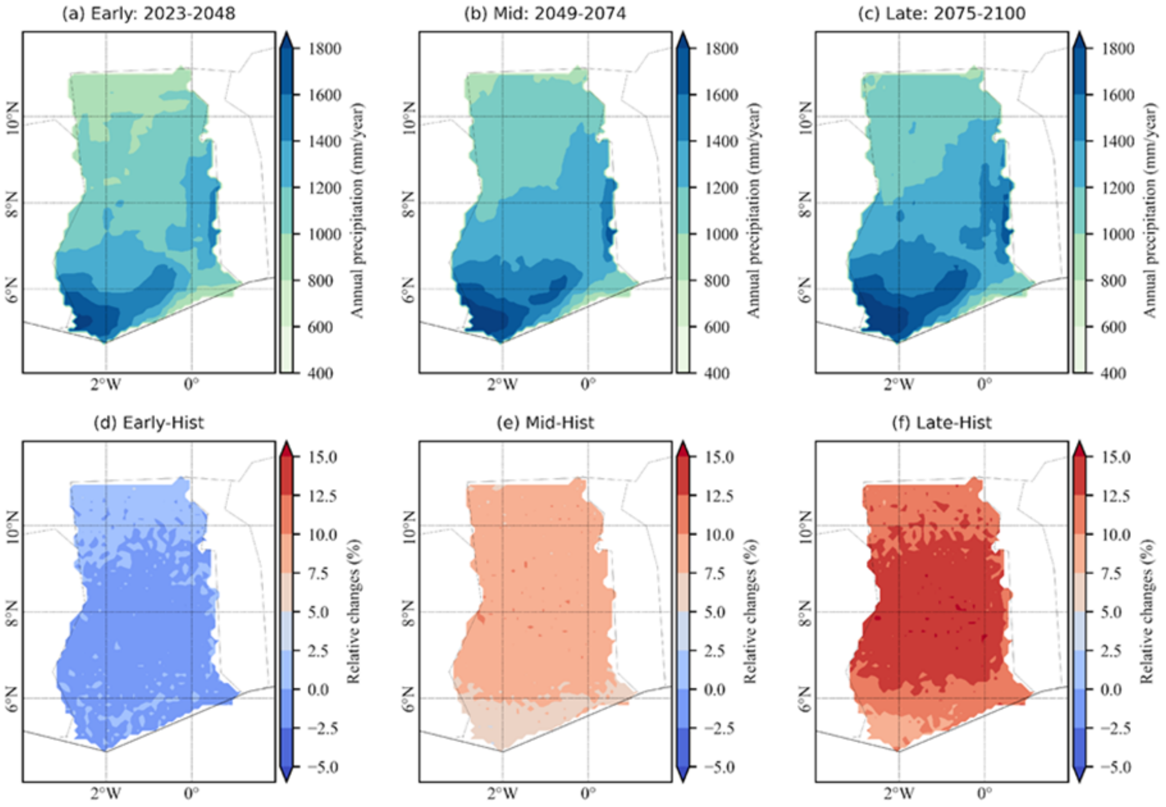
Future Projections of Change in Climate Extremes: Precipitation

Indicator	Early: 2023-2048 (SSP126/245/585)	Mid: 2049-2074 (SSP126/245/585)	Late: 2075-2100 (SSP126/245/585)
Annual precipitation	1.39/-0.33/-1.74	4.56/8.31/5.28	1.08/12.49/13.55
Extreme precipitation frequency	17.64/14.12/14.18	22.94/28.13/24.29	16.93/36.21/37.79
Extreme precipitation amount	5.86/2.66/2.79	10.71/15.35/11.88	5.23/22.72/25.11

Relative changes (%) in the projected annual precipitation and extreme precipitation in the early, mid, and late 21st centuries under three emission scenario compared with the historical period 1990–2015



Boxplots of the frequency and amount of annual extreme precipitation for historical and future projections during three sub periods (blue: early-, yellow: mid-, and red: late-21st century) under different warming scenarios.



Maps of annual precipitation and relative changes (%) of the projected mean annual precipitation amount in the early, mid, and late 21st centuries under SSP245 emission scenarios compared with the historical period 1989–2014.

Future Projections of Change in Climate Extremes: Temperature

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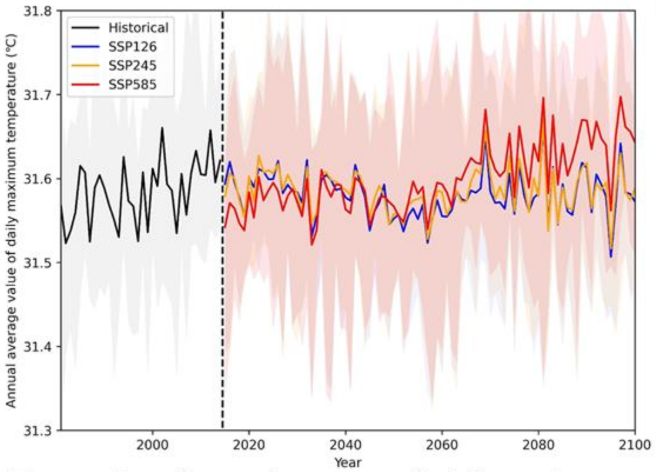
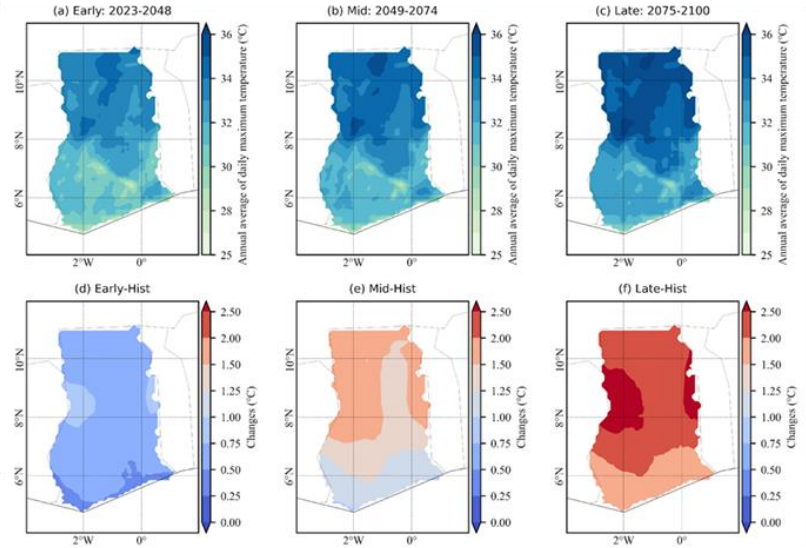
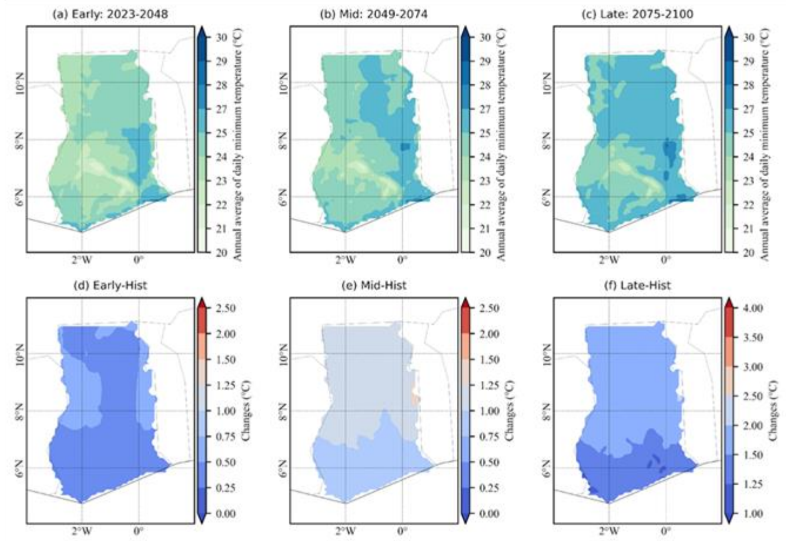


Time series of annual average of daily maximum temperature over Ghana during the historical period and future projections under SSP126, SSP245, and SSP585 scenarios. Shaded areas represent the likely range of downscaled temperature estimates.



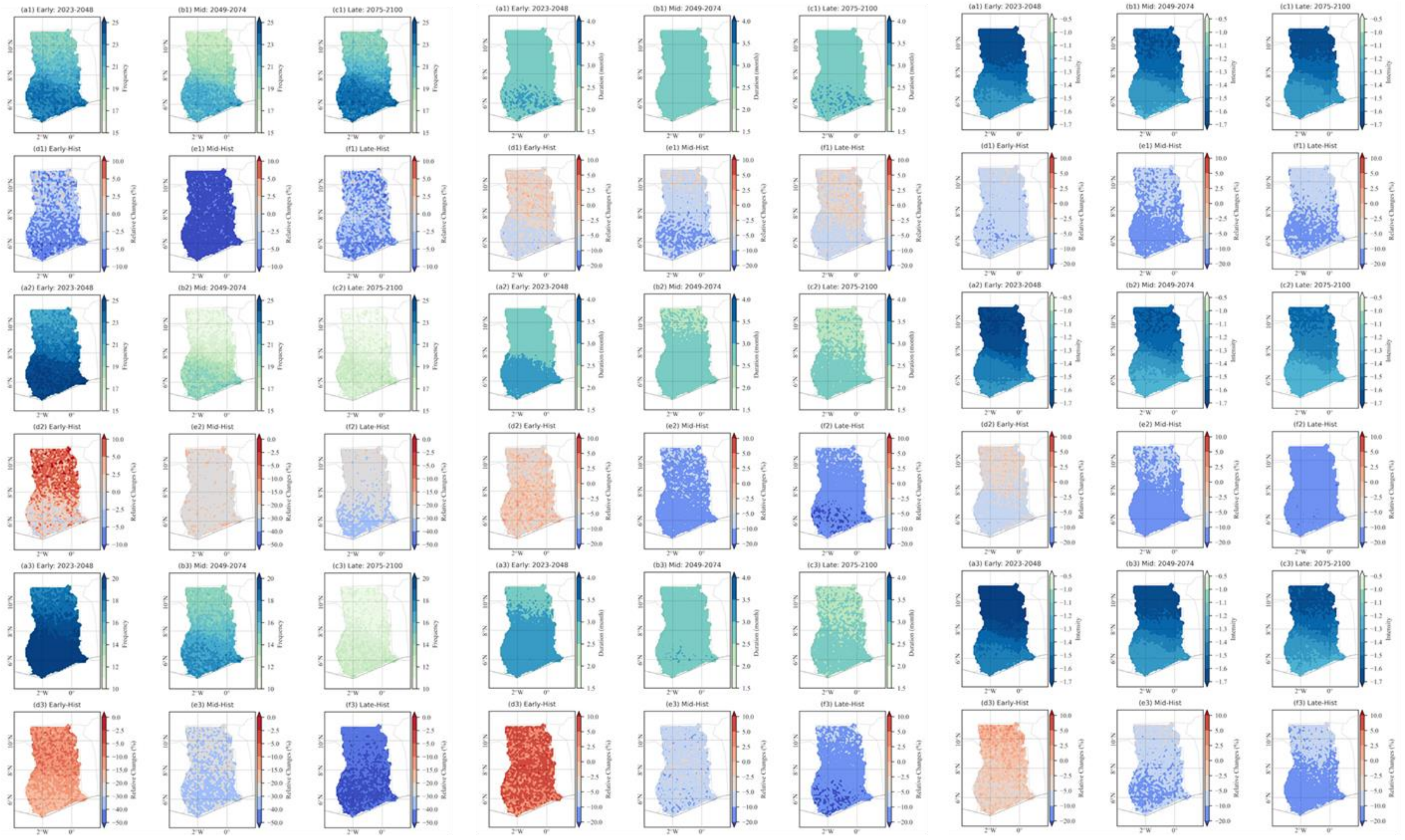
Maps of annual average of daily maximum temperature and changes in the projected daily maximum temperature in the early, mid, and late 21st centuries under SSP245 emission scenarios compared with the historical period 1989–2014



Maps of annual average of daily minimum temperature and changes in the projected daily maximum temperature in the early, mid, and late 21st centuries under SSP245 emission scenarios compared with the historical period 1989–2014

- Consistent warming trend is expected to manifest uniformly across all months
- Central regions of Ghana are projected to experience a more pronounced increase in temperatures
- Minimum temperature changes across Ghana align closely with the patterns observed in the maximum temperature projections

Future Projections of Change in Climate Extremes: Droughts

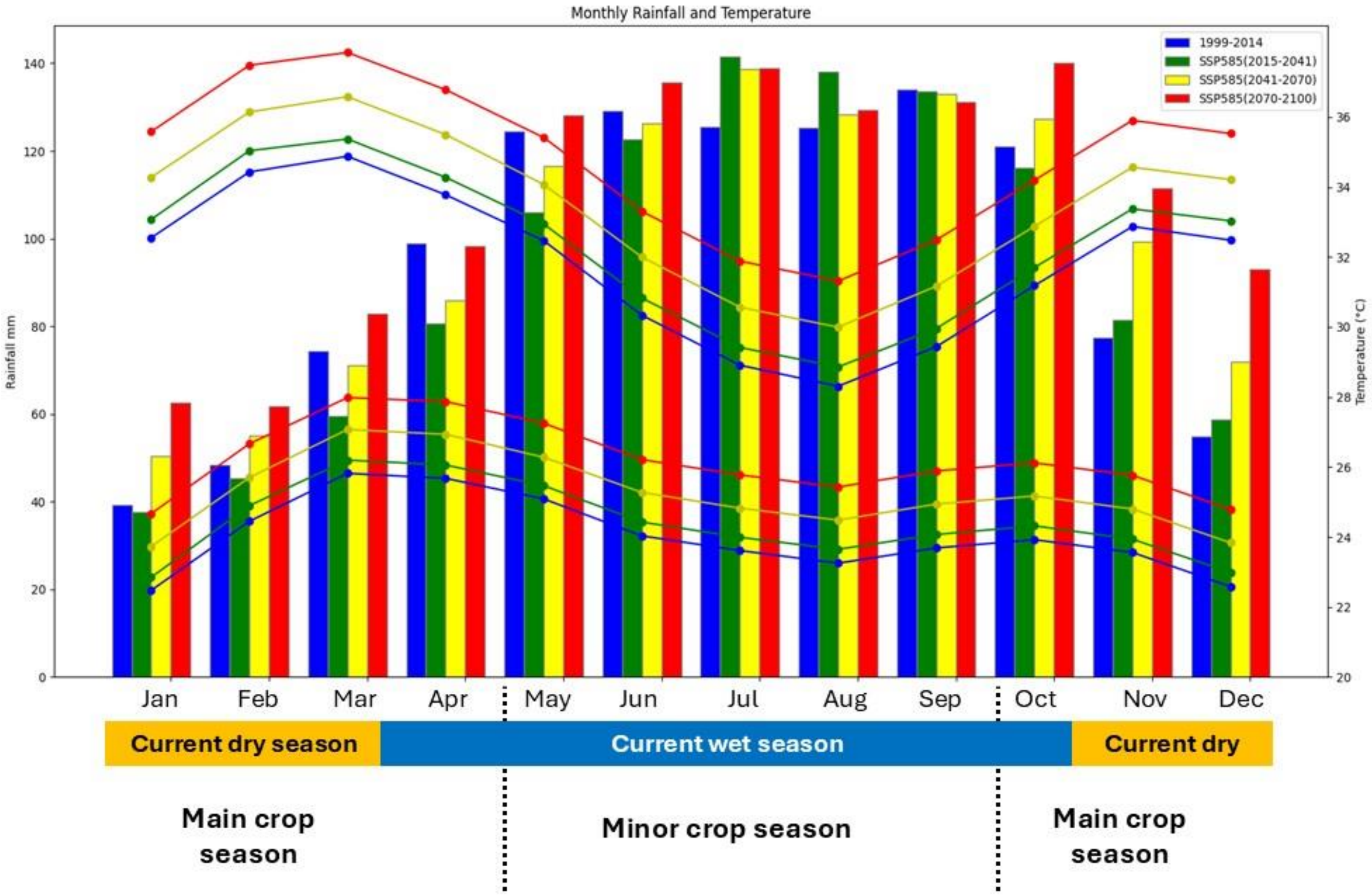


Frequency Duration Intensity

- Increase in drought severity in the early 21st century (2020-2050) under a specific emissions scenario (SSP 245)
- In northern Ghana, drought frequency is likely to increase by a projected 7% compared to the historical period

Impact of future climate change on tree crop regions

Cocoa (*Theobroma cacao* L., 1753)

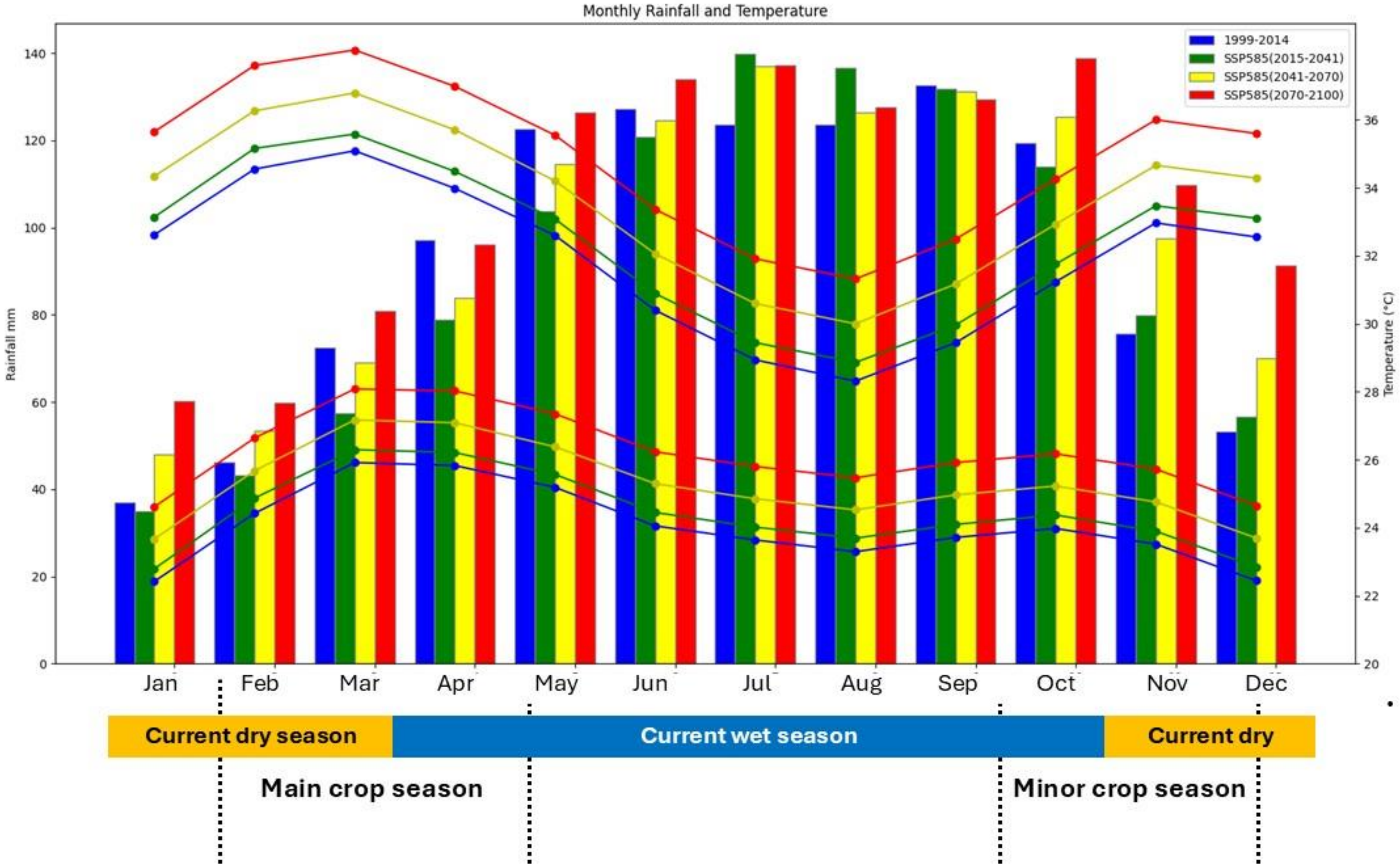


- Shade has positive effects on CO_2 absorption and distribution in the leaves (Opoku Mensah et al., 2024)
- Precipitation should be in the range 1000 – 2500 mm*y^{-1} (Ameyaw et al., 2018).
- The optimal range for photosynthesis coincided with the daily average environmental temperature of 31–33 °C (Opoku Mensah et al., 2024)

Cocoa trees require a **warm climate**. While temperatures lower than 15 °C have a direct impact on yields, high temperatures might start a fruit thinning mechanism, ultimately leading to yield loss. Precipitations should be in the range of **1300 to 2800 mm y^{-1}**; three consecutive months with precipitation lower than 100 mm (in total) have been reported to increase tree mortality.

Impact of future climate change on tree crop regions

Oil Palm (*Elaeis guineensis*)



Temperature should be in the range 18 °C – 37 °C (Rhebergen et al., 2016)

Oil palm grows best in areas with evenly distributed rainfall of 2000-2,500 mm/yr with no month with less than 100 mm rainfall (Zutah et al., 2024)

- Total chlorophyll and total carotenoids in water stressed plants dropped significantly, causing diminishing of photosynthesis (Cha-um et al., 2013).

Rainfall is considered to be the most critical factor in Oil Palm yield. The highest yield is reached at 1500 mm y^{-1}, with no marked dry season. Rainfall conditions for palm oil production are met in Eastern, Central, Western, Ashanti and Brong Ahafo Regions, and in Volta region. The soil is another key factor in palm oil production. It shall be well drained, made by clay loam, sandy clay loam, loamy sand with a 0-5 % slope and depth > 120 cm

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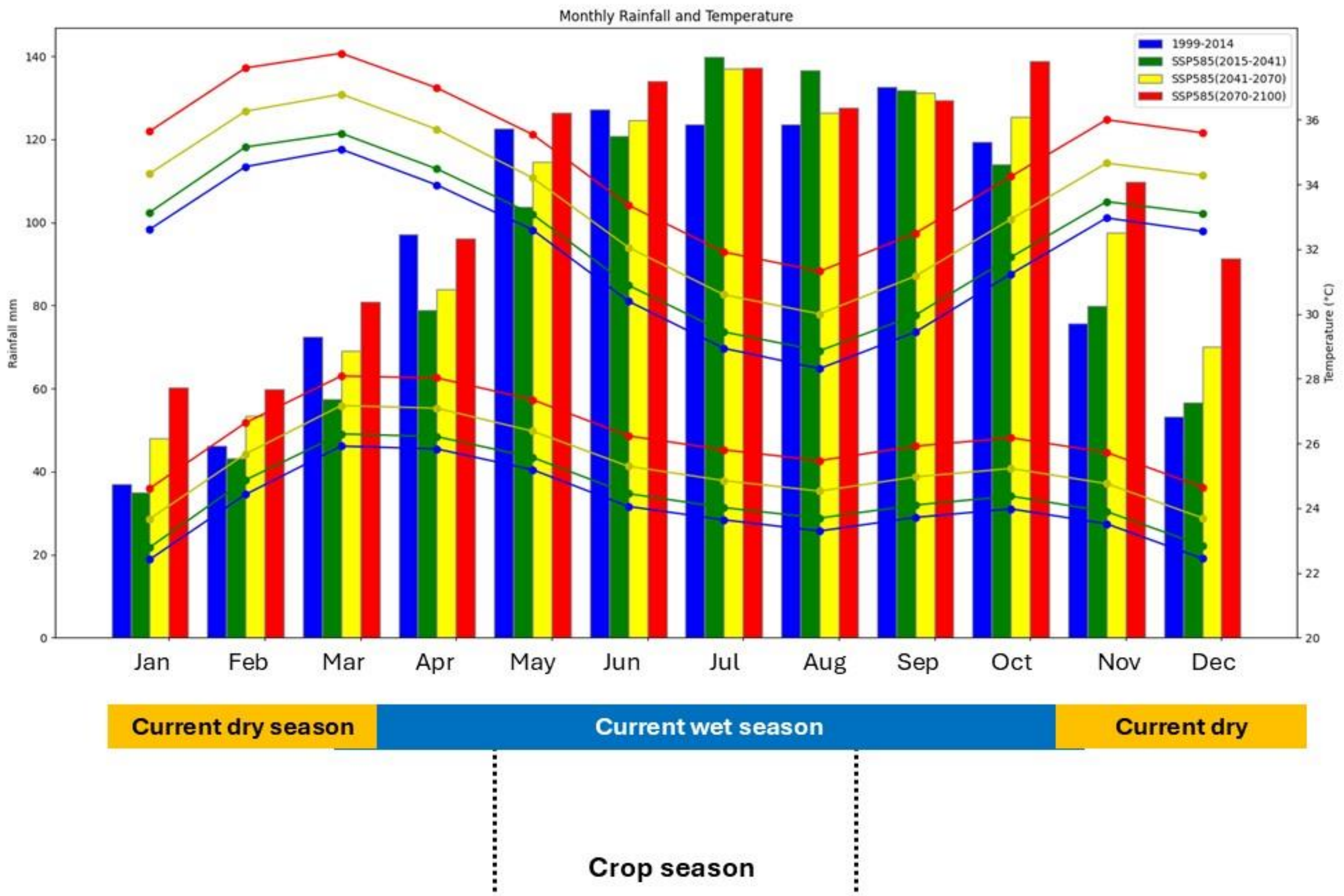
Impact of future climate change on tree crop regions

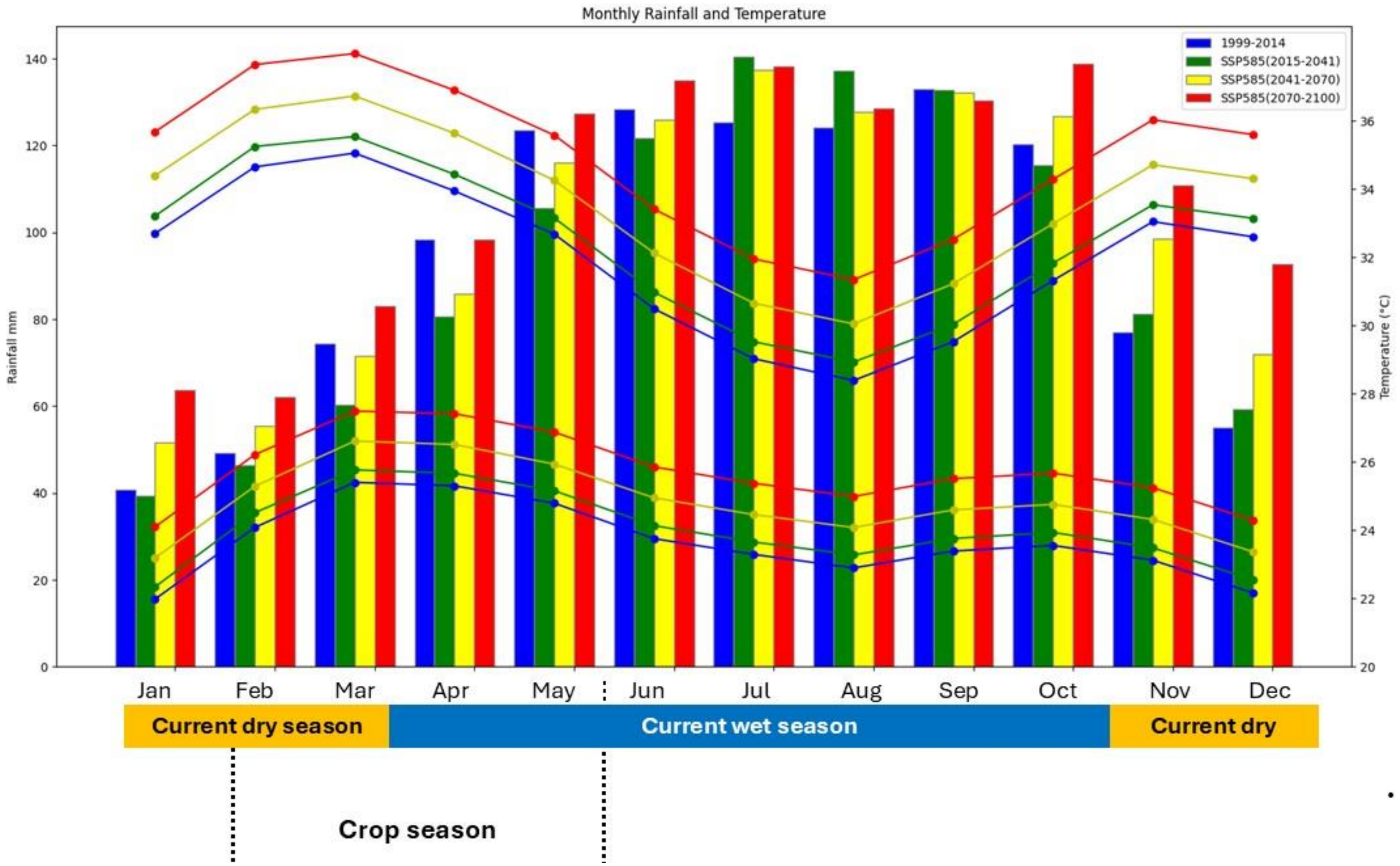
Mango (*Mangifera indica*)



- Optimal temperature is 24-30 °C (GAEZ Data Portal)
- Optimal precipitation is in the range 600 – 1500 mm y^{-1} (GAEZ Data Portal)

Impact of future climate change on tree crop regions

Cashew (*Anacardium occidentale*)



Low water levels could lead to stomatal closure, which in turn limits the capacity of CO_2 assimilation (Bezerra et al., 2008)

Optimal precipitation is between 1000 and 2000 mm $*y^{-1}$ (Dedzoe et al., 2001).

- The optimal temperature range is 24–28 °C (K.B Hettar et al., 2017)

Cashew (*Anacardium occidentale)* is mostly found in the Brong Ahafo and the Northern region. It is considered to be a drought resistant tree crop, with optimal rainfall between 1000 mm y^{-1} and 2000 mm y^{-1} and a dry period of 4–6 months. Cashew grows on a wide variety of soils, with a temperature range spanning from 15 °C to 35 °C (Dedzoe et al., 2001).

Impact of future climate change on tree crop regions

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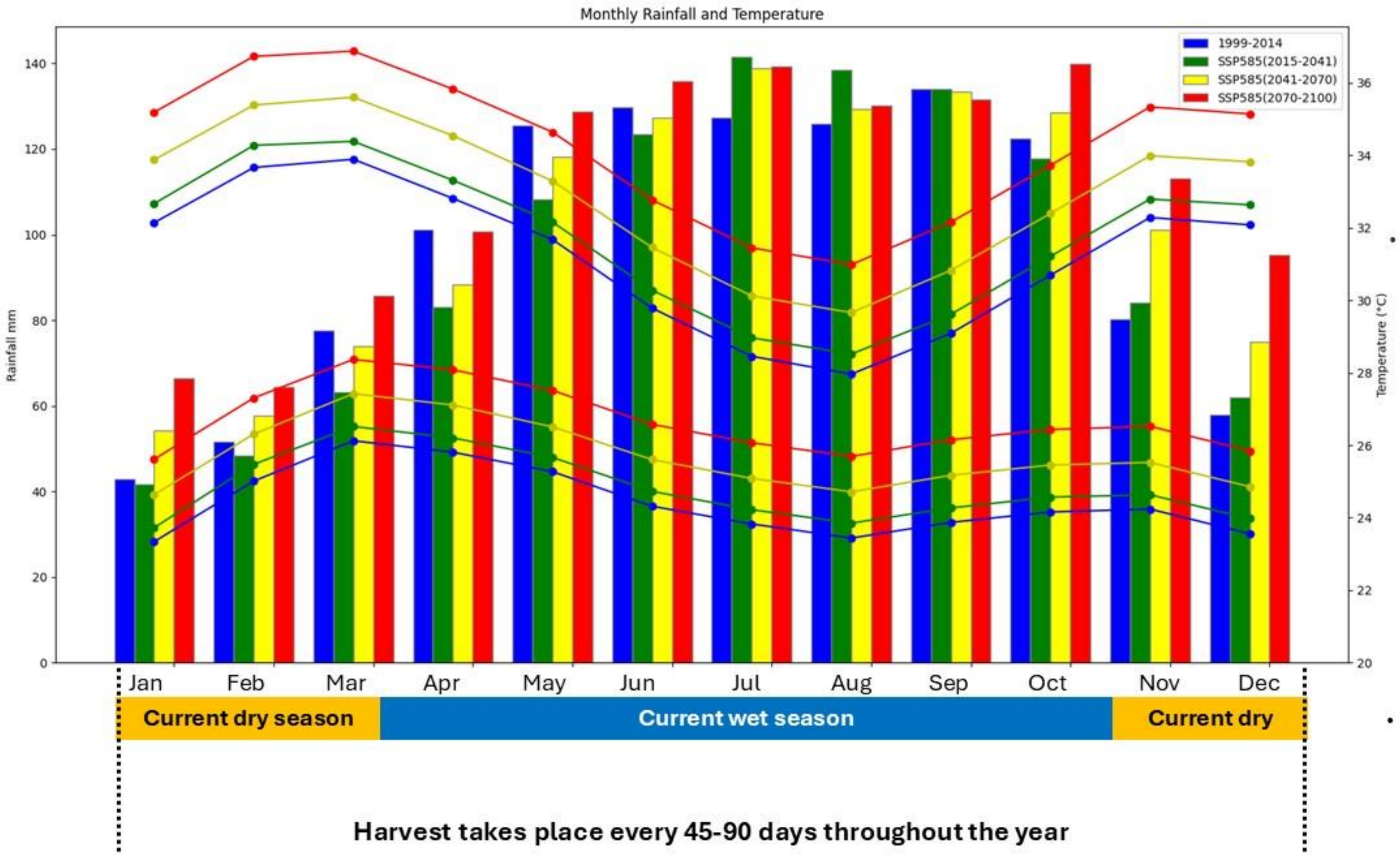
Coconut (*Cocos nucifera*)



- Cultivation of coconuts requires substantial light and the optimal temperature for growth of the palms is 27°C, with extremes of 13°C and 35°C (Gerbaud Pierre, 2011).

Precipitation is distributed evenly throughout the year and totals 1500 to 2500 mm (Gerbaud Pierre , 2011).

- Two weeks in in water-logged soils are enough to kill coconut palms (Chan and Elevitch 2006).

Coconut (*Cocos nucifera L.*) is produced in the Ghanaian coastal belt, mostly in the Western and Central regions (Honlah et al., 2024). Coconut is extremely sensitive to drought, which impacts the yield by occurring at any of the development stages; temperature higher than 32 °C may also cause a decline in productivity (Singh et al., 2013).

Eco physiological response of plants to climate change

- For most of the main tree crops (including cocoa, coconut, cashew and mango) the projected temperatureincrease of the worst-case scenario may exceeds the optimal values for growth. Indeed, temperature above 36°C are likely causing heat stress to generic cultivars of all of the tree crops.

- For almost all tree crops, the worst scenario (modeled by Prof. Cioffi and Collaborators) reports a hugeincrease of precipitations (red bars) during October, November and December compared the 1999 – 2014 time frame. Such a phenomena may alters the length and intensity of the dry season; It could also favor flooding events in soils with limited drainage.

- Even though analyzing the combined effect of the temperature increase and alteration of the precipitation patterns is not trivial, an increase in the evaporative demand of plants is likely going to occur. Therefore, projections suggest that tree crops are probably going to face both water and heat stress.

Conclusion

- Ghana's climate, consistent with observations over the past two decades, is projected to undergo dramatic shifts throughout the 21st century. These changes will be marked by significant alterations in average and extreme precipitation patterns, temperature regimes, and drought characteristics

- The primary drivers include changes in large-scale atmospheric circulation patterns, particularly the West African Monsoon, which influences moisture transport to southern Ghana. Additionally, land-use changes, such as deforestation, exacerbate both local and regional climate impacts

- Under high-emission scenarios (SSP585), Ghana is expected to experience a substantial increase in heavy and extreme precipitation, particularly during the late rainy season (e.g., November) towards the latter half of the century. These changes are likely to heighten risks of flooding, soil erosion, and nutrient leaching

- Simultaneously, both maximum and minimum temperatures are projected to rise significantly, with central Ghana expected to experience the most pronounced warming. By 2100, under SSP585, average daily maximum temperatures could exceed 31.65°C, while minimum temperatures might surpass 23.73°C. Such rising temperatures will impose additional stress on water resources and ecosystems

- Droughts are also anticipated to become more severe, intense, and prolonged, especially in the near term

- These projected changes emphasize the profound impacts of climate change on Ghana's tree crop cultivations, with serious repercussions for the environment, economy, and society.

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Extensive climate hazards and vulnerabilities assessment of the tree crop sub-sector in Ghana

Speaker: Prof. Fabio Attorre
Team Members: Kristina Micalizzi & Francesca Ferroni
Sapienza University of Rome

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Outline

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1
- *Climate Smart Agriculture (overview)*
- *Suggested CSA for Tree Crops in Ghana*

2
- *Agroforestry (Benefit, challenge and system type..)*

3
- *Conservation Agriculture (principles, how-to-do)*

4
- *Integrated Pest Management (core strategies, examples of identification & control)*

5
- *Rain Water Harvesting Systems (typologies, irrigation methods)*

6
- *Tree Crop Fact Sheet for farmer training*

This presentation includes **content directly taken from the informational materials we are developing** for farmers and stakeholders.

The goal of this project is to make climate-smart agriculture (CSA) practices **accessible**, **understandable**, and **practical** for those working with tree crops in Ghana. By using these materials, we aim to equip farmers with the **knowledge** they need to implement sustainable and resilient farming practices.

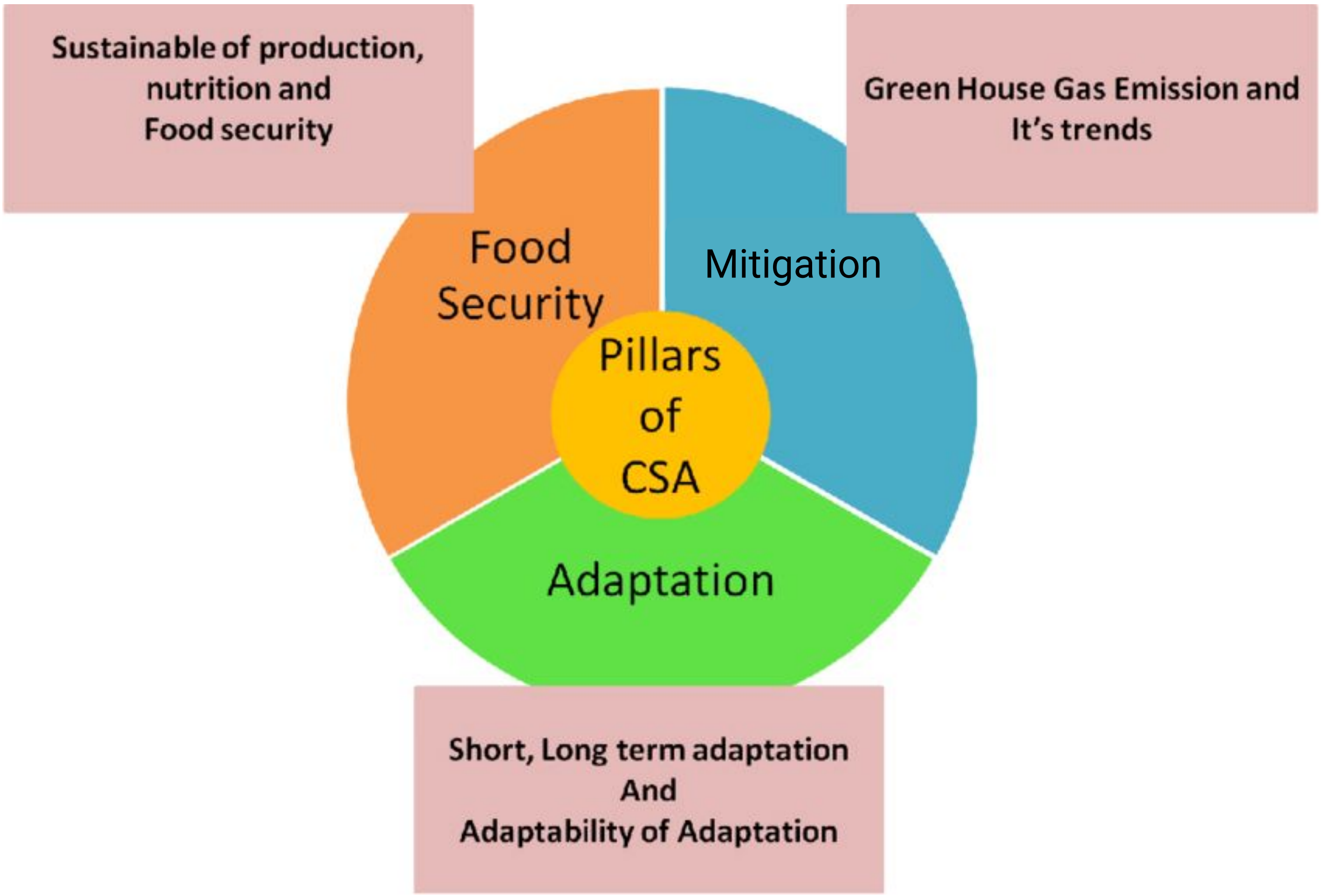
Through a combination of **theoretical explanations** and **practical examples**, we hope to foster greater adoption of CSA strategies such as *agroforestry, conservation agriculture, rainwater harvesting systems, and integrated pest management.*

Climate Smart Agriculture (CSA)

- Overview

Strategies to improve the yield of agricultural production

According to FAO, **Climate Smart Agriculture (CSA)** encompasses agricultural practices that **sustainably** boost productivity, enhance ***resilience to climate impacts***, and ***reduce greenhouse gas (GHG) emissions*** where feasible, all while supporting ***national food security*** and development goals.



Suggested CSA for Tree Crops in Ghana

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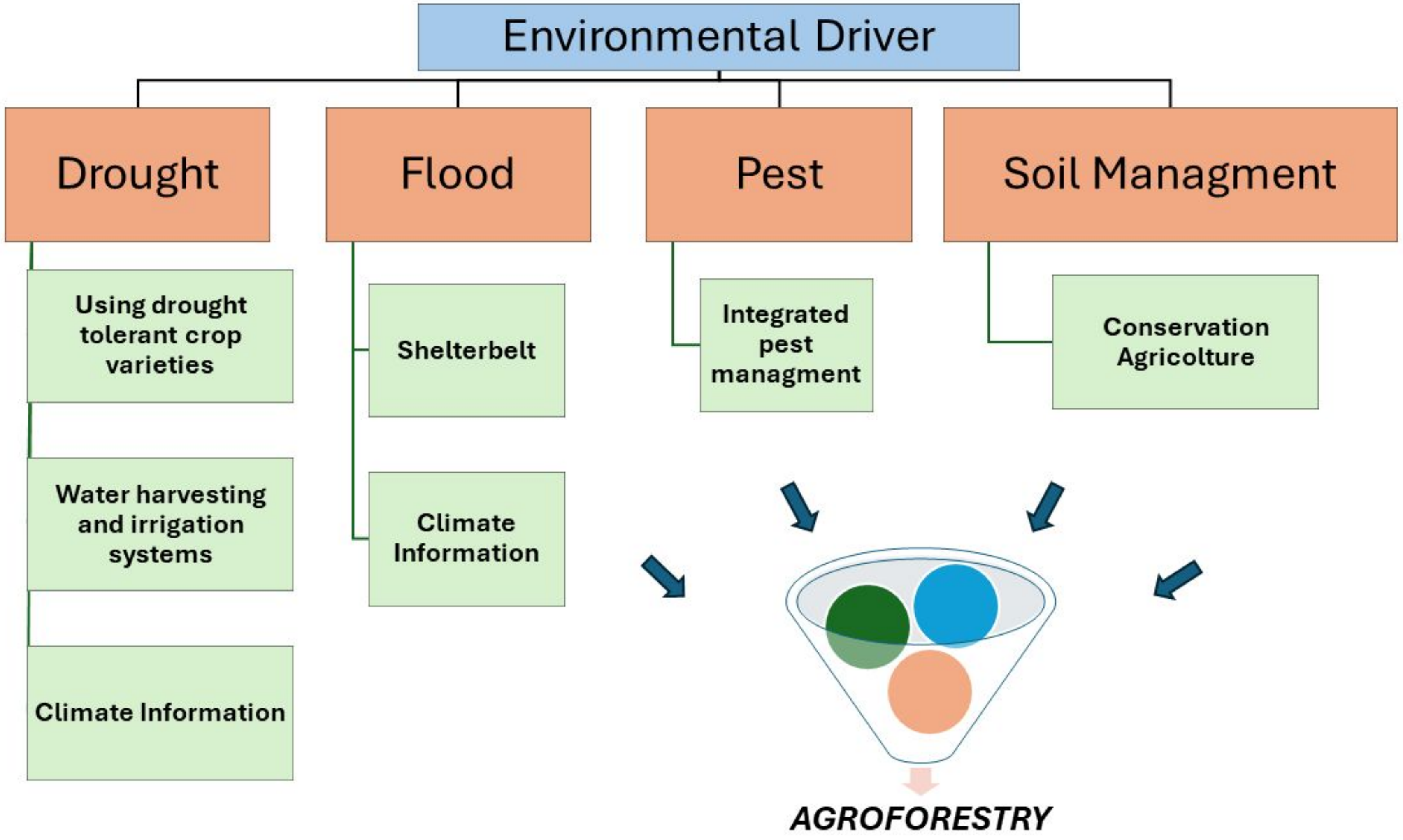

Climate-smart agriculture interventions are site/context-specific.

AGROFORESTRY

Agroforestry

Agroforestry integrates trees, crops, and sometimes livestock on the same land to create a system that benefit from the interactions of its components. These systems are designed to **maximize ecosystems services such as: productivity**, **soil health**, and make agriculture more **resilient to climate change**.

- **Improved Soil Fertility**:Trees like *Albizia zygia* are used in *cocoa* farms in the Ashanti Region to fix nitrogen, boosting soil nutrients and increasing cocoa yields by 30%.
- **Water Conservation**:Tree roots reduce soil erosion and enhance water retention, ensuring crops access moisture during dry periods.In Bono East, rainwater harvesting combined with trees like *Albizia zygia* stabilizes slopes and improves water availability for mango and cashew orchards.
- **Economic Diversification**: Farmers in Eastern Ghana intercrop cocoa with plantain for short-term income while waiting for cocoa trees to mature.
- **Climate Resilience**:Shade trees like *Gliricidia sepium* in cocoa farms reduce heat stress and protect crops from extreme weather in Ghana's forest zones.
- **Biodiversity Support**:Agroforestry systems in the Western Region combine cocoa with shade trees, providing habitats for pollinators and beneficial insects

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HOW TO DO IT?

- **STEP 1 Evaluate Personal Resources**:
  Assess available labor, equipment, finances, and land. Define clear objectives, such as income diversification, soil restoration, or climate resilience.
- **STEP 2 Biophysical Site Assessment**:
  Analyze soil type, climate, water availability, and terrain. Identify current land uses and select suitable areas for agroforestry.
- **STEP 3 Choose an Agroforestry System**:
  Select a system that aligns with your goals (e.g., cocoa agroforestry for humid zones, silvopastoral systems for savanna regions).
- **STEP 4 Plan and Design the System**:
  Identify compatible tree-crop combinations. Schedule planting with the rainy season for optimal seedling establishment and plan proper spacing.
- **STEP 5 Planting and Initial Setup**:
  Prepare planting pits, enrich soil with compost or manure, and plant trees and crops. Intercrop short-term crops like maize to generate immediate income.
- **STEP 6 Maintenance and Management**:
  Weed regularly, prune trees to optimize sunlight, and use integrated pest management. Mulch and incorporate cover crops to maintain soil fertility.

Agroforestry

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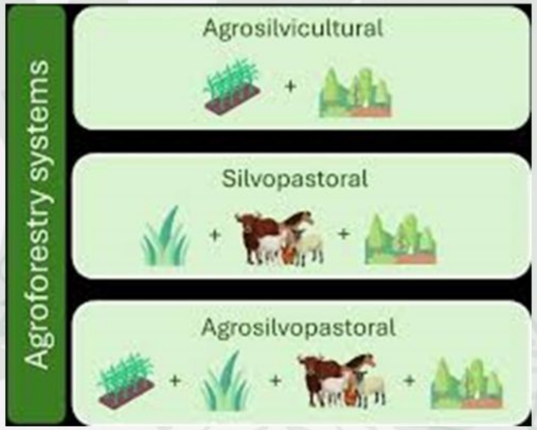
STEP 3: Choose the system type

Classification of Agroforestry's system by Components

System Types	Descriptions	Examples in Ghana
Agrosilvicultural	Combines trees with seasonal crops, enhancing productivity through nutrient cycling, shade, and reduced erosion.	Cocoa intercropped with *Albizia zygia* in Eastern Ghana.
Silvopastoral	Integrates trees and livestock pastures, improving fodder availability and soil protection.	Fodder banks with *Gliricidia sepium* or *Leucaena* in the Northern Savannah
Agrosilvopastoral	Combines trees, crops, and livestock to create a multi-functional system.	Home gardens with *mango*, *cassava*, and *poultry* (Volta and Ashanti regions)



Agroforestry

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Agrosilvicultural System - Multistrata Perennial Crop Systems

Classification	Details
System Type	Agrosilvicultural - Multistrata Perennial Crop Systems
Description	A system where multiple layers of perennial crops and trees are planted together to maximize land use efficiency and ecological benefits.
Key Characteristics	- Integrates trees, shrubs, and perennial crops in vertical layers. - Promotes high biodiversity and efficient resource use..
Primary functions	- **Production**: High- value perennial crops for income (e.g., *cacao, mango, oil palm, cashew*). - **Environmental**: Soil fertility, erosion control, and biodiversity enhancement.
Target ecological zones	Tropical forest and transition zones where rainfall supports perennial crops and diverse vegetation growth.
Examples with Key Species	Upper Layer (Timber/Shade Trees): *Albizia zygia* or *Cedrela spp.* for shade. Middle Layer (Cash Crops): *Cacao* or *rubber* for primary income; *mango* for fruit production. Lower Layer (Shrubs and Ground Crops): *Coconut, cashew*, or *oil palm* combined with food crops like *cassava* or *yam*.
	- **Cacao Systems**: Shade trees (*Albizia zygia*) with cacao and plantain. - **Mango Gardens**: *Mango* with *cassava* or *maize* in transition zones. - **Cashew Systems**: *Cashew* integrated with lower crops like *groundnuts* or *beans*

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STEP 4 Agroforestry practice design "Listing Best Bets"

Category	Criteria	Examples
Trees	Multipurpose species for timber, fruit, shade.	**Shade Providers**: *Albizia zygia, Leucaena, Cassia siamea.* - **Cash Crops**: *Cacao, Mango, Cashew, Rubber, Oil Palm, Coconut.*
Crops	Based on sunlight, water needs, and compatibility with trees.	- **Sun- Loving**: *Maize, Groundnuts, Soybean.* - **Shade-Tolerant**: *Cacao, Plantain, Yam.*

Factors	Key considerations
Access to Markets	Check for nearby buyers or processing facilities (e.g., *cashew* processing plants, cocoa depots).
Demand and Supply	Focus on high-demand crops like *Cacao, Cashew, Coconut*.
Production	Consider seasonal overlaps, such as *oil palm* fruit harvesting aligning with food crop planting seasons.
Resource Investment	Ensure sufficient returns on crops like *Mango* and *Cashew* to cover costs for labor, inputs, and maintenance.
Environmental	Select species naturally thriving in your zone (e.g., *Cashew* in Savannah, *Coconut* in Coastal regions).

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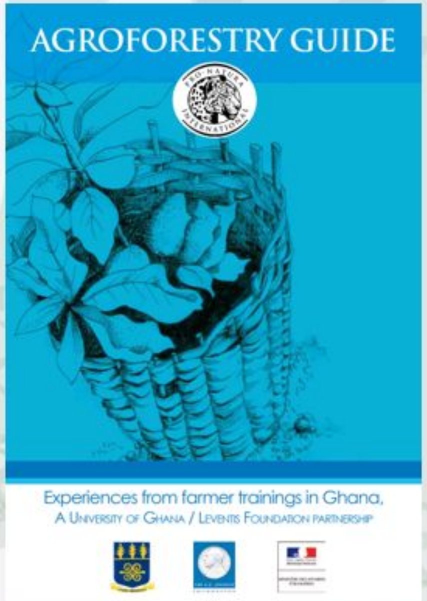
STEP 4 Agroforestry practice design "Listing Best Bets"

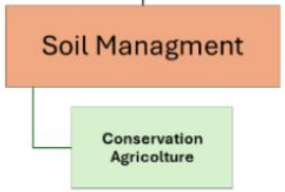
SPECIES		MAJOR USES AND FUNCTIONS																		OTHER REMARKS
BOTANICAL NAMES	ENGLISH(E) EWE(V) TWI(T) GA(G) HAUSA(H) DAGBANE(D)	FOOD AND FRUITS	SOIL CONSERVATION	SOIL FERTILITY	FUELWOOD	DYES	GREEN MANURE	CONSTRUCTION & CRAFT-MAKING	FODDER	WINDBREAKS	BEE FORAGE	LIVE FENCE	SHADE TREE	FIBRE	WASTELAND RECLAMATION	SHELTERBELT	MEDICINAL	TIMBER	ORNAMENTAL	
Acacia albida	Albida(E), Gawo(H), Puhu-wuni(D)		✔	✔	✔		✔		✔		✔	✔			✔					Coppices very well. Highly leguminous. Hedge crop.
Acacia nilotica	Egyptian thorn(E), Bagura(D)		✔	✔	✔		✔		✔			✔								Thorny leguminous drought tolerant plant.
Adansonia digitata	Baobab(E), (A)dido(V), Odadee(T), Zaadzo(G), Tua(D)	✔							✔		✔						✔			A priority savannah species.
Albizia adianthifolia	Vena(V), Pampena(T), Pampladzo(G)				✔			✔					✔				✔			Common in moist savannah zone.
Albizia coriaria	Kulefante(V), Awiemfosamina-akoa(T)							✔										✔		High forest species, desirable shade tree in cocoa.
Albizia zygia	Kulo(E), Okoro(T), Ledzo(Ga)		✔	✔	✔		✔		✔		✔		✔		✔					Highly leguminous. Useful in soil improvement.
Alstonia boonei	Siaketekre(V), Nyamedua(T)																✔	✔		Bark and leaves for medicine.
Anacardium occidentale	Cashew(E), Yevu-tsa(V), Ateaa(T), Atea(G)	✔			✔	✔					✔						✔			Cash crop, edible fruits and drought resistant.
Aningeria robusta	Samfena(T), Asanfra(V)							✔										✔		Wild fruit. Threatened forest species.
Anogeissus leiocarpus	Anogeissus(E), Kane(T), Sakane(Ga), Tsetse(V), Shia(D)	✔			✔		✔		✔	✔			✔							Savannah species. Gum yielder.
Artocarpus altilis	Breadnut(E), Yevuzi(V), Diiboo(T), Blofo nakatie(G)	✔				✔			✔									✔		Edible fruits very palatable and satisfying. Seeds can be fried or roasted. Leaves as fodder.
Artocarpus communis	Breadfruit(E), Diball(T)	✔				✔			✔									✔		Edible fruits – usually boiled. Leaves as fodder. Dye. Bark cloth. Wood used for canoes and tinder.
Azadirachta indica	Neem(E), Sabalati(V), Gyadua(T), Nim(D)				✔						✔	✔	✔		✔		✔	✔		Highly tolerant to drought. Leaves and seeds use for natural insecticide.
Baphia nitida	Camwood(E), Odwon(T), Aboloobaatso(G), Odzori(V)			✔	✔					✔		✔	✔							Good for alley cropping.
Blighia sapida	Akee apple(E), Adza(V), Akyee fufuo(T), Ayigbe atia(G), Kpihiga(D)	✔			✔			✔									✔			Avenue planting. Edible oil. Cheap furniture. Charcoal. Bark used for medicine.



Here is a list of common trees useful for agroforestry in Ghana

CONSERVATION AGRICULTURE

Conservation Agriculture



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Conservation agriculture focuses on **sustainable farming practices** that **protect soil health**, **conserve water**, and **enhance crop resilience**.

It relies on **minimal soil disturbance**, **maintaining soil cover**, and **crop rotation** to create a productive and sustainable farming system.

Reduce the intensity of soil tillage:

This principle involves minimal or slight disturbance of the soil, i.e. the soil is not ploughed or turned.
Constant turning of the soil destroys its structure and eventually forms a hard pan that prevents water infiltration and the proper development of plant roots.

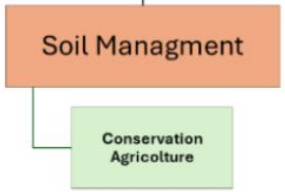
Cover the soil surface:

This is done by inclusion of live cover crops or spreading of dead vegetative material from crop residue. Covering the soil reduces its chances of being eroded by moving water or wind, conserves soil moisture, reduces weed growth and increases the rate of water infiltration into the soil while reducing evaporation.

Diversify crop rotations:

Crop rotation is the practice of growing two (or more) types of crops with different characteristics in the same space. Crop rotations should include legumes as they fix nitrogen into the soil and improve soil fertility.

Conservation Agriculture



Conservation Agriculture for Specific Tree Crops

Crop	Conservation Practice	Benefits
Cocoa	- Use banana or plantain as shade crops to prevent erosion. - Retain cocoa husks as mulch.	- Improves soil structure and reduces weed growth.
Cashew	- Plant cover crops like cowpeas. - Avoid over-pruning trees.	- Adds soil nutrients and maintains soil moisture.
Mango	- Use natural mulches like maize residues. - Intercrop with legumes.	- Prevents soil drying and reduces input costs.
Oil Palm	- Use oil palm fronds as mulch. - Maintain grass cover between rows.	- Reduces compaction and enhances water infiltration.
Coconut	- Intercrop with nitrogen-fixing cover crops (e.g., groundnuts). - Use coconut husks as mulch.	- Protects soil from erosion and adds organic matter.
Rubber	- Maintain grass or legume cover crops. - Avoid deep tillage in plantation rows.	- Prevents nutrient leaching and improves weed control.

Conservation Agriculture

Soil Managment

Conservation Agricolture

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Practical Guide for Conservation Agriculture in Tree Crops

Minimal Soil Disturbance

What to Do:

- Avoid deep plowing or frequent tillage near tree roots.
- Use cover crops or natural ground covers to suppress weeds.
- Dig planting pits for new saplings without disturbing the surrounding soil.

In Western Ghana, cocoa farmers planting saplings in no-till fields reduced root damage and improved survival rates by 25%.

Practical Guide for Conservation Agriculture in Tree Crops

Permanent Soil Cover

What to Do:

- Mulch using organic residues (e.g., coconut husks, oil palm fronds).
- Plant cover crops like legumes or grasses around tree bases. Select species suited to your region and crop cycle. For example, plant legumes like Mucuna pruriens to fix nitrogen and enrich the soil.
- Leave crop residues from intercropped plants on the field.

Cashew farmers in Brong Ahafo used cowpea as a cover crop, which retained soil moisture and added nitrogen to the soil.

Conservation Agriculture

Soil Managment

Conservation Agricolture

Practical Guide for Conservation Agriculture in Tree Crops

Diversified Cropping Systems

What to Do:

- Practice agroforestry by planting shade trees with yout principal crop or tree crop.
- Intercrop cashew with legumes (e.g., groundnuts or pigeon peas) to replenish nitrogen.
- Rotate between tree rows by planting temporary food crops like maize or millet.

Mango farmers in the Volta region intercropped with ginger, reducing soil erosion and earning extra income.

Recommended Cover & Intercropping Crops:

Recommended Cover Crops:

Drought-Resistant Options:

Stylosanthes hamata: Hardy legume that grows well in arid zones.
Arachis pintoi (Pinto Peanut): Great for nitrogen fixation and weed suppression.

Soil-Enriching Options:

Mucuna pruriens (Velvet Bean): Adds organic matter and nitrogen.
Crotalaria juncea (Sunn Hemp): Improves soil structure and reduces pests.

Foraging crops

Herbal medicine

Fabric production


Sylosanthes hamata


Archis pintoi


Mucuna pruriens

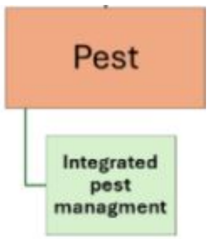

Crolataria juncea

INTEGRATED PEST MANAGEMENT

Integrated Pest Management

Integrated Pest Management (IPM) is an **environmentally friendly** approach to controlling pests.

It combines **biological**, **cultural**, **mechanical**, and **chemical** tools to manage pest populations in an **effective**, **economical**, and **sustainable** way.



Aspect	Traditional Methods	IPM
Pesticide use	Frequent and excessive	Minimal and targeted
Cost	High	Lower over time
Environmental impact	High	Low
Pest resistance	Increases with time	Reduced
Crop health	Often compromised	Improved
Farmer safety	High risk of exposure	Minimal risk

Integrated Pest Management

Core Strategies

1. Prevention (Proactive Actions)

- **Sanitation:** Regular removal of diseased plants and debris.
- **Resistant varieties:** Use pest- and disease-tolerant seeds.
- **Field management:** Proper spacing and weeding reduce pest habitats.

2. Monitoring (Understanding the Problem)

- **Regular scouting:** Check crops for pest presence or damage.
- **Traps:** Use pheromone or sticky traps to detect pests.
- **Decision-making:** Apply controls only when pest levels exceed thresholds.

3. Control (Integrated Methods)

- **Biological control:** Release natural predators or parasitoids (e.g., weaver ants).
- **Mechanical control:** Use traps, manual pest removal, or barriers.
- **Targeted chemical use:** Apply eco-friendly pesticides only as a last resort.

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Major Pests and Their Effects on Crops in Ghana

Crop	Key Pests/Diseases	Effects on Crops	Regions Found
Cocoa	- *Mirids* (*Sahlbergella singularis*)	- Feeding causes necrosis on pods and shoots, reducing yield significantly.	Ashanti, Western, Eastern
	- Black Pod Disease (*Phytophthora spp.*)	- Rotting of pods; severe outbreaks can destroy up to 30-40% of annual yield.	Central, Western, parts of Ashanti
	- Cocoa Swollen Shoot Virus (CSSV)	- Causes yellowing and swelling of leaves and shoots; infected trees lose productivity and may die.	Volta, Eastern, parts of Ashanti
Cashew	- Cashew Weevil (*Mecicorynus loripes*)	- Bores into bark, causing branches to die back; affects overall tree health.	Brong Ahafo, Northern
	- Helopeltis Bugs (*Helopeltis spp.*)	- Damage young shoots and flowers, leading to reduced nut formation.	Forest-savanna transition zones (e.g., Sunyani, Techiman)
Mango	- Fruit Flies (*Bactrocera dorsalis*)	- Larvae infest fruits, making them unmarketable; economic losses can exceed 50%.	Greater Accra, Volta, Northern
	- Anthracnose (*Colletotrichum spp.*)	- Causes black lesions on fruits and stems, reducing fruit quality and marketability.	Eastern, Ashanti, humid zones of Brong Ahafo
Oil Palm	- Coconut Rhinoceros Beetle (*Oryctes monoceros*)	- Larvae bore into crowns, damaging leaves and reducing fruit production.	Western, Central, Greater Accra
	- Termites (*Odontotermes spp.*)	- Attack roots and stems, causing tree collapse in severe cases.	Nationwide, particularly degraded lands
Coconut	- Palm Weevil (*Rhynchophorus phoenicis*)	- Larvae bore into the trunk, causing structural weakness and tree death.	Volta, Central, Western
	- Bud Rot (*Phytophthora spp.*)	- Rotting of young shoots and buds, leading to yield loss and tree death.	Coastal humid areas, particularly in Western and Central regions
Rubber	- Leaf Disease (*Corynespora cassiicola*)	- Causes defoliation, reducing photosynthesis and rubber yield.	Humid regions, particularly in Eastern and parts of Ashanti

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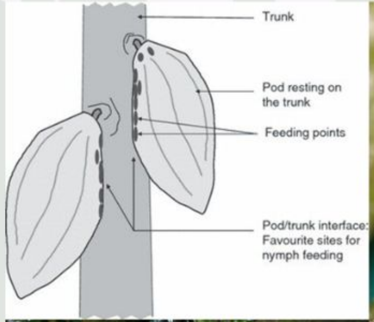
Key Cocoa Pest (Identification)

Pest/Disease	How to Recognize	Useful Tools
Mirids (Sahlbergella singularis, Distantiella theobroma)	- Dark lesions on pods and shoots. - Wilting or blackening of young leaves. - Presence of small brown bugs on pods or branches.	Magnifying lens, pest ID cards
Black Pod Disease (*Phytophthora spp.*)	- Brown or black patches on pods, starting from the tip. - Pods become soft and rot. - White fungal growth may appear under humid conditions.	Pocket knife (to check pod interior), field guide
Cocoa Swollen Shoot Virus (CSSV)	- Swelling and yellowing of leaves and shoots. - Reduced fruiting and tree stunting. - Leaf veins may appear swollen.	Observation log, training on symptom identification



Integrated Pest Management

Key Cocoa Pest (Control)

Pest/Disease	Distribution	Preventive Methods	Curative Methods	Required Tools	IPM Benefits
Mirids (*Sahlbergella singularis*)	Ashanti, Western	Pruning, chupon removal, maintaining clean farms	Release red weaver ants (*Oecophylla longinoda*);	Pruning shears, ant colonies	Reduced pod and yield damage
Black Pod Disease (*Phytophthora spp.*)	Humid zones (Central, Western)	Reduce shade, prune regularly, remove infected pods	Apply approved fungicides during black pod season	Pruning tools, fungicide sprayers	Minimized fruit loss, ecosystem preservation
Cocoa Swollen Shoot Virus (CSSV)	Volta, Eastern	Use resistant varieties; regular monitoring	Cut and remove infected trees	Resistant seedlings, cutting tools	Prevents virus spread

Useful Resources


SAL

GOVERNMENT OF GHANA

TREE CROPS DEVELOPMENT AUTHORITY

Ghana Cocoa Board

INTEGRATED PEST MANAGEMENT PLAN (IPMP) FOR THE

GHANA TREE CROP DIVERSIFICATION PROJECT (GTCDP)

Final Report

Seth Larmie, c/o SAL Consult Limited, P O Box GP20200, Accra

May, 2023

https://cocobod.gh/resource_files/integrated-pest-management-plan-for-the-ghana-tree-crop-diversification-project.pdf


REPUBLIC OF GHANA

FREEDOM AND JUSTICE

MINISTRY OF FOOD AND AGRICULTURE

West Africa Food System Resilience Program (FSRP2) – Phase 2 (P178132)

Integrated Pest Management Plan (IPMP)

February 2022

https://mofa.gov.gh/site/images/pdf/2.Ghana_IPMP_P178132_FSRP2_8Feb2022.pdf

... in our document

RAINWATER HARVESTING SYSTEMS

Rain Water Harvesting System

Drought

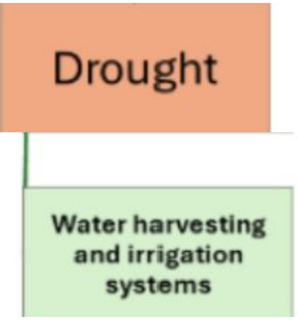
Water harvesting and irrigation systems

Rainwater Harvesting (RWH) involves **collecting**, **storing**, and **conserving** rainwater on farms or from runoff in a catchment area smaller than the farmed land.

Key Steps in RWH Project Implementation

1. **Site Assessment:**
   - Identify the average annual rainfall and its distribution.
   - Evaluate soil type (e.g., clayey soils retain more water).
   - Assess land slope and potential catchment areas.
2. **Design & Planning:**
   - Select the appropriate RWH system based on farm size, budget, and water needs.
   - Plan storage capacity to ensure sufficient water during droughts.
3. **Community Involvement:**
   - Engage farmers to ensure understanding and ownership of the system.
   - Incorporate local knowledge and labor.
4. **Construction:**
   - Use local, cost-effective materials where possible.
   - Follow safety and durability standards.
5. **Maintenance Plan:**
   - Train users on cleaning and maintaining gutters, tanks, and catchments

Rain Water Harvesting System



Rooftop Rainwater Harvesting (RRWH)

•Description: Rain is collected from building rooftops and channeled into storage tanks via gutters and pipes.
•Tanks can be made of polyethylene, ferrocement, or concrete.
•Storage Capacity: 1,000 to 10,000 liters, depending on tank size and roof area.

Small-scale farms or individual households.

Micro-Catchments (e.g., Zai Pits)

•**Description**: Small pits or bunds capture water directly in the field, allowing it to infiltrate and be stored in the soil profile.
•**Storage Capacity**: Limited to the soil's capacity, typically retaining moisture for crops within a small radius.

Farms with sloped terrain or degraded soils.

Subsurface Tanks and Cisterns

•**Description: U**nderground tanks are constructed to store water collected from surface or rooftop catchments, reducing evaporation losses.
•**Storage Capacity:** 5,000 to 50,000 liters.

Areas with high evaporation rates, such as arid or semi-arid climates.

Rain Water Harvesting System

Drought

Water harvesting and irrigation systems

From Planning to Action: Implementing Rainwater Harvesting Systems in Ghana

Efficient Water Distribution After Rainwater Harvesting

Drip Irrigation

- **Description**:
  - Delivers water directly to the root zone of trees through perforated pipes or drip emitters.
  - Minimizes water loss through evaporation and runoff.
- **Advantages**:
  - Precise application reduces waste and ensures even distribution.
  - Ideal for high-value crops.
- **Best Practices**:
  - Use a filter to prevent clogging of emitters.
  - Regularly check for leaks or blockages in the system.

Basin Irrigation

- **Description**:
  - Small basins are created around each tree to hold water, allowing slow infiltration into the soil.
- **Advantages**:
  - Simple and cost-effective, especially for small-scale farmers.
  - Helps concentrate water near tree roots.
- **Best Practices**:
  - Add mulch to the basin to reduce evaporation.
  - Refill basins as needed during prolonged dry periods.

TREE CROP FACT SHEET

Crop Fact Sheet: example

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Cocoa is a critical crop in Ghana's economy. Climate change threatens its sustainability, requiring the adoption of Climate-Smart Agriculture (CSA) practices.

Main Environmental Risks

Risk	Description
Drought	Reduced water availability during dry seasons, impacting cocoa growth.
Deforestation	Pressure from monoculture practices reduces biodiversity and soil fertility.
Pests and Diseases	Major threats include Mirids, Black Pod disease, and Cocoa Swollen Shoot Virus (CSSV).

Ecophysiological Requirements

25–30°C
>32°C Reduce growth and yield

1500 - 2500 mm
>3months drought reduce yield

Well drained pH 5.5–6.5
shallow roots, limiting the access at deep water reserves

Suggested Practices

Agroforestry Systems

Agroforestry is the integration of trees and shrubs with crops or livestock systems to create a sustainable land-use practice.

This approach enhances biodiversity, improves soil health, reduces erosion, and provides shade, which can mitigate stress for crops.

Agroforestry systems optimize resource use, such as water and light, and can help diversify farmers' income.

Rain Harvesting Systems

Rainwater harvesting involves collecting and storing rainwater for later use, particularly during dry periods.

Techniques include rooftop collection systems, farm ponds, and reservoirs.

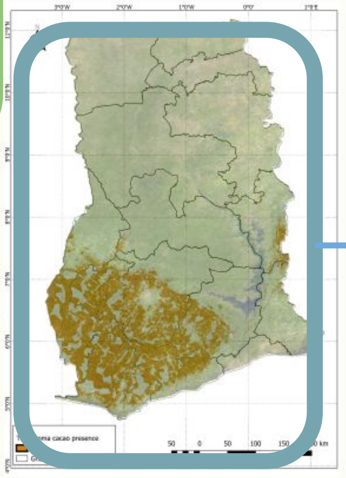
This practice helps secure water for irrigation, reduces dependence on rainfall, and mitigates the risk of both drought and flooding. It is particularly effective in semi-arid and arid regions.

Integrated Pest Managment

Integrated Pest Management (IPM) is a sustainable approach to managing pests and diseases by combining biological, cultural, physical, and chemical methods.

It emphasizes monitoring pest levels, promoting natural predators, and using pesticides only when necessary to minimize environmental and health risks.

IPM reduces production costs, enhances crop resilience, and protects ecosystems.



Main Environmental Risks

Ecophysiological Requirements

Suggested CSA practices & their descriptions

Actual distribution of the crop (when available)

Crop Fact Sheet

Cocoa *(Theobroma cacao)*

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Main Environmental Risks

Risk	Description
Drought	Reduced water availability during dry seasons, impacting cocoa growth.
Deforestation	Pressure from monoculture practices reduces biodiversity and soil fertility.
Pests and Diseases	Major threats include Mirids, Black Pod disease, and Cocoa Swollen Shoot Virus (CSSV).

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25–30°C

>32°C Reduce growth and yield

1500 - 2500 mm

>3months drought reduce yield

Well drained pH 5.5–6.5

shallow roots, limiting the access at deep water reserves

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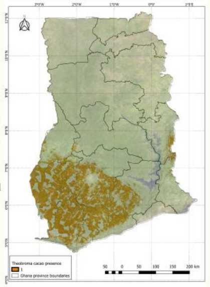

Cashew *(Anacardium occidentale)*

Cashew is a vital crop in Ghana, especially in the northern regions. It faces climate challenges, such as erratic rainfall and pest outbreaks, requiring CSA interventions for sustainable production.

Main Environmental Risks

Risk	Description
Drought	Insufficient water during key growing phases impacts yield and tree health.
Soil Degradation	Poor soil management can lead to erosion and nutrient depletion.
Pests and Diseases	Major threats include cashew weevil (Mecicorynus loripes), branch girdler (Analeptes trifasciata), and anthracnose.

Ecophysiological Requirements

24–28°C

>40°C lead to stress

700–1.500 mm

>3months drought reduce quality and yield

Well drained pH 5.5–6.5

deep roots absorbing from lower soil layers

Suggested Practices

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IPM reduces production costs, enhances crop resilience, and protects ecosystems.

Mango *(Mangifera indica)*

Mango is a high-value crop widely grown in Ghana. It is sensitive to climate variability, including drought and pest outbreaks, necessitating CSA strategies to ensure sustainable production.

Main Environmental Risks

Risk	Description
Drought	Reduces flowering and fruit set, impacting overall yields.
Soil Degradation	Poor soil management can lead to erosion and nutrient depletion.
Pests and Diseases	Common threats include fruit flies (*Bactrocera dorsalis*), anthracnose (*Colletotrichum gloeosporioides*), and powdery mildew.

Ecophysiological Requirements

24–30°C

>45°C and <10°C lead to stress

750–1.000 mm

Susceptible during flowering and early fruiting season

Well drained pH 5.5–7.0

deep roots absorbing from lower soil layers

Suggested Practices

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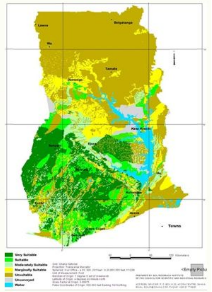

Crop Fact Sheet

Oil palm (*Elaeis guineensis*)

Oil palm is a high-yield crop with significant economic importance in Ghana. However, climate change, soil degradation, and pest issues necessitate CSA practices for sustainable productivity.

Main Environmental Risks

Risk	Description
Drought	Prolonged dry spells reduce yields and oil content in fruits.
Flooding	Poorly drained soils can lead to waterlogging and root rot.
Pests and Diseases	Notable threats include Rhynchophorus ferrugineus (red palm weevil) and Ganoderma boninense (basal stem rot).

Ecophysiological Requirements

25–32°C

<15°C reduce yield

1.500-3.000 mm

Well drained pH 4.0–6.0

deep roots absorbing from lower soil layers

Suggested Practices

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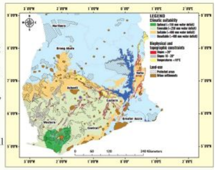

Rubber (*Hevea brasiliensis*)

Rubber is a major export crop in Ghana, with significant economic and industrial value. However, climate challenges such as prolonged droughts and soil degradation threaten its sustainability, necessitating CSA interventions.

Main Environmental Risks

Risk	Description
Drought	Prolonged dry spells reduce latex yield and tree health.
Soil Degradation	Continuous monocropping leads to nutrient depletion and erosion.
Pests and Diseases	Major threats include Corynespora cassiicola (leaf fall disease) and white root rot (Rigidoporus microporus).

Ecophysiological Requirements

25–28°C

>36°C and <10°C lead to stress

1.500-2.000 mm

Well drained pH 4.5–6.5

deep roots absorbing from lower soil layers

Suggested Practices

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IPM reduces production costs, enhances crop resilience, and protects ecosystems.

Coconut (*Cocos nucifera*)

Coconut is a versatile crop in Ghana, providing food, oil, and materials. However, climate variability, such as drought and soil salinization, threatens its productivity, necessitating Climate-Smart Agriculture (CSA) practices.

Main Environmental Risks

Risk	Description
Drought	Prolonged dry periods reduce nut production and tree health.
Soil Degradation	Coastal areas are at risk of salinization, affecting root absorption and growth.
Pests and Diseases	Key threats include red palm weevil (*Rhynchophorus ferrugineus*) and lethal yellowing disease.

Ecophysiological Requirements

27–32°C

>38°C and <20°C lead to stress

1.500-2.500 mm

Well drained pH 5.5–7.5

shallow roots, limiting the access at deep water reserves

Suggested Practices

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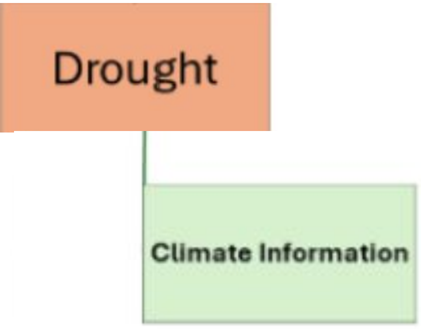
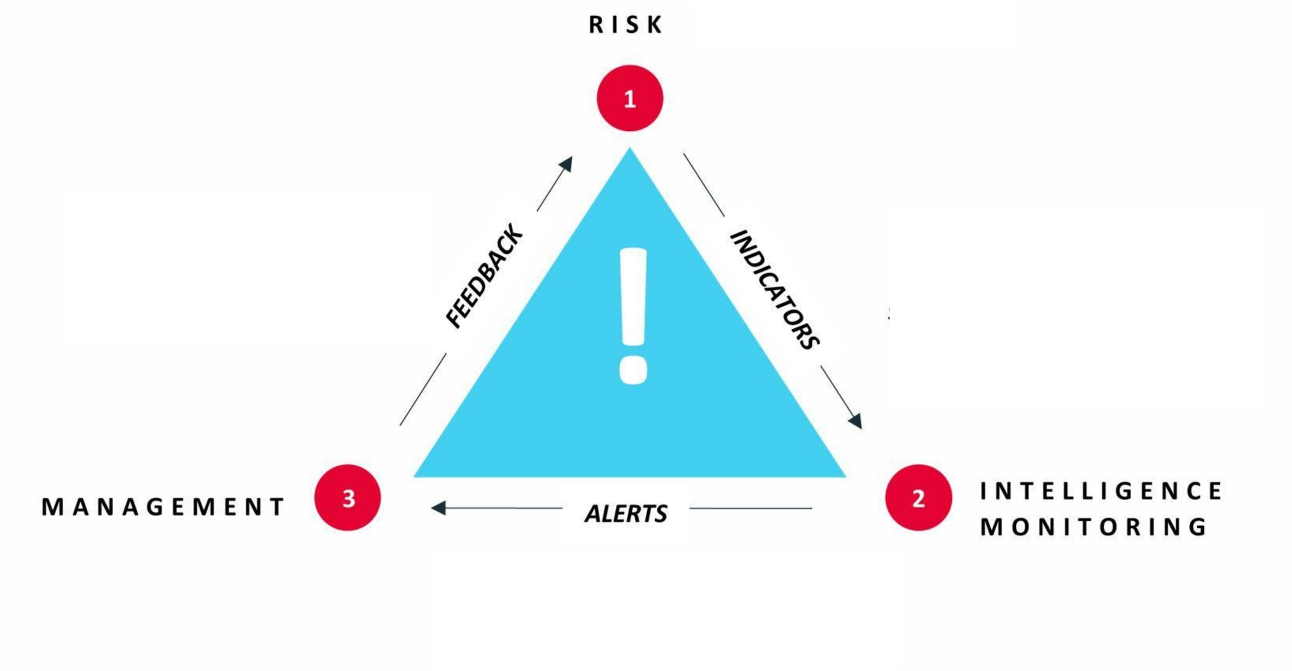
CLIMATE INFORMATION PRODUCT

Early Warning System



Another crucial tool for enhancing farmers' resilience is **Early Warning Systems (EWS)**.

These systems provide accurate and timely weather forecasts that allow farmers to better prepare for extreme weather events such as **droughts, floods, and storms**.



Implementing EWS can significantly reduce the **risk of crop losses** and **improve food security**.

These systems should also include training for farmers on how to use the information received to make informed agricultural decisions.

Conclusion

In conclusion, the selected climate-smart agriculture (CSA) practices—**agroforestry, conservation agriculture, rainwater harvesting systems, and integrated pest management**—are key strategies for enhancing the sustainability and resilience of tree crop farming in Ghana.

Additionally, **Early warning systems** can empowers farmers with timely information on drought and flood phenomena and provide information about crops' irrigation requirements. By leveraging this knowledge, farmers can take proactive measures to protect their crops, reduce losses, and optimize resource use.

The materials we have produced, including a **comprehensive report on CSA practices**, detailed information **sheets on tree crops**, and **training presentations**, are designed to support farmers in adopting these practices.

These resources aim to provide clear, actionable information that can be easily integrated into farming operations, empowering farmers to make informed decisions and improve their productivity while addressing the challenges posed by climate change.

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Thank you for your attention!

Extensive climate hazards and vulnerabilities assessment of the tree crop sub-sector in Ghana

Early Warning Systems for Flooding and Drought Forecasts

Speaker: Prof. Francesco Cioffi
Team: Dr. Afshin Shafei, Dr. Lorenzo Tieghi

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Presentation Outline

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Introduction

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Background

- **Critical Issues in Ghana:**
  - Frequent flooding and drought events due to urbanization, inadequate drainage, poor waste management, and climate variability.
  - Floods are common in Accra and Kumasi, driven by heavy rainfall and insufficient infrastructure.
  - Drought impacts agriculture in tree crop regions due to prolonged dry spells, low soil moisture, and limited warnings
  - Flood management is reactive, lacking effective forecasting and early warnings.
- **Institutional Challenges:**
  - Agencies face resource and technical capacity issues.
  - Lack of integration between data and communication systems limits EWS effectiveness.
- **Challenges of Existing EWS:**
  - Current EWS are fragmented and lack advanced prediction technologies.
  - Key challenges include data scarcity and inconsistent early warning dissemination.

Objectives

- **Review and Evaluation:** Assess existing flood and drought management and EWS in Ghana.
- **Propose ML-Based Solutions:** Introduce machine learning to improve prediction accuracy and response.
- **Stakeholder Involvement:** Recommend strategies for involving stakeholders to apply the proposed EWS effectively.

Existing Flood and Drought EWS

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- **EWS in Developing Countries**:
  - Essential for **disaster risk reduction** but often rely on **basic meteorological data** and historical records, which limits effectiveness.
  - **Floods and droughts** threaten economic livelihoods and food security, especially in areas with **poor infrastructure** and **limited resources**.
  - Enhanced monitoring tools that incorporate **evapotranspiration rates, soil moisture**, and **vegetation health, as derived by rainfall and temperature forecasts**, are needed for improved drought predictions.
- **Challenges**:
  - **Flood management** is hindered by inadequate infrastructure and planning.
  - Traditional models are **computationally demanding**, posing challenges in resource-limited settings.
- **Technological Solutions**:
  - **Machine Learning (ML)** models offer **rapid and accurate flood risk assessments** for real-time forecasting.
  - **Remote sensing and GIS** technologies are used to create flood risk maps, providing a **cost-effective** approach to disaster preparedness.
- **Global Examples**:
  - **Deep learning models** in Australia (e.g., Long LSTM networks) outperform traditional drought forecasting methods and could be adapted for Ghana (Dikshit et al. 2021).
  - **Neural network models** in St. Lucia provide rapid flood forecasting, which could be beneficial for urban areas like Accra (Cioffi et al. 2024).

Proposed Research Method: Machine Learning for Flood and Drought Prediction

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- **Limitations of Traditional Models**:
  Struggle with **complexity** and **non-linearity** of climate systems in **data-limited regions** like Ghana.
- **Advantages of Machine Learning**:
  - **ML models** leverage large datasets to improve **flood and drought prediction**.
  - Effective in capturing complex patterns in **weather and climate data**.
- **Successful ML Models**:
  - **Global Models**: FourCastNet (Pathak et al., 2022), PanGu (Bi et al., 2023), GraphCast (Lam et al., 2023) predict **extreme weather** accurately.
  - **Regional Models**: Stacked-LSTM (Karevan and Suykens, 2018) and ConvLSTM (Shi et al., 2015) enhance **precipitation and temperature trends** forecasting.
  - **Hybrid Models**: Models like **MetNet** (Sonderby et al., 2020) combine architectures for better accuracy.

Short-Term Rainfall and Temperature Forecast System

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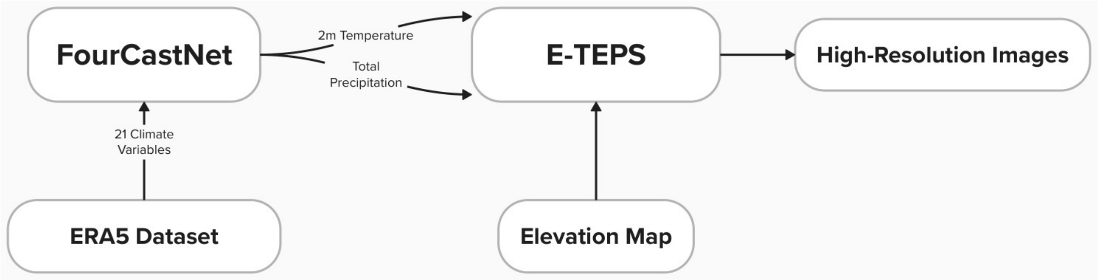
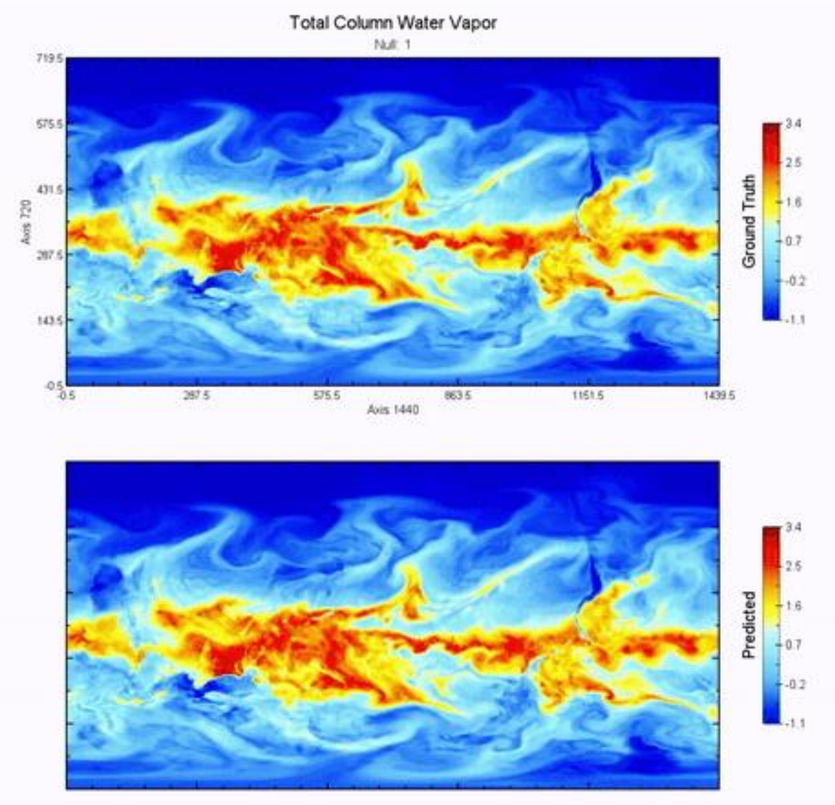
- **Overall Framework:** Combines global predictions from the FourCastNet model with a downscaling model, E-TEPS, for high-resolution forecasts.
- **Global Predictions:** Begins with global climate variable predictions generated by FourCastNet.
- **Downscaling Procedure:** Refines these predictions through E-TEPS to provide localized, high-resolution outputs.
- **Addressing Challenges:** Designed to capture broad-scale and fine-scale features in diverse geoclimatic conditions.



FourCastNet: Global Forecasting System

- FourCastNet is a data-driven weather forecasting model based on the vision transformer architecture with Adaptive Fourier Neural Operator (AFNO) attention.
- It provides accurate short to medium-range global predictions at 0.25◦ spatial resolution and 6-hours temporal resolution for variables such as surface wind speed, precipitation, and atmospheric water vapor.
- It can predict extreme weather events such as tropical cyclones, extra-tropical cyclones, and atmospheric rivers.
- It generates a week-long forecast in less than 2 seconds, much faster than IFS.



Example Output of FourCastNet model - Total Column Water Vapor

E-TEPS: Downscaling model

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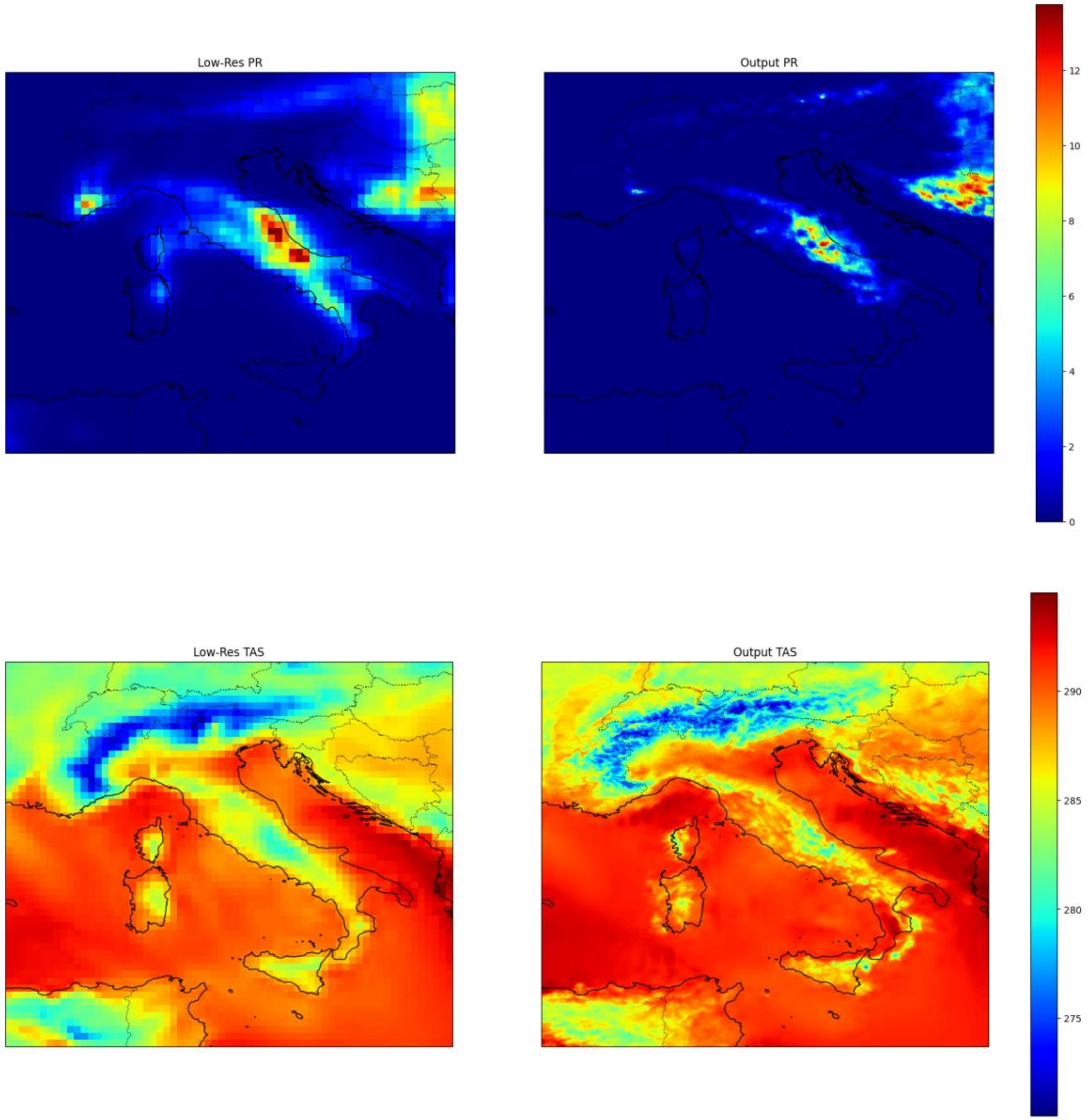
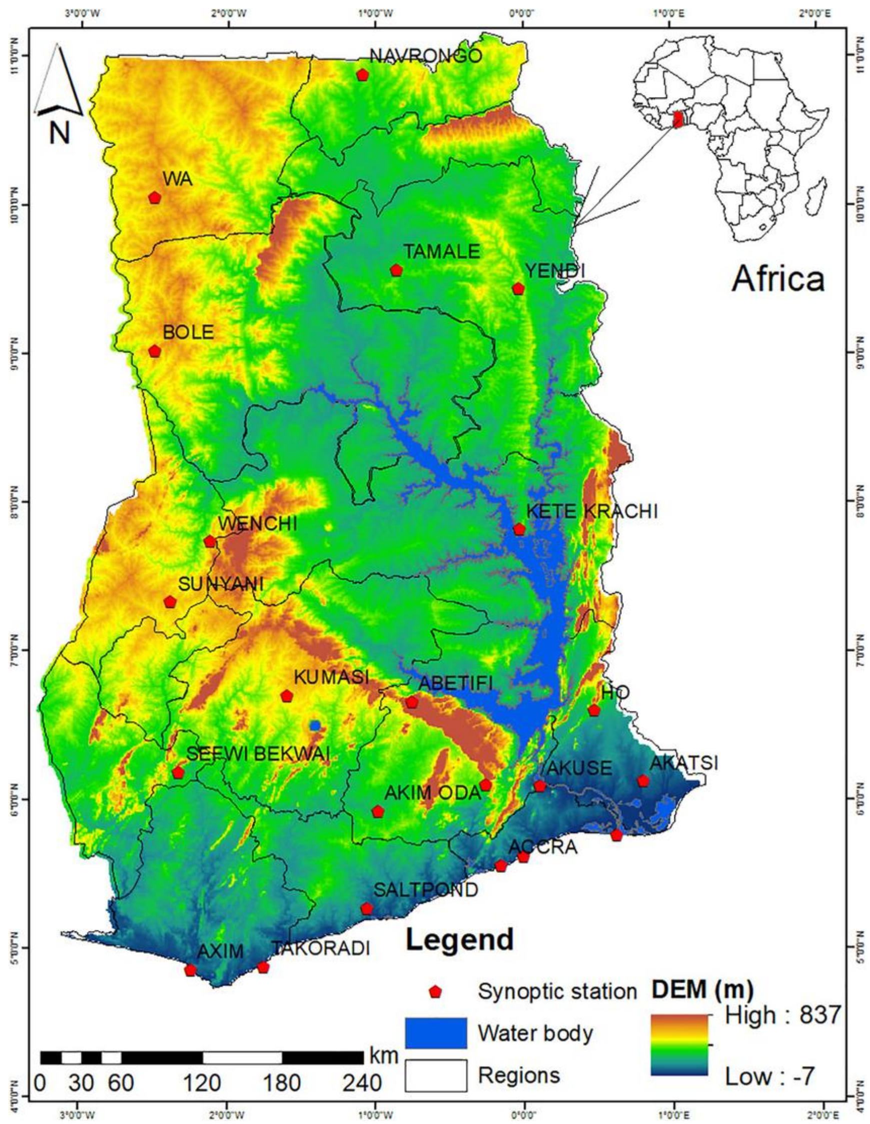
- The **E-TEPS (Elevation-integrated Temperature and Precipitation SRGAN)** model downscales global forecasts to a higher resolution, enhancing **spatial accuracy** for local climate data like **2m-temperature** and **total precipitation**.
- **Development in Italy**: Initially developed using the **CMCC dataset** over Italy. E-TEPS uses **elevation maps** as auxiliary inputs, significantly improving prediction accuracy over **complex terrain**.
- **Performance**: Demonstrates superior accuracy compared to traditional methods (bicubic and linear), showing **lower MAE, RMSE**, and higher **Pearson Correlation**.
- **Advantages**: Fast processing with cloud systems, delivering results in under **10 seconds** and preserving detail in **complex terrains**.



Emilia-Romagna Extreme Event Results for Total Precipitation and Temperature

Ghana Application

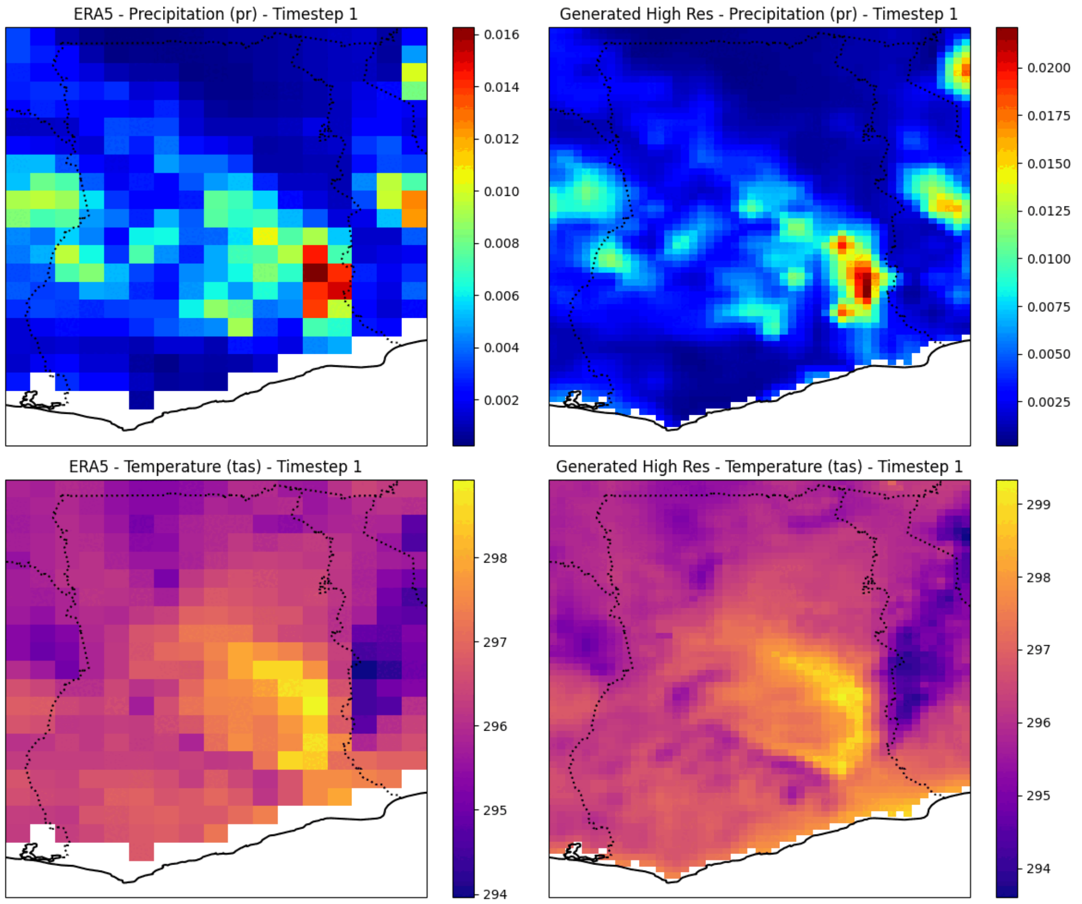
- **Adaptation to Ghana**: Expanded E-TEPS to **Ghana** using **ERA5-Land** dataset with a **9 km resolution**, tailored to the unique **flat terrain** and climatic conditions.
- **Challenges and Modifications**: Adjusted for **missing data** (NaN values) in areas like bodies of water using specialized masking techniques to maintain prediction integrity.
- Focused on handling **large-scale rainfall variations** rather than topographic influences as in Italy.



Dem of Ghana (Bessah et al. 2022)

Testing and Results

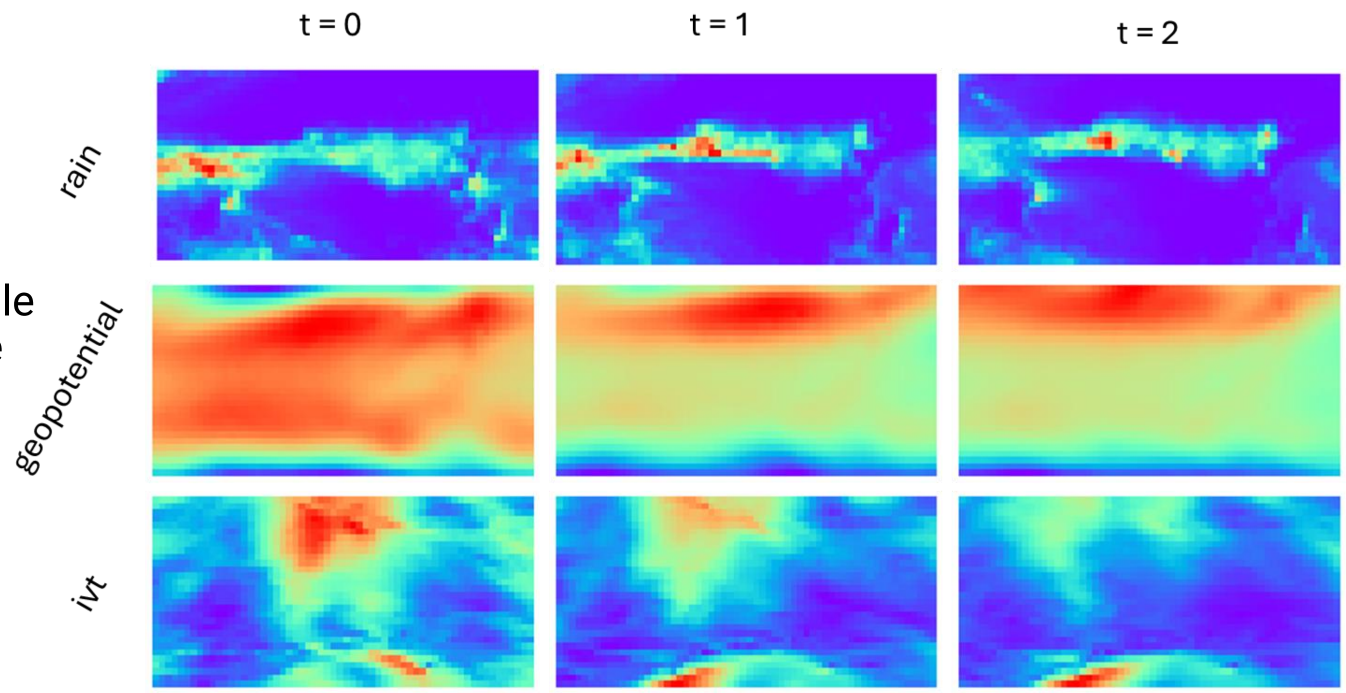
- **September 2023 Extreme Event**: Tested during an extreme weather event in **Ghana**, proving capable of generating **high-resolution**, accurate predictions.
- **Inference Results**: Demonstrated effective downscaling of ERA5-Land data, providing valuable insights for **local authorities** to take proactive measures.
- **Key Outcome**: Maintained high accuracy, delivering reliable **regional forecasts** suitable for **decision-making** in Ghana.



Results for September 2023 Extreme Event - 72 h

Drought Early Warning System (seasonal prediction)

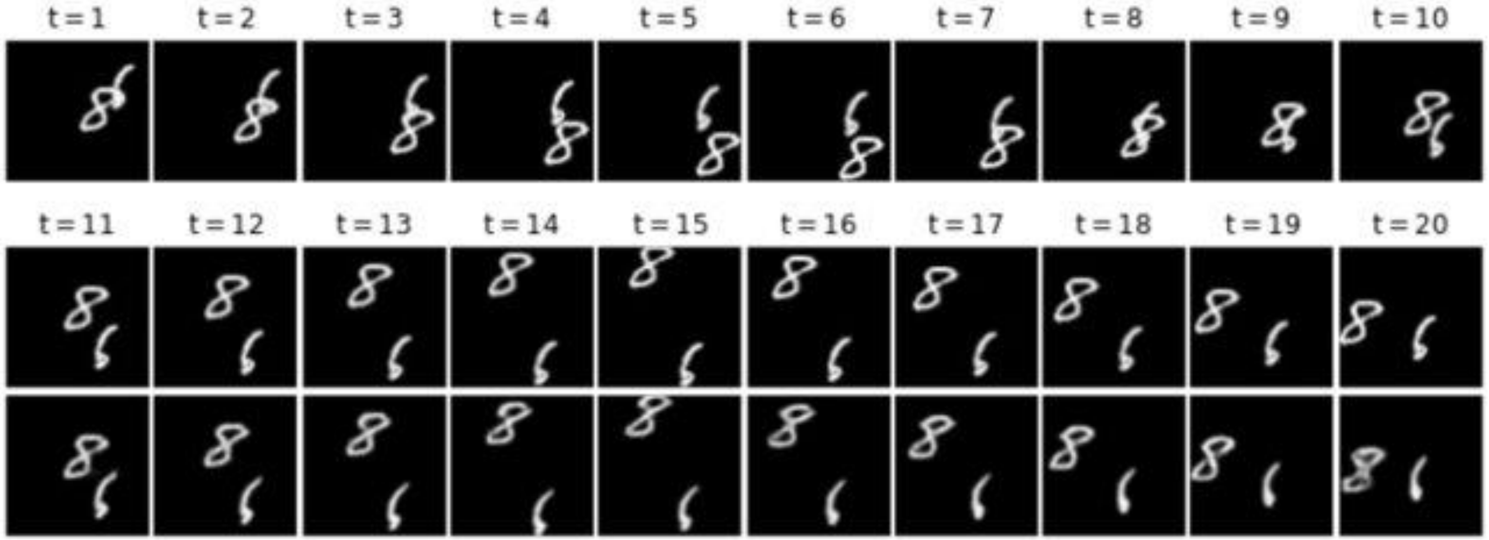
- The task here is to predict monthly rainfall amount and temperature on the area of Ghana with a lead time from 1 to 6 months with a 10 km spatial resolution
- Rainfalls and temperature are influenced by multiple meso-scale environmental factors, e.g. sea surface temperature, geopotential, humidity, winds, etc.
- The challenge is to keep in account these factors and their influence on the rainfall and temperature fields
- The multidimensionality of data, complexity of the problem and large domains advocate for advanced machine learning methods
- The advanced ML algorithms can treat such problems, at the cost of huge increases in computational resources



Example of spatial and temporal evolution of some of the considered features

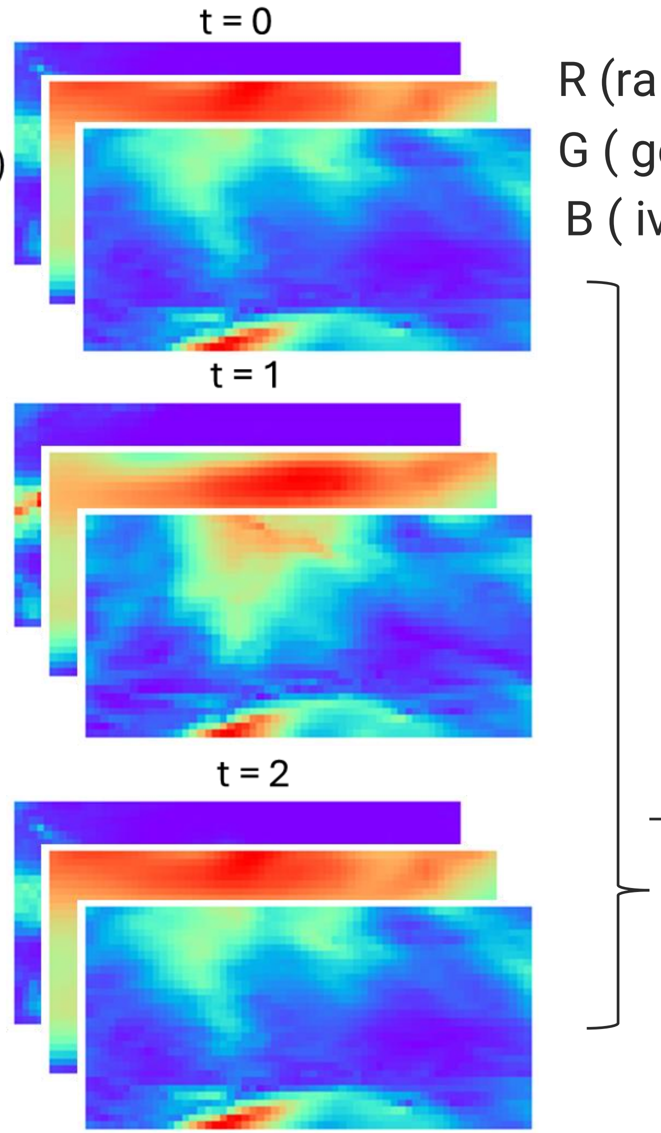
MACHINE LEARNING ALGORITHM: convLSTM

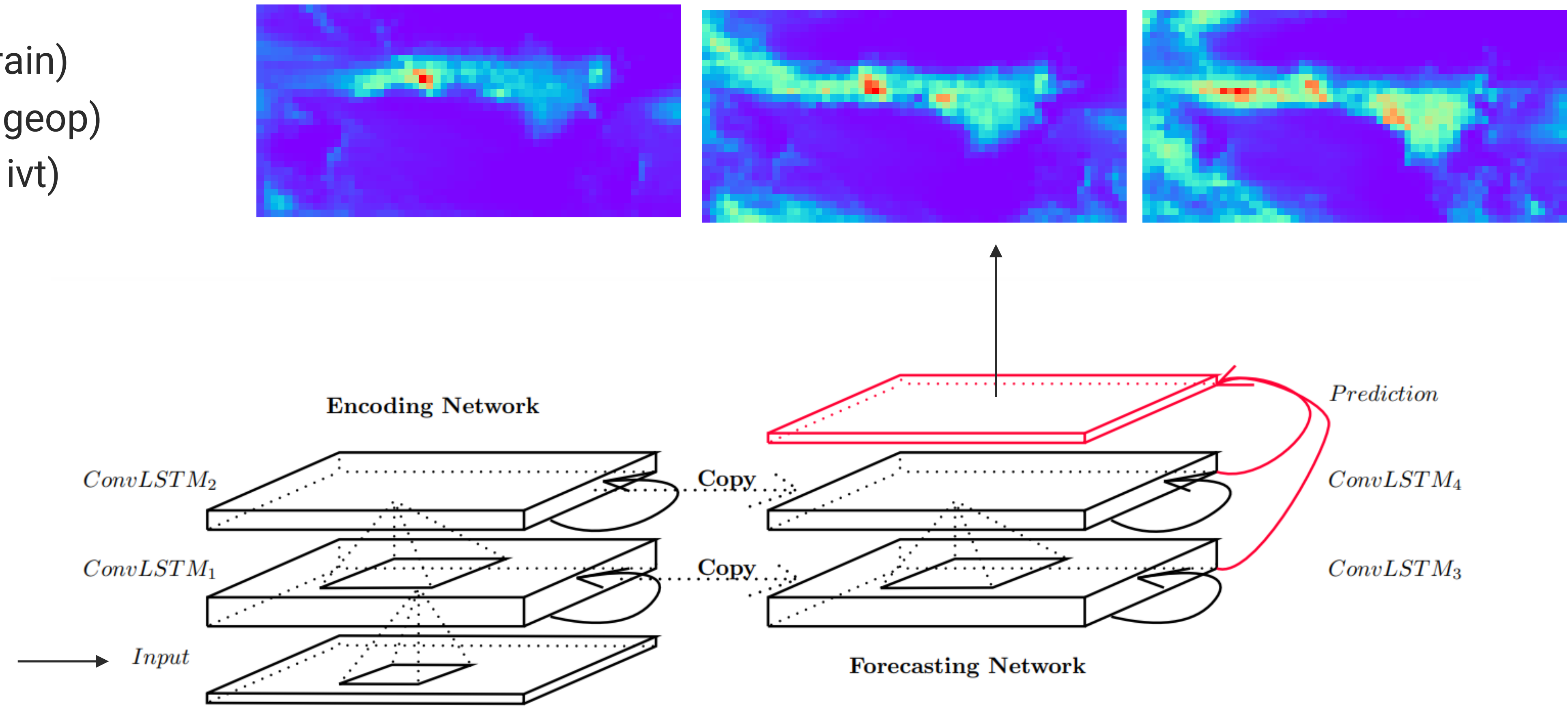
- Machine learning algorithms can be applied to a wide range of data-driven application
- Several tasks can be solved, from regression to classification tasks
- These works features an application of convolutional long-short term memory algorithm
- ConvLSTM is a type of recurrent neural network for spatio-temporal prediction
- It combines the automatic extraction of spatial features (convolutional network) and process their temporal evolution (LSTM)



Example of moving MNIST dataset: a sequence of 10 frames of moving numbers is observed and the future states are predicted using ML (DOI: 10.48550/arXiv.2305.11421)

MACHINE LEARNING ALGORITHM: convLSTM

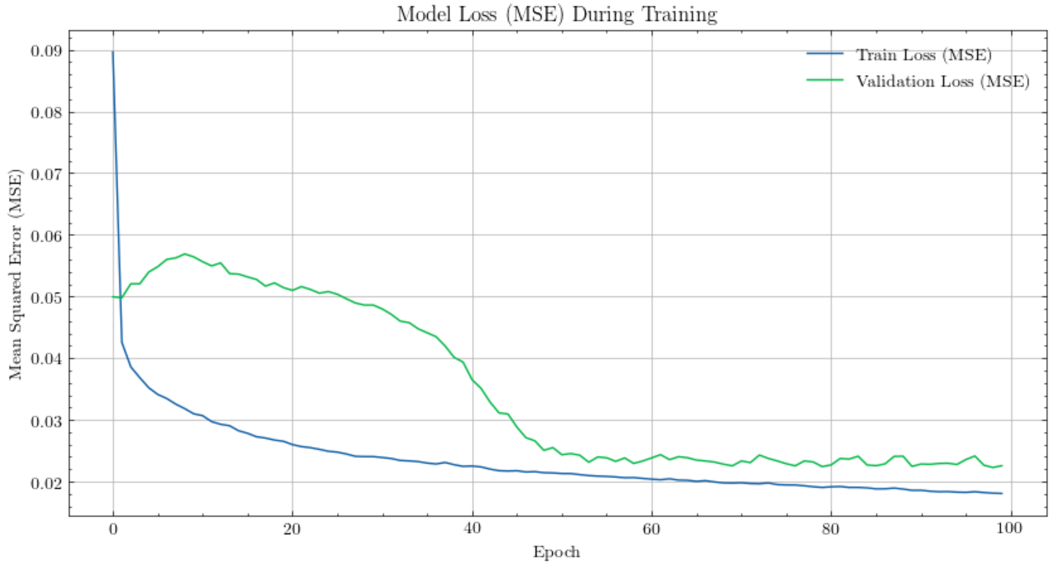


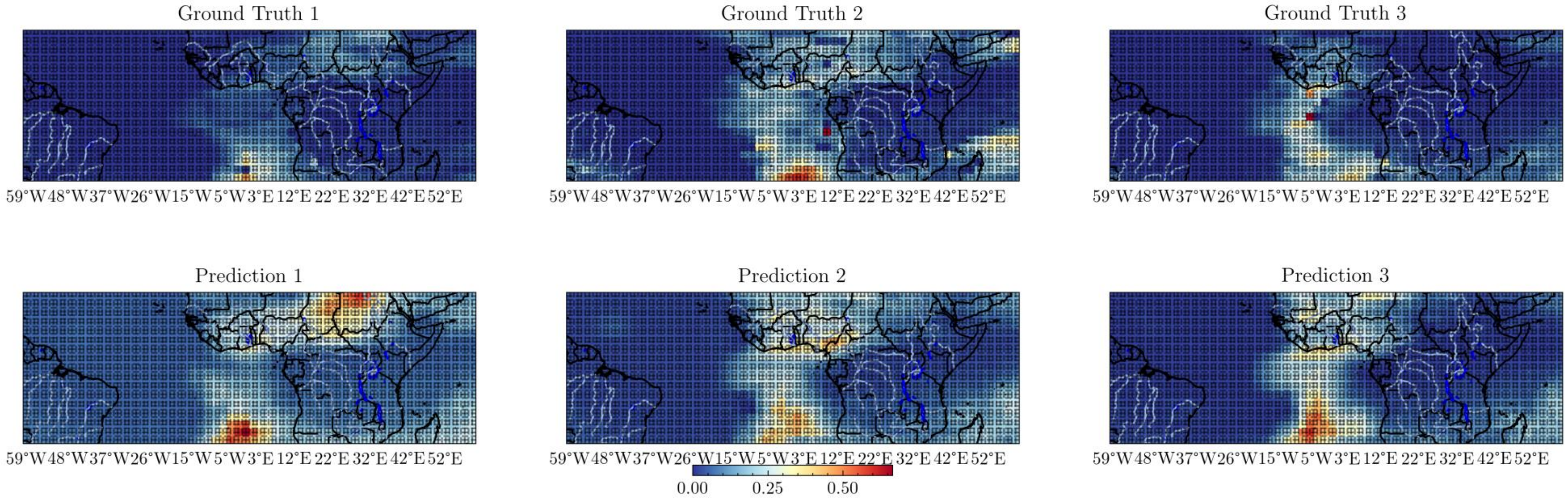


- The input to the model are constituted by sequences of rain, ivt and geopotential fields
- The output is constituted of the forecast of rainfall up to t+3
- Convolutional + Long Short Term Units neural networ for spatial and temporal analysis
- Trained and optimized using Keras on a A5000 GPU (30 min per training appr.)
- Validated against out-of-the box scenario

RESULTS

- The model has been initially trained over a large domain
- The model features over 2M parameters
- Input features: rain, IVT, temperature, SST
- The accuracy of the model is more than satisfying in a 3 month prediction
- A detailed model for the Ghana is currently under development exploiting HPC resources @ Leonardo100





Three-months forecast of the normalized rainfall and training history of the preliminar model

Benefits of the Proposed System

Enhanced Accuracy and Speed

- **Better Accuracy**: Captures complex climate patterns for diverse weather conditions.
- **High-Resolution Forecasting**: Provides precise temperature and precipitation predictions.
- **Fast Processing**: Delivers forecasts in under one minute for timely action.

Cost-Effectiveness and Scalability

- **Lower Costs**: Reduces operational expenses compared to traditional methods.
- **Scalable**: Covers larger areas or specific regions, easily updated with new data.

Long-Term Sustainability

- **Resource Planning**: Longer lead times enable efficient resource allocation.
- **Support for Agriculture**: Accurate forecasts help farmers adjust planting schedules.
- **Data-Driven Decisions**: Supports policymakers with accurate climate data.

Strengthening Data Infrastructure

- **Better Data Systems**: Encourages development of detailed geospatial data.
- **Collaboration**: Strengthens partnerships to improve data quality.

Supporting Policy and Compliance

- **Policy Support**: Helps design effective disaster risk regulations.
- **Global Alignment**: Supports international frameworks like the Sendai Framework.

Facilitating Research and Innovation

- **Local Expertise**: Encourages research in data science and meteorology.
- **Education**: Promotes new educational programs, positioning Ghana as a leader.

Role of Citizens

- **Community Engagement**: Citizens play a key role by using local knowledge and taking proactive measures. Examples include elevating house foundations, clearing drains, and relocating valuables during floods.
- **Proactive Measures**: With early warnings, communities can evacuate, protect assets, and prepare emergency supplies, reducing impacts.
- **Adaptive Farming Practices**: Smallholder farmers adapt to droughts by adjusting planting dates and using drought-resistant crops.
- **Monitoring and Data Collection**: Citizens contribute valuable data by participating in community monitoring, enhancing the accuracy of EWS.
- **Education and Awareness**: Public awareness campaigns improve responses to early warnings and encourage practices that prevent floods, such as better waste disposal and avoiding construction in flood-prone areas.
- **Challenges**: Barriers like language, literacy, and trust in authorities can affect the effectiveness of early warnings. Tailored communication strategies are essential.

Role of the Government

- **Investment in Infrastructure**: The government is responsible for building and maintaining EWS infrastructure, including hydrological networks, and communication systems.
- **Policy and Regulation**: Developing and enforcing policies for land-use planning, building codes, and environmental regulations help mitigate flood and drought risks.
- **Community Inclusion**: Inclusive policies that involve local communities ensure that EWS are tailored to their specific needs, incorporating indigenous knowledge.
- **Support for Agriculture**: Government initiatives, like agricultural extension services and water management projects, help farmers prepare for climate impacts.
- **Effective Communication**: Utilizing diverse communication channels (radio, TV, mobile alerts) ensures that early warnings reach all citizens, especially vulnerable groups.

Public-Private Partnerships (PPP)

- **Leveraging Private Sector Expertise**: Collaborations with private companies provide advanced technology, data analytics, and infrastructure support for EWS.
- **Technical and Financial Support**: Private sector resources help develop monitoring stations, communication networks, and cloud-based data processing.
- **NGO and Community Involvement**: Non-Governmental Organizations (NGOs) and community-based organizations enhance citizen engagement through education, training, and localized communication efforts.
- **Capacity Building**: Private sector involvement in training government and community members helps address technical gaps.

Conclusion

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Key Benefits of ML Integration

- **High Accuracy and Speed**: Near-real-time, accurate forecasts.
- **Cost-Effective and Scalable**: Efficient for various regions.
- **Sustainable**: Supports proactive planning.
- **Better Data Collaboration**: Enhances government and academic partnerships.
- **Community Empowerment**: Enables proactive actions.

Stakeholder Roles

- **Citizens**: Take proactive measures.
- **Government**: Invest in infrastructure and regulations.
- **Public-Private Partnerships**: Provide resources and expertise.
- **Summary**: ML-based EWS can enhance disaster management through better forecasts and collaboration, building a resilient system for Ghana.

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Surface & Groundwater Resources Potential for Irrigation of Tree Crops in Ghana in the event of rainfall scarcity: A Review

Presenters:
Anim-Gyampo, M. and Ackom, E.K.

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Outline of Presentation

Background

Aim and Objectives

Approach and Methods

Key Findings

Conclusion and Recommendation

Aim and Objectives

Aim: To comprehensively assess the potential of using surface and groundwater resources for tree crop irrigation in the event of rainfall scarcity in Ghana.

Objectives

- Assess the potential of Surface and groundwater resources for tree crop irrigation focusing on factors such as water quantity and quality, accessibility, and proximity to tree crops growing areas.
- To understand the Current situation of irrigation practices for Tree Crop
- Identify constraints to surface and groundwater resource potential for tree crop irrigation
- Propose recommendations based on the review findings

Review Methodology

- Tree Crops (TCs) production in Ghana
- Irrigation Practices in Ghana
- Rainfall Variability and Climate Change Impact on TCs
- Groundwater Potential for Irrigation of TCs
- Surface Water Potential for Irrigation of TCs
- Recommendations and Future Research

Review Findings

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A. TCs production in Ghana

- Definition;
  - TCs (cash crops) are crops cultivated over 2 or more years for income without replanting (GSA, 2023).
- Major TCs in Ghana;
  - Cocoa, Oil palm, Cashew, Rubber, Citrus, Shea nut, Coconut, Coffee, Kola, Mango, Dawadawa.
- Minor TCs in Ghana;
  - Avocado, Acacia, Baobab, Tamarind
- Mode of cultivation;
  - Predominantly rain fed; mainly small scale Smallholder farms(Armah et al., 2011)

- Factors affecting TCs cultivation/production:
  - Good agricultural environment (*Arable land, forest & water resources*)
  - Geographical location
  - Access to market (*local & International*)
  - Adequate seaport
- Significance of Tree-crop to Ghana (Social & Economic);
  - Economic
  - Align with FAO objectives
  - Contribution to several SDGs

Review Findings

Significance of TCs cont…

- Economic (ISSER, 2020);
  - Contribute to macro economy (constitute approx. 85% annual agricultural export
  - Reliable income to farmers (about 1.6m SS farm families involved in Ghana)
  - Job/employment along the value chain
  - Improve food security
- Aligns with FAO objectives (GSA, 2023)
  - Sustainable agriculture
  - Food security
  - Improved Nutrition
  - Livelihood improvement
  - Environmental conservation

- Contributes to several SDGs (TCDA, 2020)
  - Poverty alleviation (income/revenue generation)-SDG 1
  - Food security improvement-SDG2
  - Improved nutrition (Diet improvement)
  - Reforestation/Biodiversity conservation-SDG 13 & 15
  - Restore degraded land/habitat for wildlife-SDG 5

Review Findings

TCs production in Ghana cont…

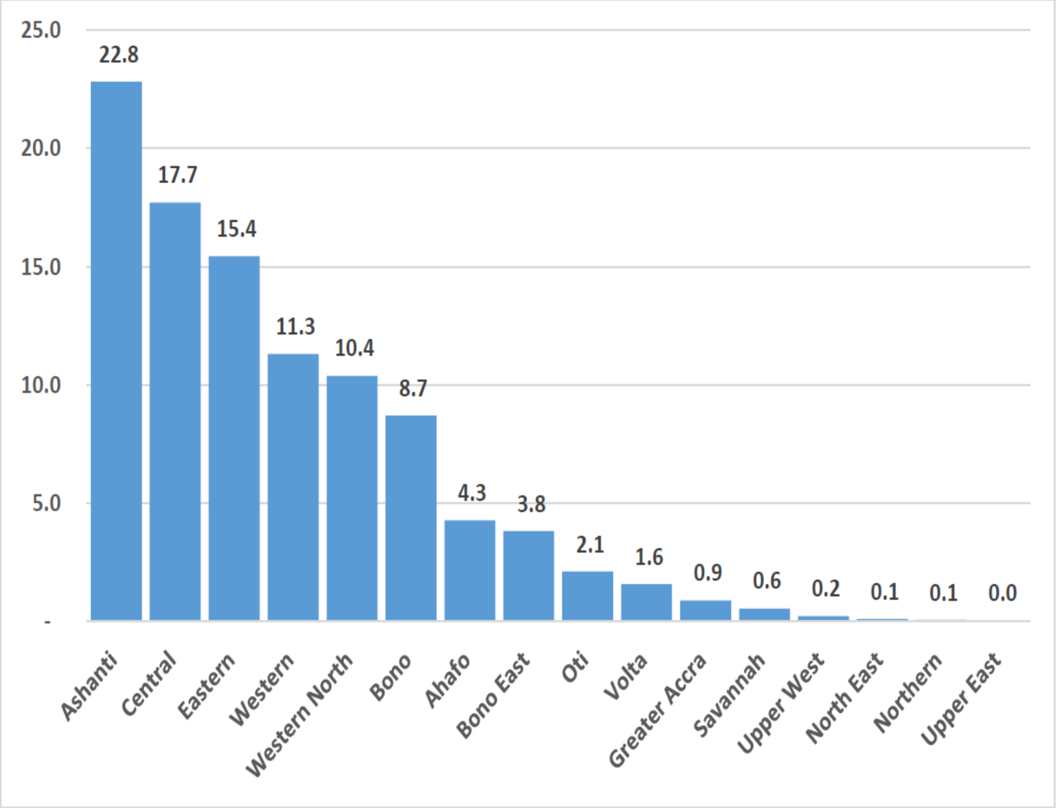

Figure 1: Major TC growing areas in Ghana

- Major TC growing regions in Ghana (AR> CR> ER> WR>WNR>BR..)
- About 78% of annual TC prod. occur in 5 regions- AR, CR, ER, WR and WNR.
- These 5 regions are all located predominantly in the Pra Basin of Ghana.
- All are predominantly located within the Semi-deciduous and Rain forest Agro-Ecological Zones (Fig. 1)

Review Findings

TCs production in Ghana cont…

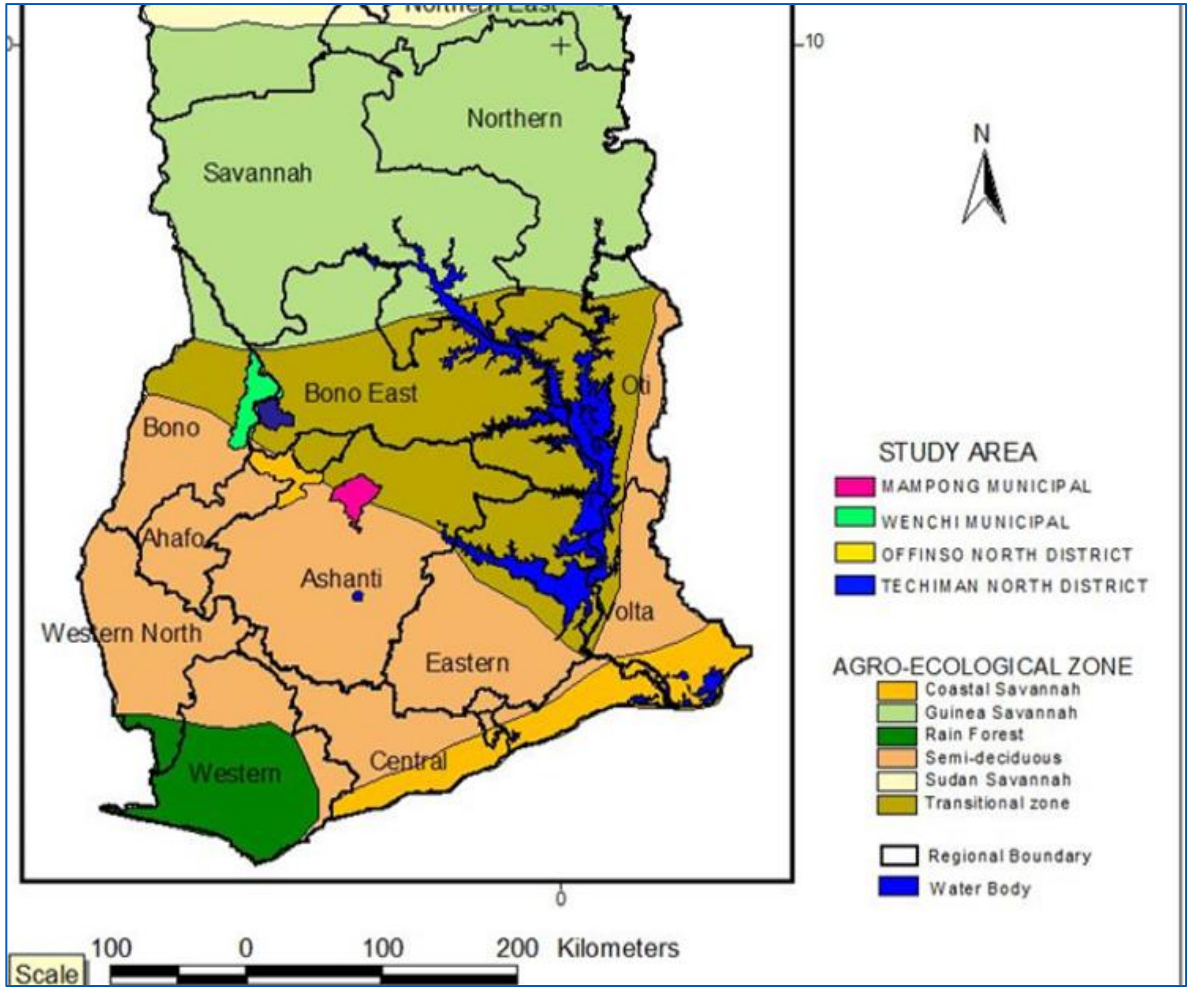

Figure 2: Agro-ecological zones of Ghana

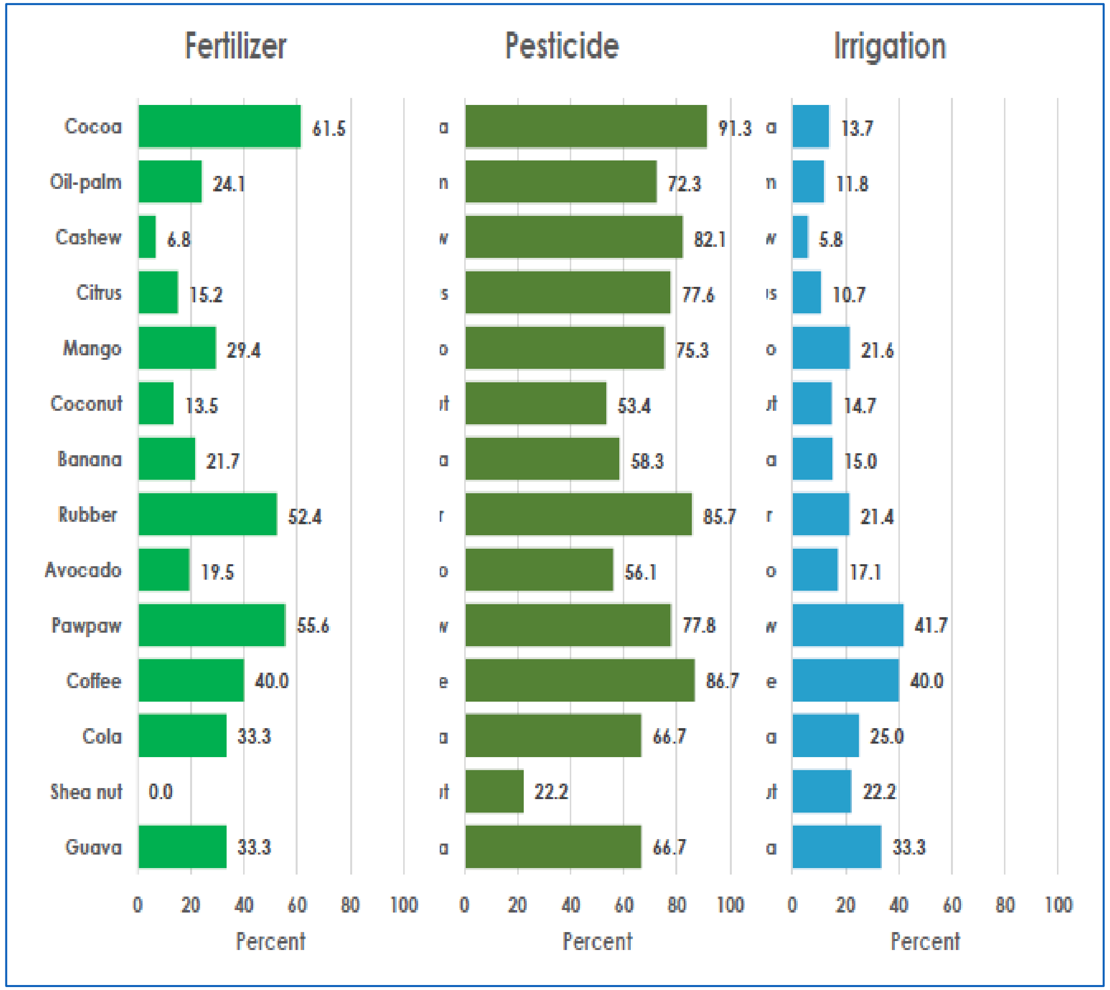

Figure 3: Status of TC irrigation in Ghana

Studies on GWP in Ghana

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- Gumma and Pavelic (2012):

Mapping of groundwater potential zones across Ghana using remote sensing, geographic information systems, and spatial modeling. Environmental Monitoring Assessment (2013) 185:3561–3579 DOI 10.1007/s10661-012-2810-y

- Akpoti et al., (2023):

Integrating GIS and remote sensing for land use/land cover mapping and groundwater potential assessment for climate-smart cocoa irrigation in Ghana. Scientific report, Nature Portfolio. https://doi.org/10.1038/s41598-023-43286-5

Review Findings

Studies on GWP in Ghana cont…

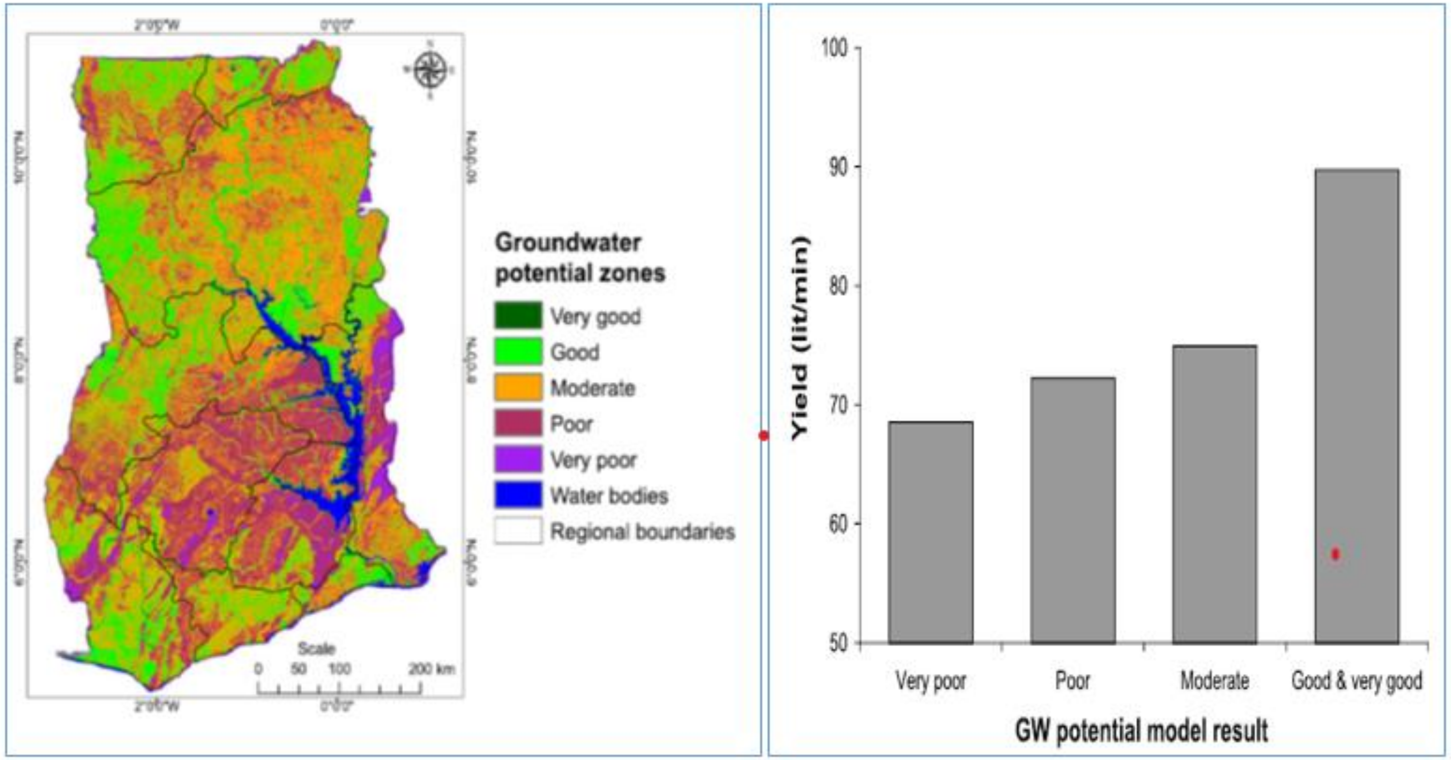

Figure 4: GWP Model (Gumma and Pavelic, 2012)

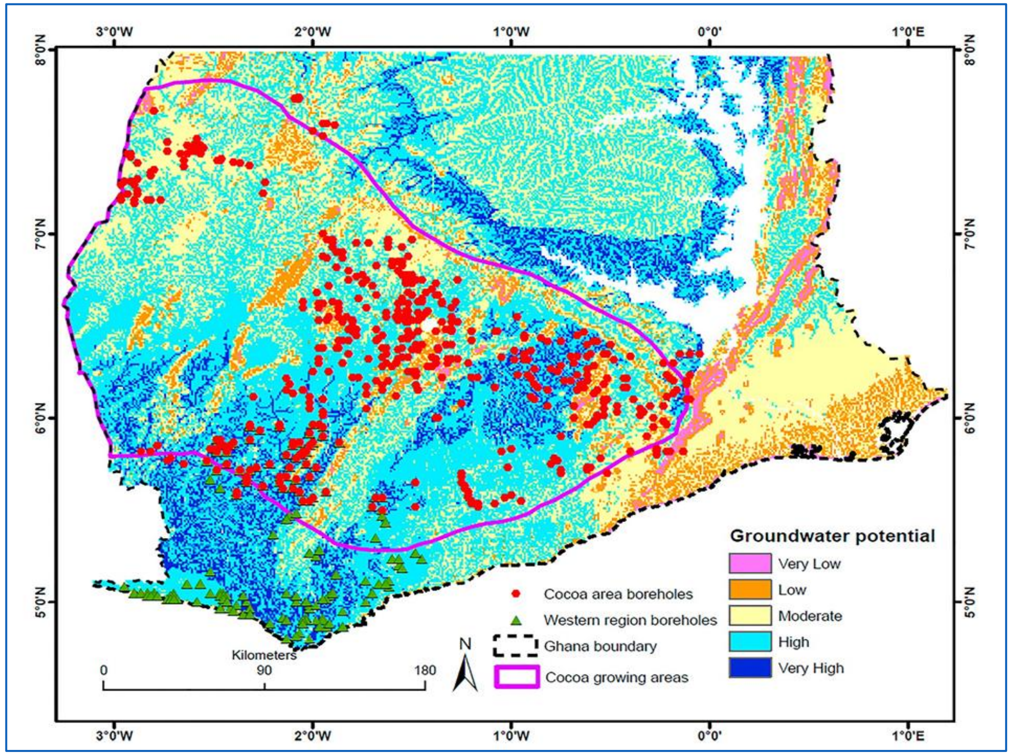

Figure 5: GWP Model (Akpoti et al., 2023)

Review Findings

Studies on GWP in Ghana cont…

- Limitations Gummah and Pavelic (2012)
  - ➢ All the 2650 boreholes from five (5) regions of Ghana, used for the ground trothing were mostly located in areas (CR, GAR, VR, UER & UWR).
  - ➢ With the exception of CR, all the remaining 4 regions do not fall within the prominent TC production areas in Ghana.
  - ➢ Therefore, the GWP map and model produced may not be a very useful source of data for assessing the GWP for irrigation in TC growing areas in Ghana.

➢ Secondly, the ground trothing to validate model was carried out by measuring the air-lift yield of the bhs.

➢ Air-lift yields are not the appropriate factor for selection the appropriate submersible pump for mechanization for water supply for domestic, industrial or irrigational purposes.

➢ BUT rather, the Safe yield. Therefore data from GWP model above are unreliable for the assessment of irrigational potential.

Review Findings

Studies on GWP in Ghana cont…

- Limitations Akpoti et al. (2023)

  - Lack of detailed investigation into the dynamic characteristics groundwater resources in the study area.
  - Limited account for the complex hydrological processes governing water resource dynamics in the region.
  - The study did not fully capture the implications of these processes on the feasibility of implementing sustainable TC irrigation practices.

- Limitations Akpoti et al. (2023)

  - All the boreholes used for the ground truthing were mostly located in areas (CR, GAR, VR, UER & UWR).
  - With the exception of CR, all the remaining 4 regions did not fall within the major TC production areas in Ghana.
  - Thus, the GWP map and model produced may not be a very useful source of data for assessing the GWP for irrigation in TC-growing areas in Ghana.

Review Findings

Rainfall Variability and Climate Change Impact on Tree Crops

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- **Rainfall Variability** Agodzo et al. (2023)

  - Studies indicate an **elevation in evaporation rates** (as high as 70%), a **reduction in highly erratic precipitation patterns**, and recurrent severe flooding and drought occurrences (Agodzo et al., 2023). Owusu et al., 2016; Bawa et al., 2015;

  - Changing duration of rainfall season with delayed onset and early cessation of the rains due to climate variability, impacting agricultural production a great deal (Agodzo et al., 2023).

- **Climate Change Impact on Tree Crops** Akpoti et al. (2023)

  - Climate change and variability associated with extreme events (e.g., floods and droughts), threaten the sustainability of tree crop production (Bawakyillenuo et al., 2020; Akpoti et al., 2023)

  - A primary dependence on surface water for irrigation may yield severe repercussions for the livelihoods of smallholder farmers, food security, economic sustainability, and the overall progress of sustainable development (Akpoti et al., 2023)

Review Findings

Surface Water (SW) Potential for Irrigation of Tree Crop

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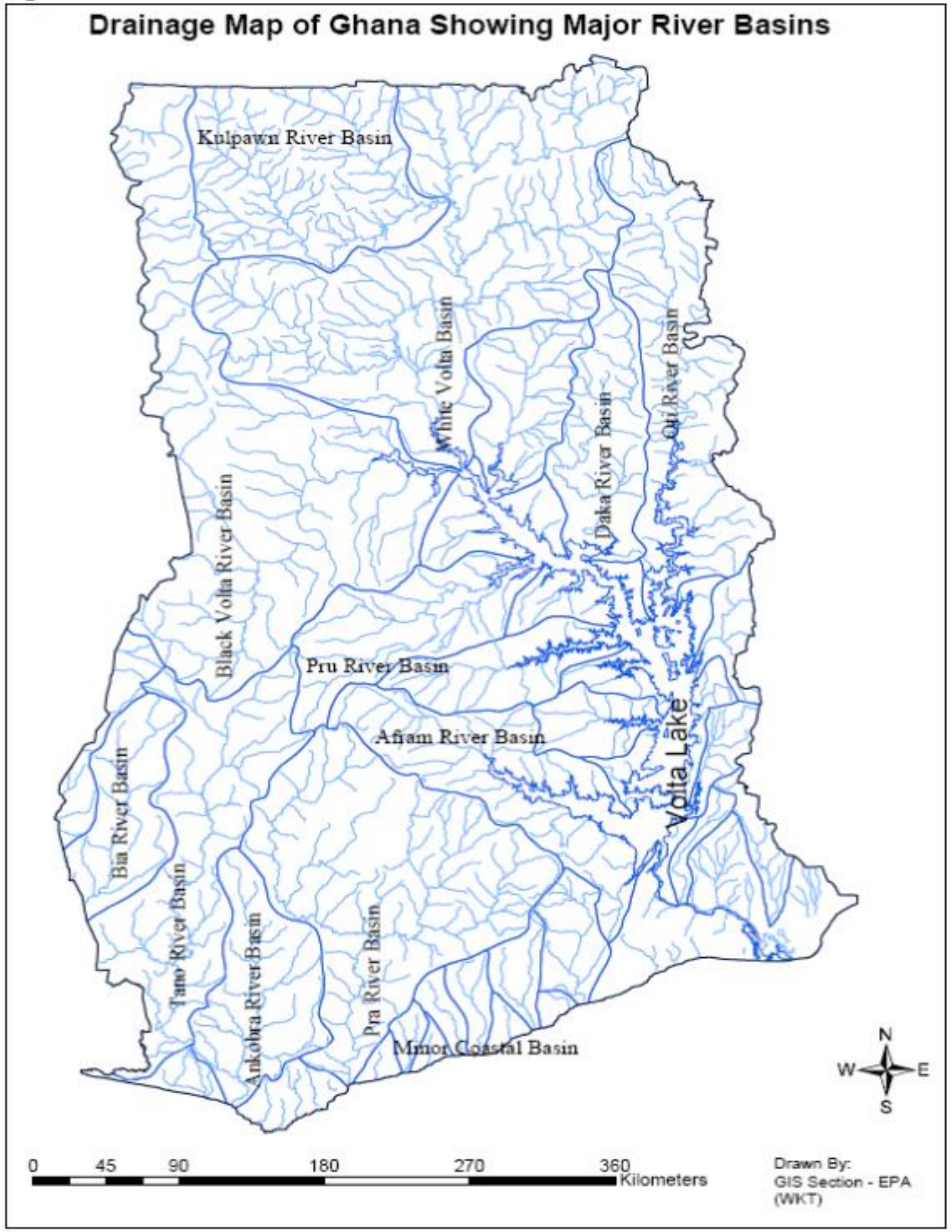
Ghana's SW resources are distributed across several river basins characterized by varying seasonal precipitation and runoff patterns

- ***Volta Basin*** - White Volta, Black Volta, and Oti Rivers
- ***South-western basin***: Pra, Ankobra, Tano, and Bia
- ***Coastal basin***: Densu, Ayensu, Amissa, Nakwa and Kakum



Review Findings

Surface Water (SW) Potential for Irrigation of Tree Crop

1. Surface Water Availability

Ghana's extensive network of rivers and basins offers a substantial surface water resource base:

- **Volta River Basin**: Covers 70.1% of Ghana's land area and supports irrigation in multiple regions.
- **Regional Distribution**: Significant surface water irrigation activities are concentrated in Northern Savannah (49%) and Coastal Savannah (26%) zones, covering tree crop-producing regions like Volta, Ashanti, and Eastern regions.

2. Existing Irrigation Systems and Utilization

(Ghana Irrigation Mapping Report, 2022;)

Surface water already supports a significant proportion of irrigated agriculture in Ghana:

- **Informal Surface Water Irrigation**: Accounts for approximately 84% of all irrigated land, estimated at 189,000 hectares.
- **Tree Crop Irrigation Potential:** Tree crops like mango, cashews, and cocoa are highly adaptable to surface water irrigation systems due to their moderate water needs and resilience in humid and savanna ecological zones.
- **Scalability of surface-water irrigation** large-scale schemes like Tono and Kpong (irrigate 2,500 hectares of crops) showcasing the **scalability of surface-water irrigation**

Review Findings

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Surface Water (SW) Potential for Irrigation of Tree Crop

3. Economic Viability

Surface water irrigation systems are cost-effective for farmers:

- **Investment Costs:** Small-scale surface water systems require \$500–\$1,000 per hectare, making them affordable for smallholder farmers.
- **Increased Yields and Incomes:** Irrigation stabilizes water availability, leading to consistent yields and higher returns from high-value tree crops such as cocoa, which contributes significantly to Ghana's agricultural GDP.

4. Technical Potential (Ghana Irrigation Mapping Report, 2022; IWMI, 2022)

The technical feasibility of surface water irrigation is well-documented:

- **Irrigation Potential Area:** Between 0.36 to 1.9 million hectares of land is estimated to be suitable for surface water-based irrigation in Ghana. The adaptability of this area for tree crops is significant given their spatial distribution.
- **Regional Focus:** In the Upper East region alone, between 130,000 and 190,000 hectares are suitable for small-scale irrigation development.

Review Findings

Surface Water (SW) Potential for Irrigation of Tree Crop

5. Challenges and Adaptation Strategies

While challenges such as high evaporation rates (as high as 70%) affect surface water availability, strategies such as:

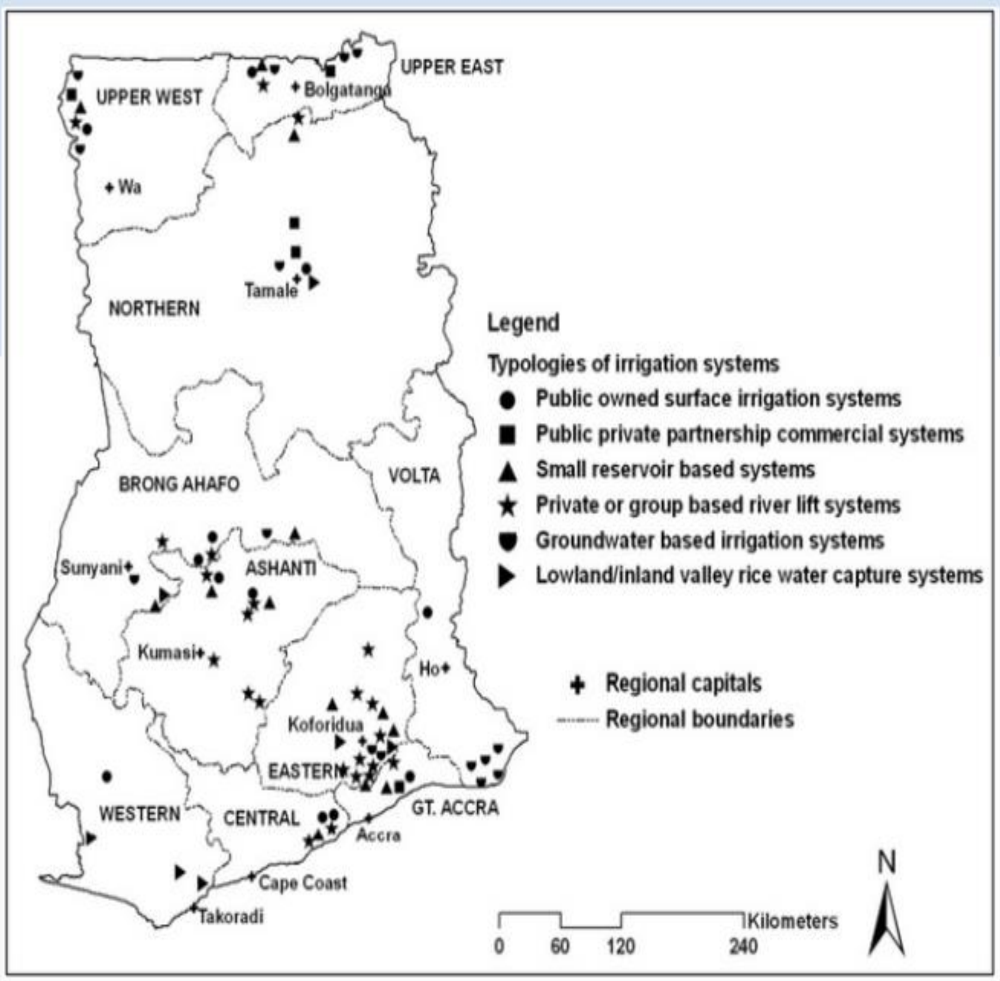
- **Solar Pump Integration:** Solar-powered irrigation systems can offset these inefficiencies, with over 2.3 million hectares suitable for solar irrigation development.
- **Efficient Water Management:** Gravity-fed systems and water storage technologies can reduce losses and optimize resource use for tree crop irrigation.
- **Climate Adaptation:** SW help mitigate risks associated with erratic rainfall by providing a controlled water source for TCs

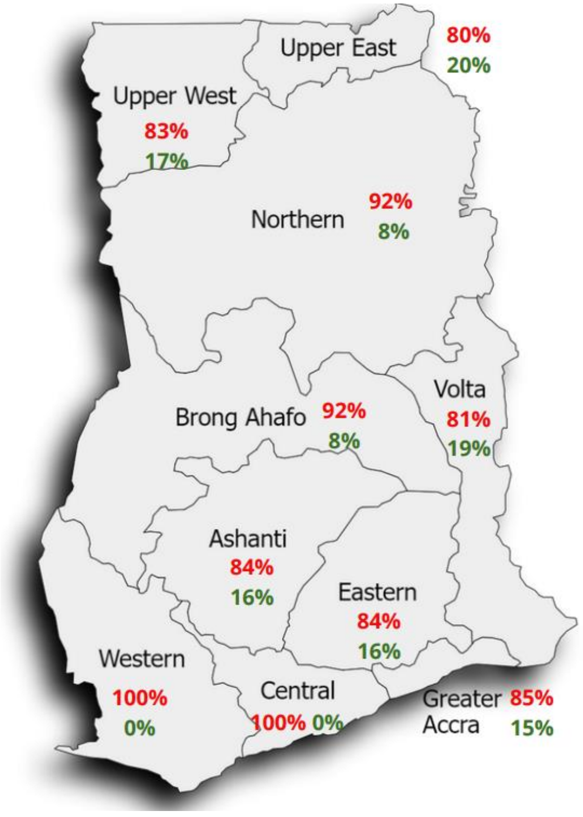
6. Quantitative Projections

- **Expansion of Surface Water Systems**: Doubling the irrigated area using surface water could increase tree crop yields by stabilizing dry-season production.
- **Economic Returns**: Investment in irrigation for tree crops could boost GDP contributions from the agricultural sector, particularly high-value crops like cocoa.

Review Findings

- **Irrigation Practices in Ghana**
- **Irrigation Topologies in Ghana**
  - GIDA maintains 22 major projects for nearly 17,000 ha of irrigated land with the Tono and Kpong irrigation projects leading the way in terms of area (around 2500 ha).
  - The Small-Scale Irrigation Development Project (SSIDP): 22 schemes
- Small Farms Irrigation Project (SFIP): 6 schemes.





XX% Surface water irrigation
XX% Ground water irrigation

Conclusion

- There is strong evidence of sufficient potential for surface water and groundwater resources to support tree crop irrigation, particularly during periods of rainfall scarcity.

- However, the challenges of infrastructure, management, climate change impacts, and the role of groundwater must be addressed.

- Effective management of SW resources for Tree crop irrigation in Ghana requires a multifaceted approach incorporating participatory management, technological tools, governance, and health considerations. These enhance water use efficiency, optimize resource allocation, and ensure sustainable agricultural practices.

- Already existing climate change adaptation strategies by Farmers. However, limited means at their disposal, but the transition to irrigated agriculture also leads to an increase in income up to 11%.

Conclusion Cont…..

- Existing studies on the potentiality of utilising groundwater as a source of reliable water supply for sustainable irrigation of TCs in Ghana are largely based largely on inferences.

- Airlift yields were used in these studies for validation of the GWP models.

- Airlift yields do not represent the true yield and aquifer for water supply for domestic, industrial or irrigation purposes but safe yield.

- It is therefore worth to note that the suggested mean minimum yield of 65 l/min as basis to evaluate the reliability of groundwater resource as a potential for irrigation of TCs is not a reliable framework.

The way forward (Recommendation)

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➢ Participatory Irrigation Management (PIM) Approach

Build an active stakeholder involvement in decision-making processes using the PIM Approach. This depends on factors such as farmer participation, resource availability, and adequate financial and technical support from governmental and non-governmental organizations.

➢ Technological and Modeling Approaches

Develop Surface Water balance models (both demand and supply) for specific irrigation dams/reservoirs targeting TC growing areas (eg. Pra Basin). This optimizes reservoir management by analyzing water availability and guiding water allocation strategies to ensure drought preparedness, water conservation measures, and managing water releases during critical periods.

Integrate GIS and remote sensing technologies to map land use and assess surface water potential, crucial for climate-smart irrigation strategies and maintaining agricultural productivity during dry spells.

➢ Effective Governance and Policy Frameworks

Addressing governance challenges through the implementation of Decentralized systems, regulatory mechanisms, and adequate institutional resourcing.

The way forward (Recommendation) cont…

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➢Health and Environmental Considerations

Monitoring surface water resources is crucial to prevent health risks from contaminants. Developing improved water sources and avoiding synthetic fertilizers can reduce these risks and ensure safe water for irrigation and domestic use.

➢Quantitative determination of groundwater in storage

It is critical that a comprehensive study of the various yields of existing boreholes within the TCs growing areas be fully appraise to establish the true minimum reliable yield of boreholes as a basis of evaluating the potential of groundwater resources for irrigation of TCs in the event of rainfall scarcity in TCs growing areas in Ghana

➢Qualitative determination of groundwater in storage

Even though not much studies on groundwater suitability for irrigation has been conducted within the TCs growing areas. There is therefore a critical need to carry out a comprehensive study to establish the suitability or otherwise of groundwater for irrigation within the TCs growing areas in Ghana.