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Desert Locust Decision Support for Improved Agriculture Production

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Abstract

The desert locust (*Schistocerca gregaria*) is widely considered to be the most dangerous migratory pest species due to its rapid reproductive capacity, long-distance migration potential, and devastating impact on agriculture and ecosystems. In addition, desert locust populations have increased rapidly, and swarms have invaded eleven countries in West Africa, severely disrupting agricultural production in vulnerable areas already facing security challenges. Timely and accurate information on the desert locust through remote sensing is critical for effectively managing and improving agricultural production, especially in West Africa, where such information is scarce. The objective of this work is to enhance the monitoring and prevention efforts against desert locust outbreaks by integrating remote sensing and decision-support tools. The tool identifies locust development and gregarization zones in order to assess the risk of outbreaks and support decision-making processes. It combines a model on the presence or absence of transient phases of the species, biotope ecological conditions, and gregarization thresholds for both juveniles and flying adults. In this paper, the Google Earth Engine platform is used to monitor eco-meteorological conditions in key desert locust survival and breeding areas using high-resolution geospatial data. The improvement initiative covers certain aspects of the user interface, real-time data updates, and a fully operational set of eco-climatic indices impacting locust multiplication. These advancements contribute to a more robust decision-support system for locust early warning and control in West Africa.

Keywords: Desert Locust, geospatial data, frontline countries, West Africa

Introduction

The desert locust (*Schistocerca gregaria*) is a species of locust—a periodically swarming, short-horned grasshopper in the family Acrididae. It is primarily found in arid and semi-arid deserts of northern and eastern Africa, Arabia, and southwest Asia, as well as Africa in general, and West Africa in particular (Yeneneh, 2005). Ceccato et al. (2007) reported that desert locust populations increased rapidly, and swarms invaded eleven countries in West Africa, severely disrupting agricultural production in areas already facing security challenges.

According to the FAO (2020), the desert locust is the most destructive migratory pest in the world. They are ravenous eaters that consume their own weight per day, targeting food crops and forage. This voracious feeding behavior poses a significant threat to food crops and pasturelands, exacerbating food security concerns in affected regions.

The desert locust is often considered one of the most important and dangerous of all migratory pests in the world (Kietzka et al., 2021). The desert locust, one of about a dozen species of locusts, is a swarming short-horned grasshopper that can migrate great distances during its gregarious phase (Simpson and Sword, 2008). In general, the desert locust breeds extensively in semi-arid zones extending from West Africa through the Middle East to Southwest Asia, threatening the livelihoods of populations in over 65 countries (Kimathi et al., 2020).

According to Cressman (2016), the systematic collection and mapping of data showed that desert locust breeding coincided with rainfall, both seasonal and sporadic, and migration was associated with downwind movements. Steedman (1988) reported that the external appearance of the locust also changes: solitary adults are brown, whereas gregarious adults are pink (immature) and yellow (mature). During invasion periods, gregarious adults form swarms that can be carried by the wind over great distances and threaten crops and pastures in about 50 countries (Ceccato et al., 2007). This particularity of the Sahelian zone requires greater attention to the harmful factors that can negatively impact harvests and threaten food security in these areas.

In 1994, FAO established the “Emergency Prevention System for Transboundary Animal and Plant Pests and Diseases” (EMPRES Desert Locust Component) to strengthen national control teams and improve early warning systems (Ceccato et al., 2007). Based on consultations and user needs assessments, the approach focused on the development of a regional service for monitoring desert locusts—one of the region’s major locust pests that have caused several food crises and famines. The objective of the work is to enhance monitoring and prevention efforts against desert locust population growth. The models determine locust development and gregarization zones to calculate the risk of outbreaks and assist decision-makers.

Materials and methods

Study areas and overall framework

In this research, two different datasets comprise both satellite imageries and field data. The field data are collected by information officers in the frontline countries of Mauritania, Mali, Niger, and Chad. The data collection process focuses on the level of gregarious areas or biotopes, as illustrated in Figure 1. During each agricultural season, information officers systematically collect data from the gregarious zones, which are centralized within the FAO Reconnaissance and Management System of the Environment of Schistocerca (RAMSES) database. The dataset includes site coordinates, site name, surface area, habitat type, rainy season start date, locust presence/absence (Y/N), vegetation type and density, soil moisture, dry spell, wet spell, infestation status, locust type, confirmation, and reliability of presence.

Limited financial and material resources, along with insecurity in most monitored areas, necessitate military escorts, thereby constraining the technicians' operational flexibility. Consequently, the integration of Earth observation data, particularly P-Locust, offers a potential solution by prioritizing areas for field visits based on predefined parameters. By integrating ground-based observations with remote sensing data, this approach enables a comprehensive analysis of locust population dynamics, facilitating the development of early warning systems and effective management strategies.

To effectively achieve the objectives listed above, high-resolution satellite data are required for improvement initiatives to cover certain aspects of the user interface, data updates, and a fully operational eco-climatic index that impacts locust multiplication. For the visualization of soil moisture characteristics, SMAP Level-4 (L4) Soil Moisture top layer (0–10 cm) data are used, with a resolution of 11 km, providing uninterrupted soil moisture data. Landsat 9 Collection 2 Tier 1 is used for calculating the Normalized Difference Vegetation Index (NDVI). Aggregated Daily ERA5-Land level (0–7 cm) is used for computing soil moisture. The precipitation curves are derived from Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) data, which provide precipitation estimates based on rain gauges and satellite observations.

The Land Surface Temperature data, sourced from the MOD21A1D dataset, are generated on a daily basis using Level 2 gridded intermediate products. The ERA5-Land Reanalysis dataset provides horizontal and vertical wind components (u and v), which are used to compute the mean wind speed within a designated geographical area.

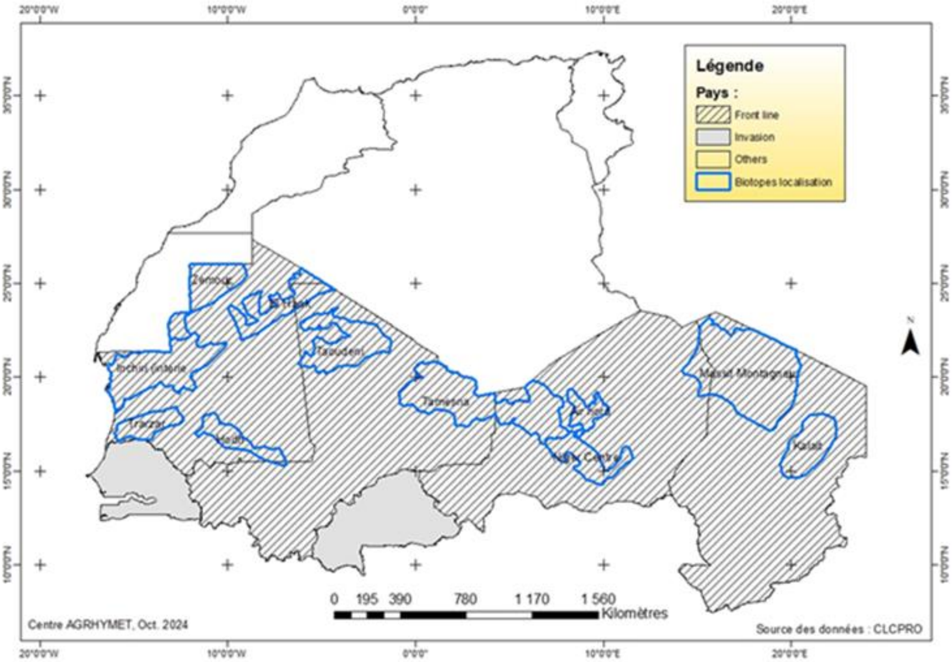

Figure 1: Localization of biotopes as areas of interest for Locust in the desert-frontline countries

The Shuttle Radar Topography Mission (SRTM) digital elevation data was utilized to incorporate geomorphological information into the platform. This dataset represents an international research initiative that acquired digital elevation models on a nearly global scale.

The forecast component for the sub-seasonal forecasts is a climate prediction model developed using a participatory approach. This model is a coupled system consisting of multiple components, including an atmospheric model, an ocean model, a land/soil model, and a sea ice model. These components collaborate to deliver a comprehensive and precise representation of current and future climate conditions.

Methods

The study enhances locust population monitoring and preventive measures via a real-time ecological monitoring platform and a predictive model utilizing Google Earth Engine (GEE). This work seeks to enhance the operational capacity for Desert Locust risk, improving information accessibility for decision-makers. This will involve developing a robust workflow and a user-friendly graphical interface to streamline analysis for information officers, focusing on prioritizing data collection sites. Figure 2 presents a Unified Modeling Language (UML) diagram outlining the locust platform analysis process.

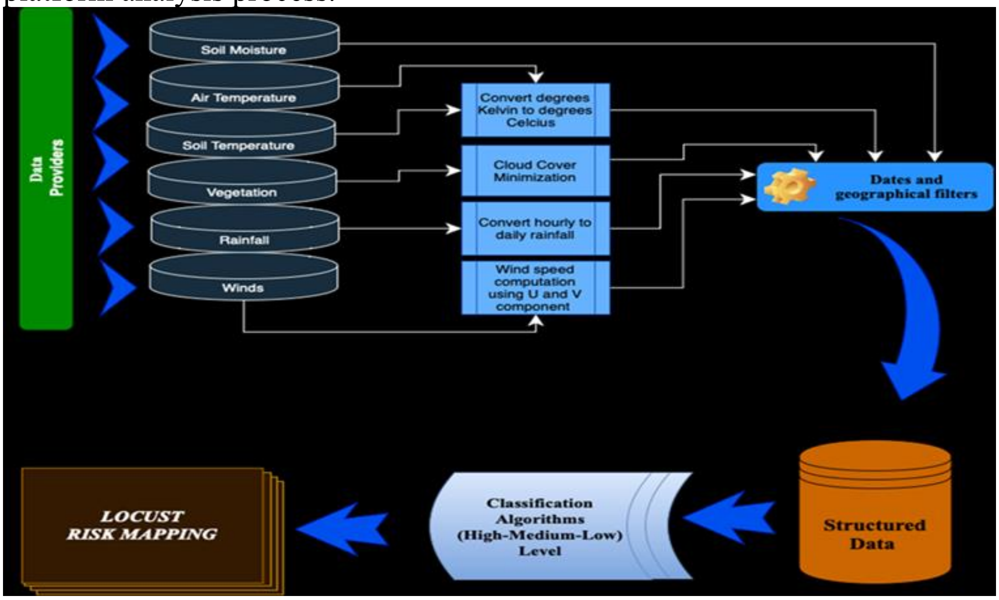

Figure 2: Unified Modeling Language (UML)diagram

Processing and classification

The platform's analysis focuses on pixel categorization into three classifications: low, medium, and high. Classification is critical, with algorithm selection determined by the nature of the classification problem (e.g., class count and type), data statistical properties, input feature quantity, and computational efficiency. For Locust, decision trees (DTs) were selected as the classification algorithm due to their intuitive nature, which provides an effective foundation for classification tasks. The labeling process is framed as a series of sequential decisions rather than a single complex choice. Decision sequences constitute the branches of the decision algorithm (DA), with tests conducted at the nodes, while the leaves represent the labels (see Figure 3).

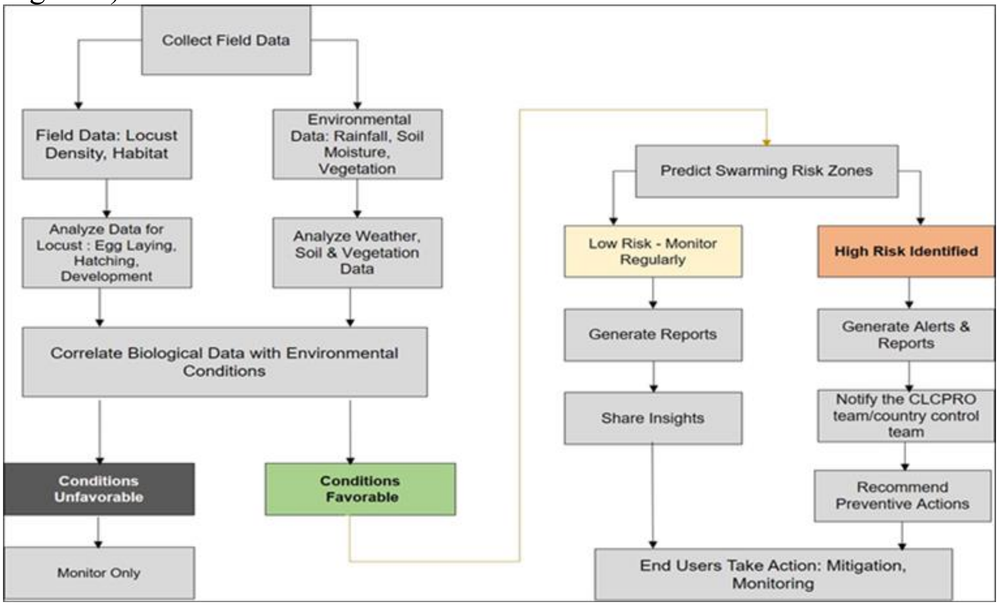

Figure 3: Decision tree

Results

Suitable breeding map for different Desert Locust species based of Field data

Peterson (2006) reported that the environmental niche of a species is considered to consist of three components: abiotic conditions (e.g., temperature, humidity, and soil type), biotic conditions (e.g., species interactions, predation, invasion), and accessibility, which describes non-biotic conditions.

For this study, suitable breeding analysis was conducted based on abiotic conditions such as soil moisture and vegetation condition. In this investigation, we considered only the locations of detected areas called biotope locations or breeding locations.

Based on the overlaying of desert locust suitability areas with the vegetation layers (Figure 4) of those countries, it was predicted in 2021 that the likelihood of desert locust breeding was high in the central regions of Niger and Mauritania. However, in other countries, such as Mali and Chad, most of the breeding populations occurred in regions with low or absent vegetation.

Field data collection is carried out by information officers in the frontline countries of Mauritania, Mali, Niger, and Chad. Data are collected at the level of gregarious areas or biotopes, as illustrated in Figure 4A, B, and C. These figures reflect the type of field data collected, which can be combined with Earth Observation data to achieve effective monitoring. Figure 4A and B show the updated gregarization areas and vegetation conditions in frontline areas, and Figure 4C shows the updated gregarization areas and the spatial distribution of soil moisture.

When conditions are favorable for reproduction (i.e., moist sandy/clay soils for oviposition and green vegetation for hopper development), desert locusts increase in number and change their behavior from solitarious to gregarious, as reported by Bennett (1975). Under optimal temperature and habitat conditions, a single female can produce 16 to 20 viable offspring in a single generation (WMO, 2016).

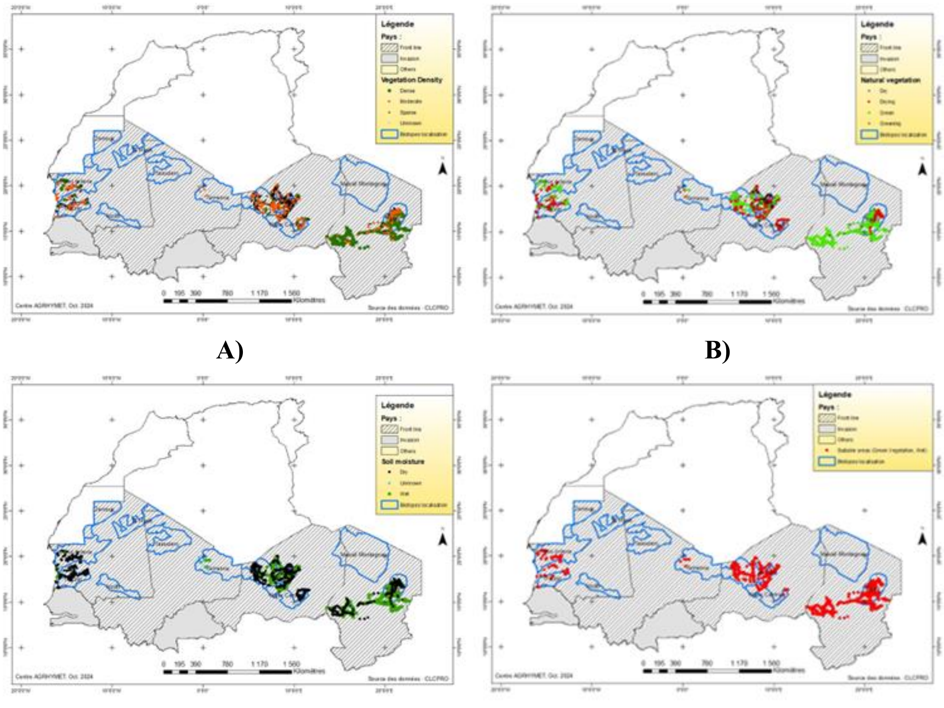

Figure 4: Spatial distribution of A.) vegetation density, B.) natural vegetation, C.) soil moisture, D.) suitable areas for Desert Locust development reflected this situation during 2021.

The breeding suitability map was computed using parameters collected from fields such as Soil moisture, vegetation density, natural vegetation (see Figure 4 A, B and C) reflected this situation during 2021. According to Symmons and Cressman (2001), the desert locust hopper development depends on the weather conditions and the vegetation cover. The results ofthe breeding suitability map are presented in Figure 4D. For a better interpretation, the suitable breeding zones are spatially distributed in the center of Niger, Chad and west of Mauritania. The results indicate that areas not suitable for breeding include Mali. An overlaid layer of the desert locust suitability map in red indicates the areas with the onset of vegetation and soil humidity favorable for desert locust. This study shows how climatic parameters and vegetation influence the spatiotemporal dynamics of locust occurrence.

Locust platform

Youngblood et al. (2022) stated that locust development is highly dependent on the state of its ecosystem, meteorological conditions, and land use practices. There are a vast number of existing datasets that can be used for locust management. The platform that evaluated the spatial distribution of the breeding conditions is important because it helps planners make sustainable land use decisions (Basu et al., 2020). The Locust platform serves as a tool for monitoring and analyzing locust population dynamics for regional decision-makers. Enhancements enable users to customize selections for specific geographic areas, timeframes, and countries, thereby improving interactivity. Users can access a comprehensive range of weather indices with defined thresholds for breeding and invasion risk, facilitating real-time insights into locust dynamics.

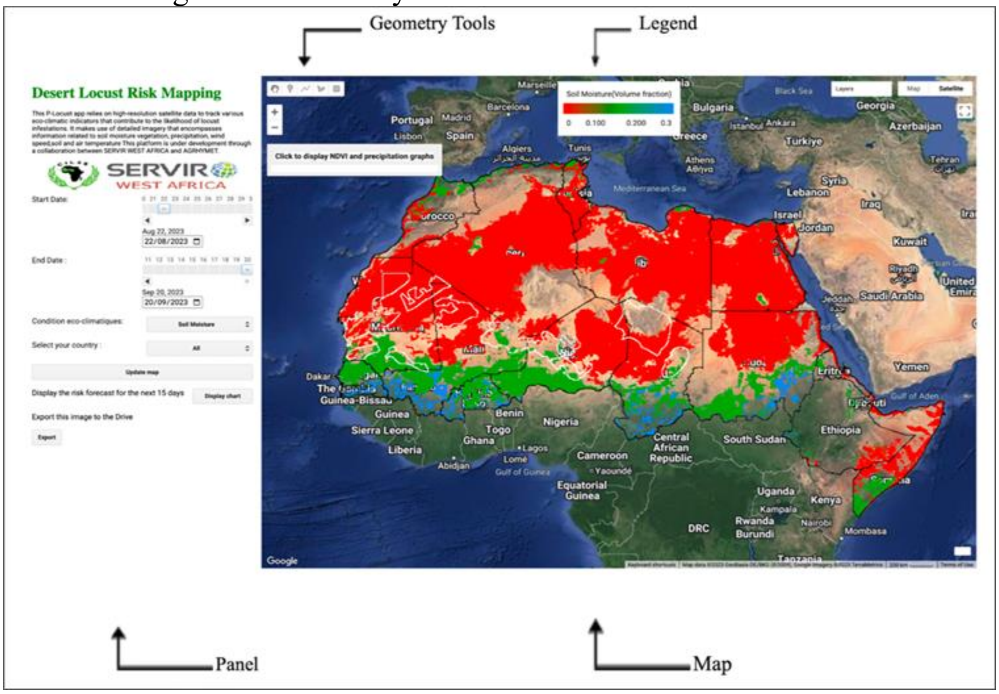

Figure 5: Platform interface, Link:
https://code.earthengine.google.com/?scriptPath=users%2Fkkidia3%2Fawash%3AP_Locust
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Additionally, the platform now includes a vegetation layer based on the NDVI index, aiding in the identification of potential locust habitats in targeted countries, thereby allowing users to evaluate habitat suitability and mitigate infestation risks. Integrating interactive widgets, intuitive functionalities, and user-friendly visualizations has improved the comprehension of eco-climatic factors associated with locust risk. The platform also visualizes eco-climatic conditions from the past 30 days and provides forecasts for various parameters, enabling users to anticipate future locust population fluctuations. The educational aspect, featuring machine learning courses, has further augmented the platform's analytical capacity. In summary, the outcomes of this project have evolved the locust platform into a dependable and invaluable resource for locust geospatial information and analysis, offering users unparalleled customization and insights into locust environmental dynamics. This study provides a reliable tool that will guide survey teams to monitor potential breeding areas.

Discussion

The results achieved on the P-Locust platform represent a significant leap forward in our ability to monitor and analyze locust dynamics with precision and user-friendliness. The comprehensive improvements made have led to a platform that empowers users to customize their selections, including specific geographical regions, timeframes, and countries, enhancing the interactive experience. Users can seamlessly access a wide array of meteorological indices, each with specific thresholds for reproduction and invasion risk, providing real-time locust dynamics information. Furthermore, the platform now offers a vegetation classification layer based on the NDVI index and climatic factors, aiding in the identification of potential locust populations within specific countries, enabling users to assess locust habitat suitability and predict infestation risks. It has been increased with interactive widgets, intuitive features, and user-friendly visualizations, making it easier for users to understand the eco-climatic factors related to locust risk.

Additionally, the platform visualizes various eco-climatic conditions over the past 30 days and provides predicted estimates for different conditions, allowing users to anticipate future fluctuations in locust populations. Also, the results of this study have transformed the P-Locust platform into a dependable and invaluable resource for locust geospatial information and analysis, offering users unprecedented customization and insight into locust dynamics.

Conclusions

The platform now offers a user-friendly and customizable interface, making up-to-date information easily accessible. This work represents a significant step toward addressing the challenges posed by Desert Locust infestations. Additionally, continuing to enhance the capacity of technicians responsible for information on Google Earth Engine (GEE), a new feature of integration of sub-seasonal forecasts data is needed to improve the tools and Dissemination of information were needed. According to this study, several environmental factors influence the presence of locusts in West Africa.

Precipitation, the density of vegetation cover, relative humidity, and temperature in the gregarization areas were distinguished as most influential factors for seasonal outbreaks of the locust population. Further work was needed to investigate the influence of the sub-seasonal information on the breeding suitability. Regular field data collection and investigation should be employed to achieve better results for the real-time study and early warning system.

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Data Availability: Data availability: The data presented in this study are available here:
https://code.earthengine.google.com/?scriptPath=users%2Fkkidia3%2Fawash%3AP_Locust

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Conflict of Interest: The authors reported no conflict of interest.

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