Sudan Geographical Journal

مـجـلـة الـسـودان الـجـغـرافـيـة

Faculty of Geographical and Environmental Sciences, University of Khartoum- كلية علوم الجغرافيا والبيئة، جامعة الخرطوم

Volume 1 July 2017 Number 2

The Geography of Desert Locust in Sudan; Depicting of Niches using Modis Satellite Images

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Abstract: Recent FAO reports have mentioned several outbreaks of Desert Locusts putting large economically agricultural areas of the country at risk of environmental damage and socio economic disaster. Civil wars and financial constraints limited ground survey efforts. This study tested the hypothesis that the Desert Locust niches could be understood through serial satellite images. Such an understanding would aid in identifying priority areas for fast control. Data from satellite sources and Desert Locust occurrence data from Plant Protection Directory were integrated in GIS media. Change detection techniques using RS and GIS were applied. Results showed significant correlations were registered between metrological, edaphic, Vegetation and other Eco geographical parameters tested. Moreover predicted Desert Locust densities in the locust niches exceeded the FAO threshold value for ground spraying control. A Desert Locust vegetation damage risk map was produced to help decision-makers through an early warning system for where and when control operations must take place.

Keywords: Satellite, Desert Locust, Ecological Niche, Risk, Time.

المستخلص:أشارت التقارير الحديثه لمنظمة الفاو الى الانفجار العددى للجراد الصحراوى ممايضع مساحه اقتصادية زراعيه عريضة من البلاد تحت خطر الضرر البيئي والكارثة الاقتصادية الاجتماعيه.الحرب الاهلية و محددات التمويل قللت مجهودات المسح الارضى.هذه الدراسة تختبر فرضية ان مساكن الجراد الصحراوى يمكن فهمها من خلال سلسة من صور الاقمار الصناعية. سيساعد مثل هذا الفهم فى تعريف المناطق ذات الاولوية للمكافحة السريعة. تم دمج البيانات من ادارة وقاية النبات والاقمار الصناعية فى نظام المعلومات الجغرافية، وطبقت طريقة تحديد التغير باستخدام الاستشعار عن بعد.ا ظهرت النتائج ارتباطاً جوهرياً تم تسجيله بين مقاييس المناخ وأفق التربة والنبات ومقاييس ايكلوجية جغرافية اخرى.اضافة الى ذلك، تزيد كثافة الجراد الصحراوى التى تم التنبؤ بها فى مساكن الجراد الصحراوى عن قيمة حد منظمة الفاو للمكافحة بالرش الارضي، بناءًا عليه .تم انتاج خريطة خطر الجراد الصحراوى لتساعد متخذى القرار من خلال نظام انذار مبكر لتحديد اين ومتى تنفذ عمليات المكافحه.

كلمات مفتاحية: قمر صناعى،جراد صحراوى، مسكن ايكولوجى، الزمن.

1. Introduction

The Desert Locust *Schistocerca gregaria* (Forskal, 1775) is a member of the orthoptera Family acrididae (short-horned grasshoppers). Locusts were mentioned in holy books such as the Torah, the Bible and the Quran (Latchininsky, 2013). The Desert Locust life cycle includes three stages: egg, nymph and adult. Female Desert Locust lay eggs in sites that present certain conditions: soil moisture is critical for egg development and the rate of development is dependent on temperature from as few as 24 days to as many as 55 days. Individual locusts are concentrated by large scale meteorological features such as wind convergence, rainfall and green vegetation. Desert Locust plagues have been known to last 4-22 years, while recession periods have been recorded extending 1-10 years (Cheke and Tratalos, 2007). Desert Locust infestation is considered as a food security issue for up to 1 billion people in 60 nations (Cressman, 1997, Lecoq, 2003) in Asia and Africa and covers about 20% of the of Earth's land mass (Cressman, 2008). As an example, in 1958, Ethiopia lost 167,000 tons of grain because of locust infestation; the amount lost was enough to feed one million people for one year.

Many outbreaks have been subsequently documented in the Red Sea State (Johnston, 1926, Darling, 1936, Woldewahid, 2003, Werf *et al*, 2005). In North Kordofan, the solitary phase was reported by Darling (1934). Wide spread outbreaks were reported during 1926, 1940 – 1941, 1949 – 1950, 1968 – 1978, 1987 – 1988, and 2004 (FAO, 2005), and during 2007-2012 (Eltoum, 2013). In 1954, Sudan lost 55000 tons of grain to locust infestation (Nur, 2007). In 1989, the Tokar Delta was attacked by locust with 55% damage to Dura grain (Nur, 1992).

The distribution of Desert Locust has long been recognized to be influenced by presence of preferred food plants, as well as plant community structure (Elbashir, 1966, Culmsee, 2002, Weref *et al*, 2005, Obaid and Elbashier, 2008, Eltoum, 2013). Two breeding seasons, corresponding to the summer and winter rains are reported in Sudan (Eltoum, 2013). Most agricultural products cultivated in Sudan are subject to Desert Locust infestation (Ahmed and Hamid, 2010). The availability of suitable environment accelerate the multiplication of this pest which remains a threat to crops, plants and pastures especially to an expanding agricultural project in the Northern states of Sudan. Current practices for combating locust infestations aims to reduce the insect populations, prevent plagues, and avoid damage to crops and pastures (Cecato, 2004). Negative effects on locust populations are brought to bear by resident predatory birds' species that are known to consume huge amounts of locusts during control of the outbreak is reported (Culmsee, 2002). The challenge in the future of Desert Locust control is to assure food security with minimal environmental adverse impacts.

This study analyzes the environmental requirements of the Desert Locust, in the form of correlations between outbreak locations (in time and space) and diverse environmental variables. Once such requirements have been identified and tested rigorously, the research proceeds to assess the distributional potential of Desert Locust across Sudan. The outcome of these exercises is a novel view of Desert Locust ecology and distribution that hold interest both in the realm of basic science, but also in terms of avoiding agricultural disasters caused by Desert Locust plagues. The objectives of this study are to detect vegetation damaged by Desert Locust infestation, predict Desert Locust breeding areas in Sudan, and to assess the spatial and temporal progression of Desert Locust infestation.

2. Materials and Methods

2.1. Data

The MODIS Enhanced Vegetation Index (EVI) images version 5 was used in this study for vegetation monitoring. MODIS images were freely downloaded from the website of the International Research Institute for Climate and Society at Columbia University (IRI, 2010). Images obtained during the rainy season were used to monitor Desert Locust activities in the summer breeding areas of Sudan during 2007 - 2015.

Climate data (ground truth data) were collected from historical normals (30 years) recorded at several metrological monitoring ground stations. Climate data suggested by metrological experts was screened for matching the satellite observations and saved in an Excel spread sheet. The data was plotted in the base map (Sudan country map). Metrological stations data was correlated with satellite images for each climate parameter (rainfall, temperature, wind and humidity).The pixel value of each metrological parameter from satellite images was matched with the ground metrological station records.

We also used data layers summarizing Sudan soil orders prepared from (Soil Atlas of Africa), and Sudan farming systems prepared from IRI and FAO map (available at IRI website) to interpret our results in grater details.

Ground survey data sets from the Locust Division, Plant Protection Directorate Khartoum North Sudan (PPD), were used as ground truth data. The data indicate geographical location (longitude, latitude) and entomological data for 2007 – 2015. For ground surveys FAO standard methods were followed by survey teams. The surveyed area and density per square meter were recorded. The threshold level was counted for insecticide spraying. The presence and absence of Desert Locust in the surveyed area was registered.

2.2. Analysis methods

The occurrence data were overlaid on the various environmental data layers to extract characteristic of each points from satellite images using remote sensing and GIS technologies. The data set was overlaid over Sudan satellite images using ArcGIS 10. Suitable projection GCS_WGS_1984, Datum: D_WGS_1984 were used. Spatial analyst, Zonal attribute and extract multi values to point were performed to extract digital numbers of the pixels from the set of the raster images. The result was exported as a database file format and saved in a folder. The exported output data set result was opened in Excel spread sheets format and used in tabulating points characteristic, correlations test and statistical analysis.

The digital rainfall values 4-25 were used to mask the area unsuitable for minimum and maximum rainfall in the Desert Locust ecological niche. The soil order was extracted in the Desert Locust high density niche habitat. A wet soil map was produced to simulate the sandy moist surface favourable for female Desert Locust for egg laying .The damaged vegetated areas were filtered by the land use map to detect damage in agricultural plants. This damage could be assigned to Desert Locust activity according to its location and range of digital value of the loosed pixel values (-1 to -11). The correlation equation was generated with false pixel values to detect the pixel value correlate with a threshold value of 200 and 1000 adult per hectare used for control operations FAO (1.2) threshold level. The density predicted was plotted in the EVI satellite image of November 2014 to visualize the Eco. Geo. Model.

3. Results:

3.1. **Temporal Variation of Desert Locust densities**:

The highest densities of Desert Locust were registered during 2011, 2013 and 2014 .The densities were not uniform across localities or years and clustered in specific geographical regions. High Desert Locust density was reported in 2011 in three geo location points that exceeded the FAO threshold value.

3.2. Ecological patterns:

3.2.1. Rainfall

As in figure (1) the rainfall patterns scenario in May 2014 represents variation in rainfall in the Desert Locust niche suitable rainfall zone. In the north the masked zero was extended and the suitable zone restricted to the south near to the masked high rainfall area. The prediction of the scenario in Aug 2015 represent a different scenario, most of the area in the middle will be activated except part of the Red Sea zone located in the zero level during this period of time. These facts indicate that the rainfall is the main factor but there may be other response factors besides rainfall in the rainfall zone.

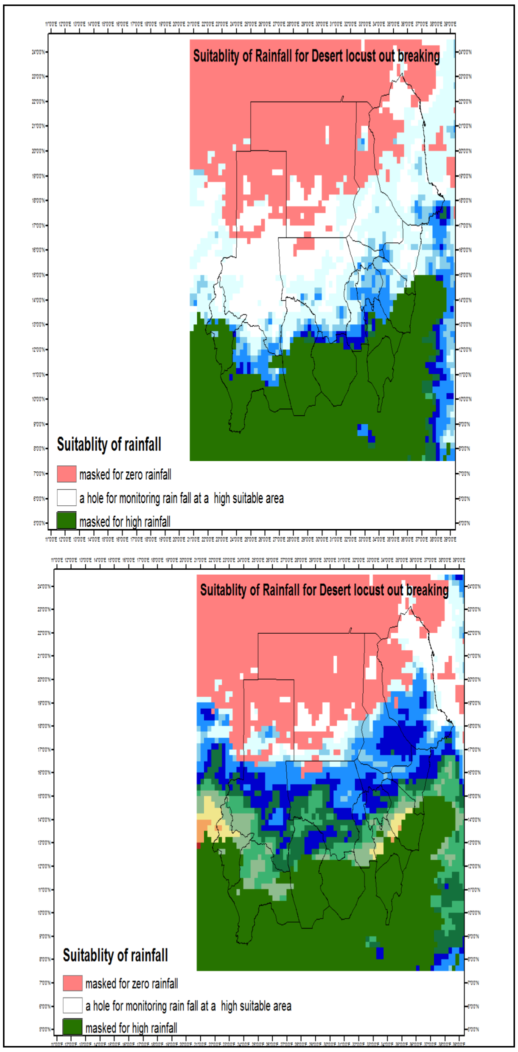

Figure (1): Rainfall patterns in the Desert Locust ecological niches scenario May2014 and Aug2015

3.2.2. Specific humidity (P.T.O)

Different levels of specific humidity were found in the rainfall zone of the ecological Desert Locust niche habitat at the time of the high Desert Locust density reported.

3.2.3. Edaphic patterns

The result showed that high Desert Locust density correlates with soil orders having digital value of 4, 9, 16,17,25,26 and 31 shown on figure (2). To trace these facts in ArcGIS, the colour metric graph of the soil order was used to correlate soil order with Desert Locust high densities.

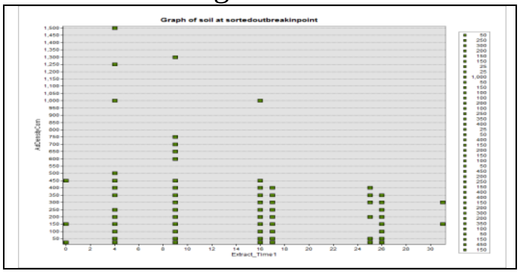

Figure (2): Correlation of Soil orders and Desert Locust adult/ hectare

3.2.4. Interactions; Wet Soil and Specific humidity

The results showed that specific humidity, as a response factor for rainfall and temperature in general, divide and separate the regions' Desert Locust niche habitat into seven classes, depending on the temperature and rainfall. The first class (15- 40) represent dry areas while the values in the last class (131- 200) represent a high limit for specific humidity favourable for the high Desert Locust density. Figure (3) shows the scenario as represented in November 2014.

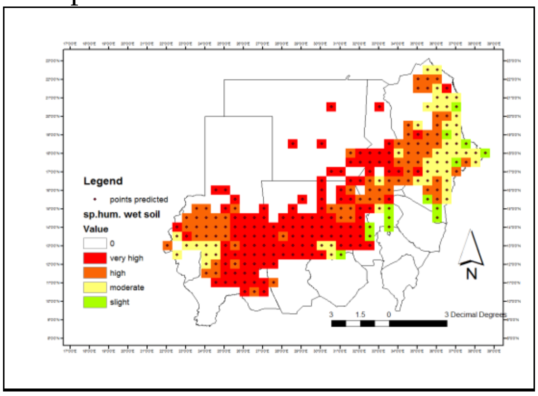

Figure (3): Average specific humidity in wet suitable soil orders in the Deseret locust niches habitat in Sudan Nov 2014.

The dry areas were removed. The regions were classified into five classes that represent the average specific humidity in wet suitable soil orders in the Deseret locust regions during that time. The red (dark) colour represents very high interaction in suitable areas, while green (light) ones represent slightly important areas.

3.3. Farming system

Landuse and farming systems in the Desert Locust ecological niche habitat regions which were extracted from Sudan farming system map were; rain-fed agricultural areas, irrigated agricultural areas, grazing areas and sparsely vegetated areas.

3.3. Interactions of Vegetation, Wet soil, Specific Humidity and farming systems

The vegetated areas which support the Desert Locust life cycle intersected with wet soil and at specific period e.g. November 2014. A suitability map was produced to represent these interactions.

4. Discussion:

Variations of the spatial and temporal distributions were found. This finding agreed with findings of other researchers who have reported on the temporal and spatial variation of the Desert Locust or other animal and insect species (Johnston, 1926, Darling, 1934, Darling, 1936, Abaker, 20011, FAO, 2015, Townsend, 2015). There are many factors beside the rainfall variation that explain this temporal and spatial distribution (Despland *et al*, 2004).More than 200 adult locusts per hectares were reported at many locations. The FAO control strategy is to spray insecticide at this level (FAO.1) to prevent grouping and forming of swarms (Anstey *et al*, 2009). Ground spraying of insecticide was done by the surveying teams (FAO, 2009). Desert Locust in one point in day 20 of April 2011 reached 1000 adults per hectare, aerial spraying might be done (FAO.2). Two years later in November 2013, all location points exceeded the FAO.1 threshold value required for ground spraying of insecticide and four points reached level 2 of the FAO were (1000 adult per hectare). This has happened as predicted by the research findings and FAO models (Eltoum, 2013 and FAO, 2013). In April and November 2014, Desert Locust densities were still higher and the density reported exceeded that of the years 2011 and 2013.

The range of the average annual rainfall digital value in the Desert Locust ecological niche was 4-25 in the raster images, this is equal to less than 100 mm of rain reported in the ground metrological stations. This finding is similar to that reported by (Anymba *et al*, 2005) for rainfall in the Desert Locust habitat for this region (25-150 mm), while the range of rainfall digital value was (0-246) in the Sudan region, this is equal to less than 600 milliliters of rain reported in the metrological stations. In general this maximum limit of rainfall (100 mm) limited the vegetation type and agricultural practice (choice for specific crop) in these areas. The minimum limits near to zero level support the desert vegetation and allow the presence of grasses from time to time. In accordance with this scenario, thus climate change may play an important role in changing the patterns of rainfall in a semi desert eco zone. This will change the vegetation patterns to be more like the vegetation in the Desert Locust ecological niche. Using this information, a rainfall suitability map was produced. The rainfall zero level was masked because it is unsuitable for egg laying by female Desert Locust because of the fact that, a lack of moisture in the top 20 centimeters of the soil surface prevents egg development and hatching. Rainfall greater than 100 mm (maximum level) was masked because the high Desert Locust density was not registered there in the sorted data. This will be illustrated in the other parameters patterns.

The results indicate poor and weak correlation ($r^2 = 0.008$) of the digital value of the rain fall and Desert Locust density registered during January, February, October and November. The rainfall digital value 2 is equal to zero although this correlation is poor, it reflects two issues: the first one is that the shower rainfall in winter in the Red Sea coast triggered Desert Locust breading in this region. This is in agreement with previous findings (Johnston 1926, Darling, 1936, Woldewahid, 2004, Werf *et al*, 2005). The second issue is that the Desert Locust life cycle from egg to adult completed in one to two months in the Red Sea coast of Sudan as suggested by the FAO reports from this region before. There were no correlations with the rainfall digital values, $r^2=0.00$ in March, June, September and December. Positive correlations were found with the rainfall digital values $r^2=$ (0.011, 0.054, 0.012, and 0.012) in April, May, July, and August. Since high density was recorded in April and November 2014 this correlation is very important. Outbreaks were also registered in 2011 and 2013 in April. This finding is in agreement with observations of expert entomologists, e.g. Bashier in 2014 (personal communication) that there is breeding of Desert Locusts in April from time to time beside winter and summer breeding seasons in Sudan.

The soil is a very important factor; it acts as a hatchery for the Desert Locust. Clay soils are not a true breeding area for the Desert Locust although the vegetation which it supports could be infested by the Desert Locust. The soils that contain a specific level of sand in its structure are favourable for female Desert Locust for the egg laying process and development (Symmons and Cressman, 1994). The soil must contain specific moisture at specific temperature. It also must support the favourable vegetation types for instars and adult stages. The results showed that the suitable high density areas are located in specific areas in Sudan. This is a good indication for changing the control strategies and monitoring processes that deal with this problem in the future. Also, it gives an idea about how the problem was formulated through time and its relation with other problems in these regions of Sudan.

The distribution of Desert Locust influenced by the presence of preferred food plants as well as the plant community structure (Elbashir, 1996, Culmsee, 2002, Weref *et al*, 2005, Obaid, 2008, Eltoum, 2013). Desert Locusts are a major pest for cereal crops. Since they invaded sorghum, millet and wheat crops (Ahmed and Hamid, 2010, Nur, 2007), the Desert Locust extracted here overlapped with areas which have this type of agricultural practice and vegetation patterns besides other sparsely vegetated areas.

Using the EVI satellite images dataset the vegetation in the Desert Locust niches could be grouped into four main groups. The range of digital values (75-101) assigned for green vegetation associated with Desert Locust high density niche, while (65-75) for dry and slight green vegetation, (55-65) for scarcely vegetated areas and the last group (51-54) for empty soils. This finding supports the finding of (Eltoum, 2013) which stated that Desert Locust niches vegetation could be classified in to different groups based on the EVI digital value. The vegetated areas in the Desert Locust eco niches may represent a different status in the acquired satellite images. The losses in vegetated areas biomass may be attributed to many factors; Desert Locust is one of them (Eltoum and Dafalla, 2014). A map showing the prediction of the damaged plants due to losses in digital values of the vegetated areas is in figure 5. Three main groups of vegetated areas could be classified in accordance with this fact; damaged areas (red color), no change in vegetated areas (greenish brown areas) and green growth vegetated areas (green color).

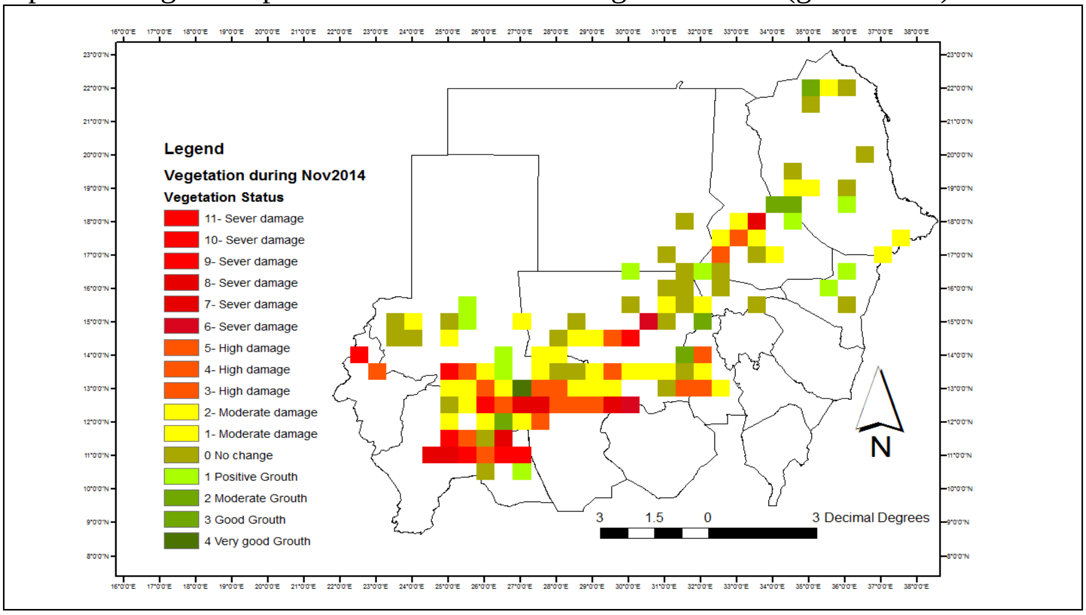

Figure (4): Prediction of the damaged plants in niches 2014.

Most of the very highly suitable vegetated niche habitats are located in part of Darfour, Kordofan beside part of White Nile, Khartoum, River Nile, Kassala and Red Sea states. This is also evident proof of why Desert Locust associate with sorghum and millet vegetation (Ahmed and Hamid, 2010). Although the situation in Gezera State was moderate, it is critically important. The dominant soil type in Gezera is clay soil thus the presence of Desert Locust niches indicate the formation of wet sandy surface in the upper 20cm of the soil. This may refer to movement of sand particles to these niches by wind or water from elsewhere. Since the Gezera scheme is an irrigated agricultural project it represents the third possibility of the active vegetated Desert Locust niches beside winter and summer rainy seasons vegetated areas that further research may suggest in these dimensions. These facts may help government authorities to priorities and schedule control strategies and monitoring process. The correlation test was generated to extract the Desert Locust density per hectare in these niches. The result showed that a high correlation (r^2 = 0.925) was found between these interactions and the Desert Locust density in these niches. The correlation equation used to predict densities in these niches is:

$X = (y - 21319) / 4074$

The three statuses of vegetation were also presented (damaged, no change and green growth).Accordingly the correlation between damaged agricultural crops and Desert Locust density as predicted in the model was generated. The result showed a significant correlation (r^2 = 1) between the desert density and the interaction of damaged crop vegetation, specific humidity and wet soil. The results revealed that a pixel value of 1000 and 4000 could be used as a threshold value for ground and aerial spraying (figure 5).

The equation was generated for all possible pixel values in the damaged vegetated areas, where all points correlate well (r^2 = 1) with this equation. Thus all of these damaged areas are within Desert Locust niches and refer to Desert Locust activities in these niches.

5. Conclusion

The results showed that active niches were geo located in Darfur regions, the border of Kordofan, Khartoum States, Red Sea regions, River Nile State and some active niches were located beside the irrigated sector in Kassala State (figure 5).

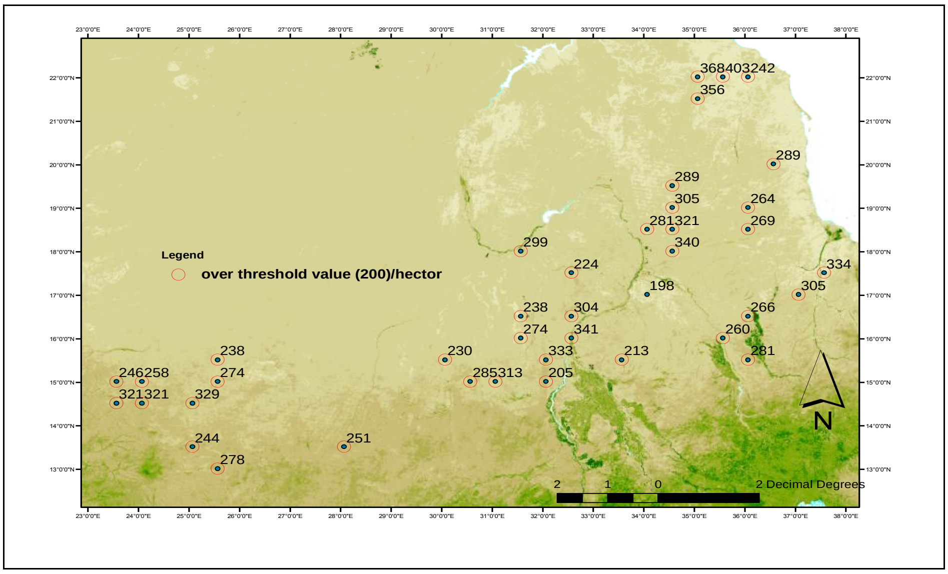

Figure (5): Predicted Desert Locust density/hectare in active niches in November 2014 in Sudan.

The damaged vegetation could be easily depicted using these data. Figure (6) represents a risk map of the predicted damaged vegetated areas in Sudan. The model also predicts affected vegetation in the border countries.

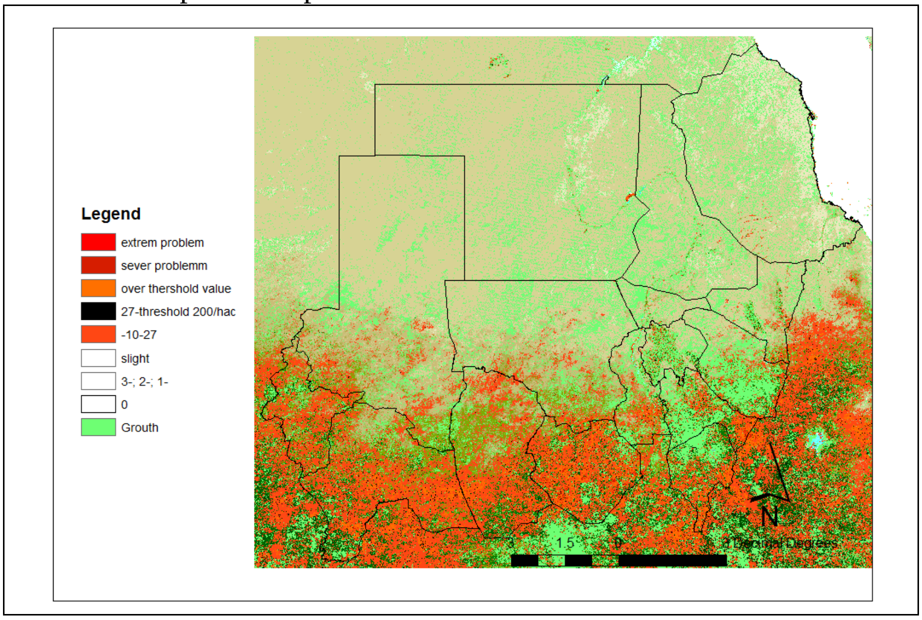

Figure (6): Risk map of the Desert Locust damaged vegetated areas in Sudan October 2015.

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