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Full Length Research Paper

Landscape architects perception of their role in the mining industry in England

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Landscape architects have a broad based academic training that prepares them to undertake a variety of different challenges in planning, design, construction and management of land. The purpose of this study was to establish their perception regarding their role in the mineral extraction industry in England. The study involved an online survey of landscape architects practicing in different organisations in England. It was established that they deemed their involvement in the industry as very important. They however have a perception that their involvement is not well appreciated. They also indicated that their representation in the industry is very low. For the mineral extraction industry to fully benefit from the expertise of landscape architects, it has to have a better understanding of what the professionals can offer. More importantly, landscape architects and organisations that represent them should endeavour to showcase and market the profession and expertise.

Key words: Mineral extraction, landscape architecture, quarry reclamation, mineral planning authority.

INTRODUCTION

The landscape architecture profession is relatively new compared to other design professions like engineering and architecture. Just like any other developing profession, landscape architecture has and is still finding itself new niches in planning, design, development and management of land. This new niches are mainly in industries that have typically been dominated by other professions such as the mining industry, history (Historic Landscape Characterisation), archaeology among others. This is possible because landscape architecture training prepares candidates to proficiently deal with specific issues within these industries. The training equips them with understanding of ethics, aesthetics, and socio-ecological issues (Roberts, 1999). It is a multi-disciplinary profession that incorporates horticulture, ecology, botany, applied and fine arts, environmental psychology, physical sciences, geology, and architecture. This background enables landscape architects to be able to marry different aspects of the environment to develop sustainable landscapes. They have the capacity to plan, design, build and manage landscapes of all types, (Buchko and Hitch, 2010).

Mineral extraction is an engineering science dominated industry. Reclamation of mined sites on the other hand requires contribution from experts from a number of professional groups such as engineers, biologists and

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ecologists (Buchko and Hitch, 2010; McKenna, 2002). This domination includes areas within which landscape architects can have profound impact such as mine planning, design and reclamation. This is still the case today because rightfully so, the industry's primary role is to extract minerals from below the earth's surface. This requires specific expertise from engineering specialists. The secondary role of the industry is to ensure that they extract the minerals in an environmentally friendly manner. They also have to ensure that land extracted of minerals is put back to some productive use after the decommissioning of extraction activities. These roles require input from other professions such as ecology, environmental science, biology and landscape architecture, (Berger, 2008). Of the four professions mentioned, only landscape architecture can be seen as not a traditional science profession, (Krutka and Jingfeng, 2015; Kuter, 2013).

"Reclamation offers substantial opportunity to the profession to expand, design and of reoccupation of synthetic space and ecology", (Berger, 2008). The profession applies art and science to develop built environments marrying aesthetics to functions in the landscape. The question is "how would the reclamation process and results differ if those in the design world were a part of the mining process from the beginning"? (Buchko and Hitch, 2010). Within the pure science professions, landscape architects may be looked at as applying subjective principles in an environment that is clouded by objective problem solving, (Arbogast, 2008). Because of this reason, there is potential for the mineral extraction industry to shun and exclude landscape professionals from their teams of expertise, (McKenna, 2002).

In England, landscape architects have been involved at different stages of the mineral extraction process, (Baida, 2012). They serve the industry working for Minerals Planning Authorities (MPA's), mineral operators, private companies that serve the mineral industry, mining and reclamation research organisations and other organisations that provide expertise such as the Royal Society for the Protection of Birds (RSPB), Natural England, the Department for Environment, Department of Food and Rural Affairs, (Defra) and others. They are usually only engaged during the planning stages of a mine either as consultants or at Mineral Planning Authority level. As consultants landscape professionals are usually engaged as part of an Environmental Impact Assessment team. They usually focus on Landscape and Visual Impact Assessment (LVIA) of proposed mining installations. They may also be involved in the development of reclamation scheme which are a pre-requisite for an operator to be awarded planning permission for mineral extraction. They can also provide an interface between mine-site design, engineering and environmental issues (Dempsey et al., 1979). Among other things they can be very helpful in siting and laying out a mineral extraction site taking into consideration the operational requirements and environmental issues including fitting and blending the mine buildings, waste, extraction pit into the natural surrounding slopes concealing them from important views, (Dempsey et al., 1979; Jellicoe, 1980). As MPA's, landscape architects mainly provide technical advice to mineral operators on issues pertaining to their applications for mineral planning permission. It involves assessing impacts statement as well as proposed reclamation schemes. They are also involved in the reclamation of mine sites, especially those that were abandoned after decommissioning.

According to Dempsey et al. (1979), the involvement of the landscape architecture profession as a source of creative thinking and planning has long been active in Europe. In England, a number of different mineral extraction sites have had considerable input in their design from distinguished landscape architects of the past centuries. The Hope Cement Works in Hope, Derbyshire, England, is one of those extra ordinary sites. Sir Geoffrey Jellicoe developed the master plan for the site. His input into the site design was in relation to planning and design of the facility in order for it to blend with the surrounding landscape with minimal negative visual impacts, especially from distant and sensitive viewpoints. Sitting on a rolling landscape of the Derbyshire Peak District, the site had a high potential to be visible from the numerous high points surrounding it. However, Jellicoe designed the site to take advantage of the rolling topography to hide it from certain potential views (Jellicoe, 1980). To date, the mineral operator still uses the Jellicoe master plan to design and develop parts of the site.

Another site that has been influenced by distinguished landscape architects is the Panshanger Park gravel extraction site in Peterborough, Hertfordshire, England. This site was an estate of the Desborough family until 1954. It was opened for sand and gravel extraction in 1998 (Herts and Middlesex Wildlife Trust, 2015). As an estate, the site was first designed by landscape architect Humpfrey Repton. Two other landscape architects, Lancelot "Capability" Brown and John Adey Repton also contributed to the designs of the estate in later years (Herts and Middlesex Wildlife Trust. 2015). Some of the designs by these professionals were never implemented, while those that were implemented have been overshadowed by over growth and lack of management over time. Since the takeover by a mineral extraction operator, parts of the site have been quarried for gravel and some have been reclaimed. The operator uses Lancelot Brown's master plan of the site as a basis for the site's reclamation master plan. Even though the master plan was developed for a different purpose, (residential estate) it still has relevance and more importantly tells a story of the development of the site.

In Cramlington, Northumberland, England, landscape architect Charles Jencks designed the "Lady of Northuberlandia", a park designed in the shape of a nude woman, which was completed in 2012 (Krutka and Jingfeng,

Table 1. A summary of the overall results.

Parameter	Organization	Importance of Landscape Architects in Mining	Perceived level of appreciation	Representation of Landscape Architects in Mining	Role or Input of Landscape Architects in mining
Number valid	20	19	19	19	19
Number missing	0	1	1	1	1
Mean		4.421	3.053	2.579	3.211
Std. Deviation		0.769	0.970	1.121	1.182

2013).

Despite these examples and many others that are not mentioned in this paper, it is still appropriate to ask the question; 'Is the mineral extraction industry in England enjoying the full benefits that the landscape profession could provide?' The purpose of this study was to establish how landscape architects in England perceive their involvement in the mineral extraction industry. The study was also intended to highlight the different roles that landscape architects are playing in the industry.

METHODOLOGY

An internet based questionnaire was developed to solicit responses from landscape architects with roles in the mineral extraction industry in England. Respondents were invited to participate in the survey through unsolicited emails. A Uniform Resource Locator (URL) link to the survey was copied into the emails. Potential respondents were sort from MPA's and private practicing landscape architects with specific interest in the mineral extraction industry in England.

To establish landscape architect's perception of their involvement in the mineral extraction industry the following questions were asked;

1 How important is the role of landscape architects in the mineral extraction industry?
2 What is the level of appreciation for landscape architects in the mineral extraction industry?
3 What is the level of representation for landscape architects in the mineral extraction industry?
4 How much input do landscape architects have in the mineral extraction industry?
5 What roles related to the mineral extraction do landscape architects play in their organisations?

The first question was rated on a scale of 1 to 5, 1 being "not very important" and 5 being very important". Questions 2, 3 and 4 were rated on a scale of 1 to 5, 1 being "very low" and 5 being "very high". The last question was an open ended question intended to establish the different roles related to mining that respondents played in their organizations.

RESULTS AND DISCUSSIONS

A total of twenty responses were gathered. Of the twenty responses, nineteen (95%) were completed in full. Of the nineteen responses, fifteen (79%) were from landscape architects working for MPA's and four (21%) responses were from those working in private practice. Even though this is an unbalanced sample size between MPA and private practicing landscape architects, it was assumed that all respondents were conversant with the constitution, representation and roles of landscape professionals in the mineral extraction industry.

The results show that landscape architects perceive their technical input in the mineral extraction industry as very important with a mean rating of 4.4. They also have a perception that they have an above average role or input in the industry, with a mean rating of 3.2. Despite these high ratings regarding their involvement, they think their representation in the industry is below average with a mean rating of 2.6. The results also show that landscape architects think that the level of appreciation they get from the mineral extraction industry is average with a mean rating of 3.1, (Table 1). This is because "the value of a landscape architect and the contribution and skills they can offer are still a relative unknown within the mining world" (Baida, 2012).

An independent-samples t-test was conducted to compare the perceptions of landscape architects working for MPA's to those working in private practice. There was no significant difference in how they perceive their involvement. The magnitude of the difference between the two groups of landscape architects, represented by Eta squared is very small. The low values of Eta combined with high values of *p* indicate that the difference is insignificant (Table 2). It shows therefore that both groups of landscape architects have the same perception about their involvement in the mineral extraction industry.

Respondents also noted a number of different roles that they play within their organisations which are related to the mineral extraction industry. The roles generally revolve around providing expert advice on landscape planning, design, construction and management related to reclamation and mitigation of landscape and visual impacts caused the mine operations. Another major role involves the actual planning, design, construction and management of sites (Garmony et al., 2007). This is where the landscape architects are doing the job as opposed to providing advice to mineral operators. A summary of these roles as extracted for the results is as follows:

Table 2. Comparison of perception between two groups of landscape architects

Question	Organization	N	Mean	Std. Dev	t	*p*	E_{ta} squared
Importance of landscape architects in mining	Mineral Planning Authority	15	4.40	0.828	-0.225	0.825	0.003
	Private Practice	4	4.50	0.577			
Perceived level of appreciation	Mineral Planning Authority	15	3.27	0.884	2.014	0.060	0.193
	Private Practice	4	2.25	0.957			
Representation of landscape architects in mining	Mineral Planning Authority	15	2.73	1.163	1.174	0.256	0.075
	Private Practice	4	2.00	0.817			
Role or input of landscape architects in mining	Mineral Planning Authority	15	3.13	1.246	-0.540	0.596	0.017
	Private Practice	4	3.50	1.000			

i. Assessment and advice on development planning involving mineral extraction.
ii. Assessment and advice on landscape and visual impacts caused by mineral extraction.
iii. Advice on reclamation and mitigation of landscape and visual impact caused by mineral extraction.
iv. Landscape and Visual Impact Assessment.
v. Mine or quarry reclamation (planning, design, construction and management).
vi. Advice on scoping.
vii. Expert witnesses.
viii. Policy development.

It is evident from these roles that not only can landscape architects provide essential expertise to the mineral extraction industry but they can also do it at different stages of the mineral extraction process, from mineral planning up to closure and reclamation, (Aasen, 2012; Kuter, 2013).

Conclusion

A question that may arise from this study is whether the mineral extraction industry has a holistic understanding of the potential contributions that landscape architects could provide. On the other hand, one can also ask whether landscape professionals have positioned themselves and marketed their expertise wide enough to attract the industry. It is imperative that organisations such as the Landscape Institute (LI) in England, American Society of Landscape Architects (ASLA) in the United States of America, the Canadian Society of Landscape Architects (CSLA) in Canada, and others are at the forefront in promoting the works of landscape architects in the industry.

This study can help individual landscape architects and professional organisations representing them to realise that more effort needs to be focused to integrating them more seamlessly into the mining industry. The study also highlights the different expertise that landscape architects in different organisations are providing to the industry as well as enlighten professionals in the mining industry who may not be aware of the expertise that landscape architects can provide.

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Full Length Research Paper

Analysis of dendrometric characteristics of *Acacia senegal* (L.) Willd. (Fabaceae) in the semi-arid Sahelian area: A case study of silvopastoral zone in Senegal

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The study gives an analysis of the dendrometric parameters of a middle Sahelian species (*Acacia senegal*) in semi-arid environment to get better knowledge of its behavior. The research lays the principle that the species behaves differently according to the ecogeographical stations. So, its characteristics change from one environment to another. That is why it is important to do a specific study for every big zone. The study was done in Silvopastoral zone, more particularly in the area where *A. senegal* is popular in the country. The study aims to deepen the knowledge of *A. senegal* dendrometric parameters. The following parameters were measured: diameter of the base, breast-height diameter (1.3 m), breast- height circumference, total height of the tree, length of the trunk and width of the houppier. The sample consists of a population of 76 feet locust trees in Senegal. The study confirmed the hypothesis that the characters of the species vary according to the zone where it is found.

Keys words: *Acacia senegal*, dendrometry, Sahel, Senegal.

INTRODUCTION

Rain forests have a global role in the stabilization of the climate; besides holding some carbon (Clark, 2004), they refresh the atmosphere and favor precipitation. The populations and local residents of the forests gain from the vegetation which gives them life and other immediate profits (Ickowicz, 1995).

Acacia senegal is a shrub rarely exceeding 6 m height. It presents a very muddled shape at early age; later, it transforms into a tree and short trunk further with natural pruning, which starts from the third year. Its grey bark is cracked on the trunk; has grey - clear or grey - darkened and smooth young twigs and branches. These are branched out, giving rise to a crown with parasol shape. The trunk rarely exceeds 1 m. The longevity of the species does not seem to exceed 25 - 30 years (Poupon, 1984).

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Photo 1. *Acacia senegal* in pure plantation (Thiam, on 2013).

Table 1. Sample distribution and average height according to the tree age.

Year of planting	Age (years)	Number	%
1991	15	18	23.7
1999	12	6	7.8
2002	9	10	13.2
2004	7	18	23.7
2005	6	16	21.1
2006	5	8	10,5
	Total	76	100

Rural populations develop some strategy to combat desertification and degradation (Jouve, 1997).

To get some water during rain scarcity, the gum tree develops a root system that is very important (Photo 1). The side roots colonize the superior horizons of the ground of about ten meters around the trunk. Parallel to this running system, the species develops a pivot of more than 10 m depth as compared to the grown-up subjects. The plant adapts well to arid conditions (Barry et al., 1984).

In Senegal, the area where *A. senegal* locust tree is distributed is limited to the north by the valley of the Senegal River and to the South by 800 mm pluviometer(Bille, 1997).

The zone sheltering the best natural plantation of gum trees, which is the main part where Arabic gum in Senegal is produced, can be subdivided into four sub-zones: the North sandy Ferlo, the South sandy Ferlo, the armoured Ferlo and the Ferlo of transition (Hiernaux et al., 1994).

Drought causes approximately 60% disappearance of trees. Also, the fire on dunes and rodents in the slums destroy numerous individual trees (Diouf, 2010).

The objective of the study was to improve the knowledge on the dendrometric measures of *A. senegal* in semi-arid Sahelian zone in Senegal.

Presentation of the study area

Of 70 000 km² surface (more than a third of the territory), the Silvopastoral zone or Ferlo is in the south of the pond of the Senegal River and is part of the Sahelian Zone (CSE, 2009). The central geographical coordinates are 15° 53 ' N; 15° 15 ' W 15.88, 15.25; the height is about 25 m. For "Vallée du Ferlo", the ground remains relatively flat.

The climate is of tropical, semi-arid, monomodal type with very hot variant (Toure, 2002). The annual precipitation is 300 mm (Station of Linguère). Harmattan contributes to the erosion of its grounds and desertification is aggravated by droughts cyclic as in the 1973s, 1983s and 1984s.

The vegetation is thinned out there. The landscapes consist of dry savanna, steppe and dune. Thorny plants survive in the area more easily than other species. In rainy season, the region covers itself with a fine herbaceous carpet, but for the rest of the year, the grounds are naked and particularly vulnerable. Goats compete for shoots in the herds of zebus led by the Peulh shepherds (Thiam, 1998).

MATERIALS AND METHODS

The main materials used are: Libra of 100 kg capacity, rope, saw, knife, machetes, iron pickets, decameter, long ribbon-meter of 1.5 m, precision balance of 5 kg, chain saw, forest compass, GPS, digital camera.

Documentation

This work is based on the knowledge of *A. senegal* in respect to its ecology, historic and political aspects of reforestation in Senegal; as well as its adaptability to drought conditions, and the constraints in the agrosilvopastoral systems.

Sampling

The investigations were performed on individuals of more than 5 years old (Table 1). The measured tree parameters are as follows: total height (m); length of the trunk (m); base diameter (cm); circumference of breast height level (cm); crown width (m); and diameter at breast height (cm).

To realize the various sites, the geographical address and coordinates were obtained by means of a GPS. For every age, individual samples were the object of the investigation. The study is thus done on 9 sites (Tables 2 and 3).

Dendrometric measures

The various moderate parameters in every tree are the following

Table 2. Presentation of the sites of the study.

Site number	Site name (village)	Number of trees	Programs
1	Thiékène Ndiaye	6	POA
2	Nguith	8	Asyila
3	Gouloum	12	Asyila
4	Warkhokh	8	Asyila
5	Tessékéré	6	GMV
6	Labgar	8	GMV
7	Widdou Thingholy	11	GMV
8	Sombe	8	Asyila
9	Dahra CRZ	9	CNRF
	TOTAL	76	

Table 3. Height age.

Age	12	9	7	6	5	4	2
Average height	5	4.2	3.4	2.7	2.7	1.7	1.5

ones: a- total Height of the tree; b- Length of the trunk; c- Diameter on the base; d- Diameter at breast-height; e- Circumference at 1.3 m; f- Width of the houppier.

RESULTS

Total height of tree

Calculations made from data showed a general average of 3.1 m with a standard deviation of 1.2. This shows that the dispersion around the mean is very tight. Thus, the tree is believed to measure up with the age of senescence, which is 12 years for our sample (Figure 1).

Length of trunk

For our sample, the length of the trunk, taken between base and first branches, varies between 0.2 and 1.7 m. The length of the trunk does not have a large variation, unlike the total height that displays a net variation based on age. The age of maximum growth is 12 years, as well for the trunk than for the total height.

Crown width

The crown width is not a good parameter based on the age of the individuals; its variation is not very marked (Figure 2).

Circumference of breast height

The largest circumference is obtained at 12-year-old. Beyond this age, the circumference decreases because of the decline in the rate of humidity and the decrease in the thickness of the bark which is more and more fibrous.

DISCUSSION

The height of the tree varies according to the soil level. So trees in the depressions are longer than those at the top of dunes. This is certainly due, as confirmed by Gaye (1984), to the availability of the groundwater; and in the development, swiveling is very important to the species.

Beyond 12 years, locust tree of senegal begins to lose a part of its bark because of senescence and infestation of termites. The various variables measured on the ground were analyzed under the angle of their extremes (Figures 3, 4 and 5). The latter allowed us to know the limit of the growth of the locust tree of senegal in the context of the Sahelian zone, particularly in the area of the study.

The various obtained parameters show that we have shrub of Sahelian type (chap). *A. senegal*, due to its adaptability to difficult conditions, presents a small-sized morphology, which makes it a good food for small animals, particularly goats. The covering on the ground depends on the density of the species but the width of houppiers starts with a small cover on the ground. In pure plantation, the spaces are on average 5 m by 5 m, with 400 feet per hectare. So, the projection on the ground gives enough covering because of the strong density of plantation. This situation provokes a competition between trees, slows down growth and reduces the rubber productivity.

For more important space (8m by 10 m) with a work on the preliminary ground before the plantations are buried, the plant develops normally and benefits mostly from some ground water.

Conclusion

Many studies were made on *A. senegal* to know its characteristics (FAO/ANGMV, 2010). In spite of these

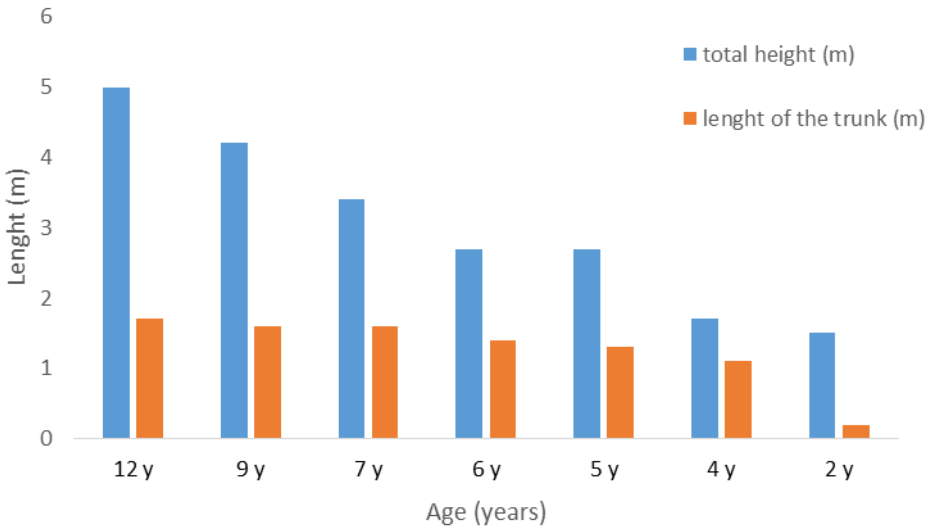

Figure 1. Measures of length of trees.

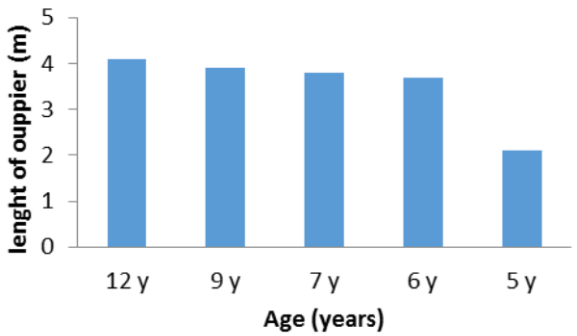

Figure 2. Average crown width.

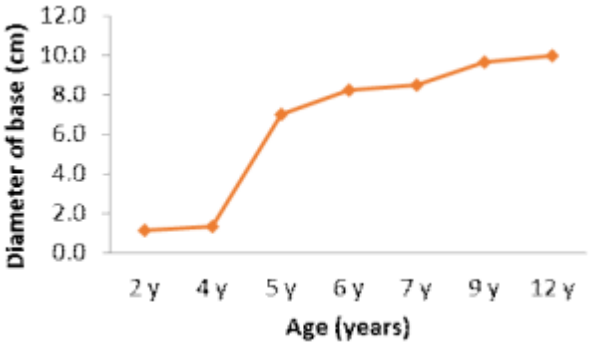

Figure 4. Diameter of base on the age of tree.

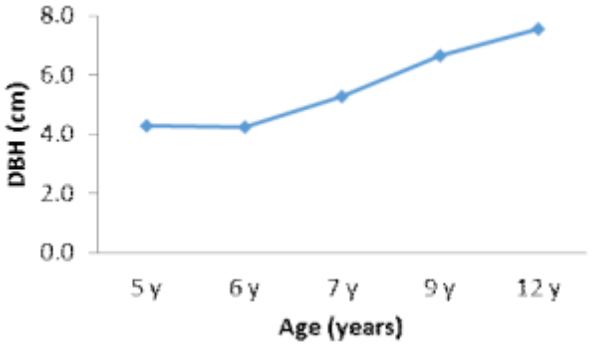

Figure 3. DBH depending on the age of the trees.

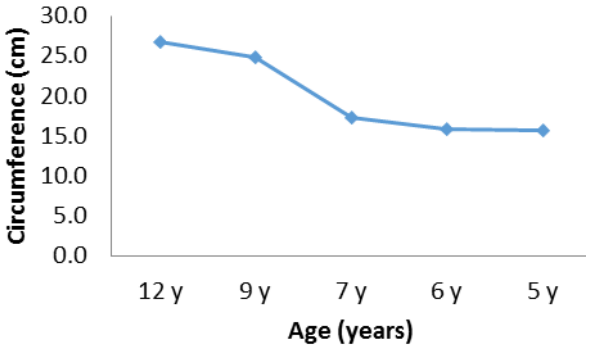

Figure 5. Average girth at 1.3 m.

efforts, few made a reference to the middle Sahelian dry and semi-arid Africa *A. senegal*. The study of the species in a specific environment justifies itself in many respects. Indeed, many results used before now do not take into account the specificities of the species (Ndiaye, 2004).

The main ligneous botanical species in silvopastoral

zone should be the object of specific study and kept in a database, as a system of follow-up of the dynamics. It appears that the study of the species offers several assets which are among others, the consideration of the conditions of the environment and the dynamics of the forest ecosystems.

Conflict of Interests

The authors have not declared any conflict of interests.

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Spatial, seasonal and inter-seasonal variations of thunderstorm frequency over Nigeria

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Using a 10-year daily data thunderstorm and dry thunder (thunder without precipitation) that spans from 1991-2000, the spatial, seasonal and inter-seasonal variations of thunderstorm frequency have been investigated with results which include the production of seasonal and inter-seasonal maps of dry thunder (thunder without precipitation) and thunderstorm frequencies. Results showed that there exists a latitudinal belt of reduced thunderstorm activity between 8 and 10°N. Also, due to absence of little dry season (LDS) over the south-eastern part of the country, they do not experience double maxima of thunderstorm activity. Hence, the weather over the country has been observed as not following the latitudinal divides. Also, the thunderstorm activities over the country are more prominent over the coast, but gradually decrease towards the inland with anomaly over Ilorin and Yola. Though, several authors have carried out series of researches on the thunderstorm activities but none have been able to look at the seasonal and inter-seasonal variations of thunderstorm frequency over Nigeria. Hence, the need to look into this aspect came as a result of the fact that thunderstorm activities is one of the most contributing systems to total precipitation in Nigeria.

Key words: Thunderstorm, seasonal, frequency, latitude, Nigeria.

INTRODUCTION

Studies have shown that the greatest proportion (with about 70%) of the annual rainfall of West Africa countries comes from deep convective systems (Adelekan, 1998; Omotosho, 1985). This has been discovered to be largely as a result of the occurrence of thunderstorm systems that contribute mostly to the summer rainfall (Byers and Braham, 1949; Balogun, 1981).

Several definitions have been given about thunderstorm ranging from being merely a storm containing lightning and thunder (Ahrens, 2000) to being a convective storm that is accompanied by lightning, thunder and other variety of weather such as local heavy shower, hails, gusty wind, sudden temperature change and occasionally tornadoes (Alexander and Aloni, 2015).

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However, as a weather system, thunderstorm has been observed to usually comprise fluctuating ensemble of “cells” and produces a contagious precipitation area of about ~100 km in horizontal scale in at least one direction (Houze, 1993). Within each of these cells are; updraft flows, precipitation showers and downdraft flows. While the updraft flows arise as a result of the formation of a gust front ahead of a thunderstorm cell, the low-level downdrafts arise from the flow of low theta-e (low θe - which is dry and cold) towards the cumulonimbus cloud, at the level of the African Easterly Jet (AEJ). This air is driven by melting, evaporation and hydrometeor drag (Srivasta, 1985 and Knupp, 1988).

However, further studies (Smull and Houze, 1987; Kingsmill and Wakimoto, 1991; Biggerstaff and Houze, 1993; Smull and Augustine, 1993) have revealed the occurrence of upper-level downdrafts at the sides of the upper portion of updrafts. The economic importance of this system has been documented as a fundamental component of the climate and a key element of the water cycle and a global atmospheric electric circuit (Changnon, 2001b). Also, thunderstorm is one of the major contributors to flooding and soil erosions (Adelekan, 1998), leading to loss of lives and causing great damages to properties worth millions of dollars in Nigeria (IFRC and NEMA, 2012 reports). Enete et al. (2015) showed from their study that thunderstorms accounted for 32% of flight cancellation with 218 occurrences, 0.2% of diversion with 291 occurrences and 24% of delays with 526 occurrences at Port-Harcourt International Airport between 2008 and 2013. In some areas, thunderstorm contributes greater percentage of about 60% to the annual rainfall (Obasi, 1974), while 70% or more of annual rainfall is associated with the moving belt of thunderstorms (Omotosho, 1984). In Nigeria, the greatest of the three rainfall systems is thunderstorm, producing about 45.7% of the total summer rainfall (Orisakwe, 2015).

Researchers have carried out several works on thunderstorm rainfall, perhaps due to the associated phenomena they produce; heavy rainfall, lightning, hail, gusty winds, etc (Changnon, 2001a; Omotosho, 1985; Adelekan, 1998). Others worked on the seasonal distribution of thunderstorm days (Mulero, 1973), the distribution of thunderstorm rainfall (Balogun, 1981) discussed the seasonal and spatial distribution of thunderstorm, while Omotosho (1985) worked on the separate contributions of thunderstorm, squall lines and rainfall to the total rainfall in Nigeria. But more recently are the works of Ologunorisa (1999) and Dai (2001) who made use of data from over 15000 stations throughout the globe to study global precipitation and thunderstorm frequency, and Ologunorisa and Alexander, (2004, 2007) also dwelt on the annual thunderstorm trend and fluctuations and the diurnal variations of thunderstorm activity over Nigeria. As observed, few works have been done on thunderstorm days and frequency with little or none written in the area of seasonal, inter-seasonal and spatial variations of thunderstorm frequency especially over Nigeria.

This is an area where changing climate variables, have the potential of affecting either negatively or positively, by decreasing or increasing the frequency of occurrence of thunderstorm, seasonally, inter-seasonally and spatially. In addition to studying the wet thunderstorm, the characteristics of dry thunder was also studied. Therefore, this study made use of thunderstorm data so as to establish a fact on the seasonal and inter-seasonal variations of both dry thunder and thunderstorm vis-à-vis the amount of rainfall seasonally over Nigeria.

Using the thunderstorm dataset, this work was aimed at presenting a synoptic view of the frequency as well as the spatial distribution of both the dry and wet thunderstorm, in the face of changing climate variables. In order to achieve this, the following objectives were drawn up which include to: a. separate from the entire thunderstorm data the number of occurrence of both the dry and the wet thunderstorms; b. ascertain the trend and inter-seasonal variability of both the dry and wet thunderstorm in the event of changing climate variables; and c. present the spatial display of the frequency of occurrence of thunderstorm and dry thunder over Nigeria.

METHODOLOGY

Daily thunderstorm and the associated rainfall amount data spanning a period of ten (10) years (1991-2000) extracted from the daily record of observation from Nigerian Meteorological Agency, Oshodi, Lagos, constituted the main data.

Nigeria lies between large land surface and water body, and close to the Equator as shown in Figure 1. It is between the latitudes 4 - 14°N and longitudes 3 - 15°E. To the east of Nigeria is Cameroun, on the North is the Republic of Niger, while to the West and south are the republic of Benin and Atlantic Ocean, respectively. Nine (9) Stations within Nigeria were considered with such spread that covers all the climatic zones of the country; the Sahel savannah, Guinea Savannah and the tropical rainforest, with three representative stations as shown in Figure 1.

In the register of observations, the record of the times of start and end of rainfall events; presented under three columns (0600 to 1800 h, 1800 to 0600 h next day and 0600 to 06 h next day), the rainfall amount and the meteorological system (that is Squall lines, Thunderstorm or Monsoon), responsible for the rain and their times of start and end. It is through the column for the rainfall amount that we were able to ascertain whether or not rain accompanied the occurrence of thunder, while the column for weather, showed us whenever there was the occurrence of thunderstorm, with or without rainfall.

However, there have been different classifications of thunderstorms, ranging from;

i. *in situ* and slow-moving storms (maximum gusts less than 24

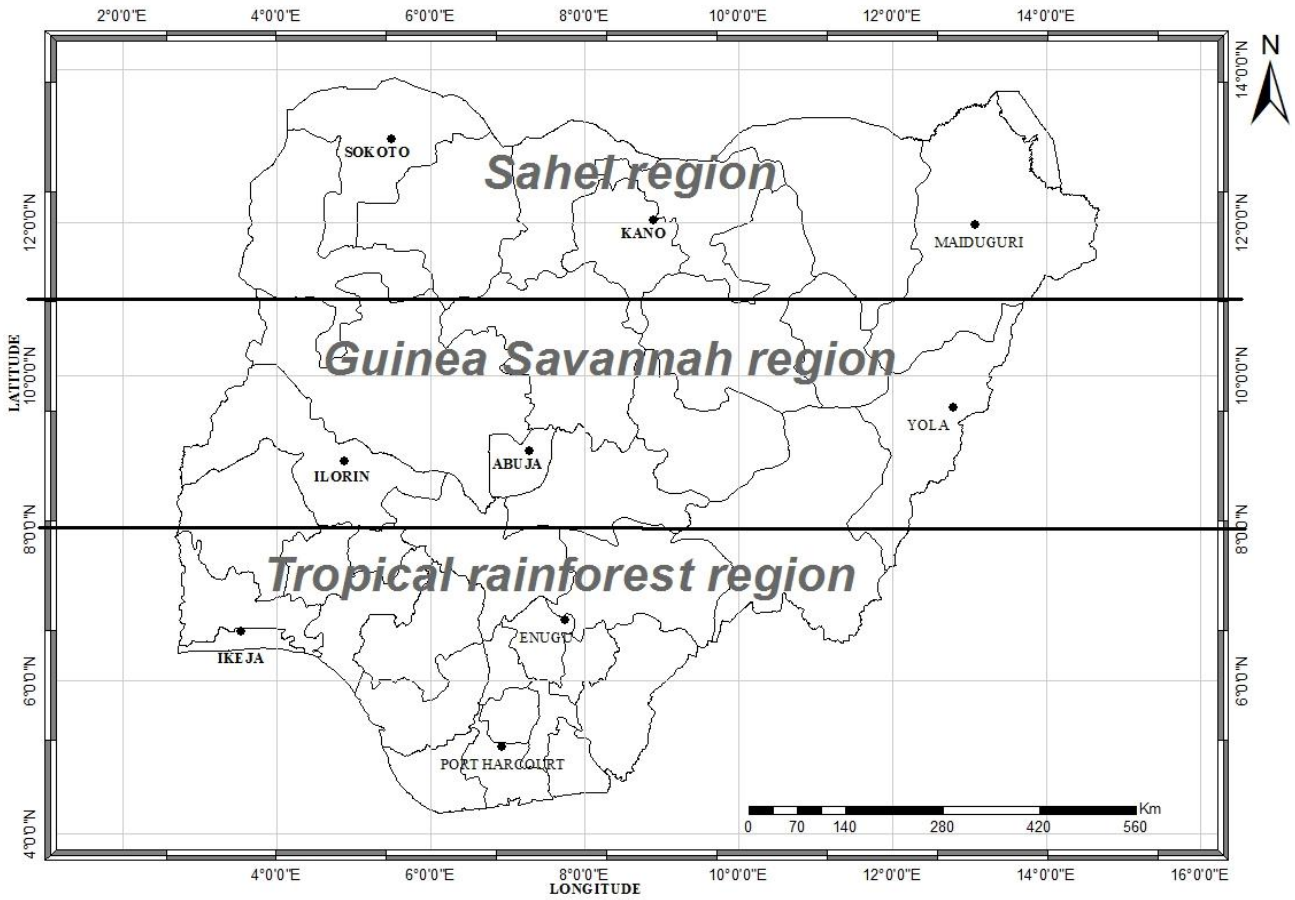


Figure 1. Map of Nigeria showing the stations and the climatic zones (adapted from Omotosho and Abiodun, 2007).

knots) and squall lines with gusts greater than 24 knots (Omotosho, 1985, 1987) using surface data; and

ii. air-mass thunderstorm and severe thunderstorms according to the strength of the wind shear (Ahrens, 2000).

But here, considering the association of rainfall with the occurrence of thunderstorm, we were able to classify thunderstorm into; dry thunder (with trace or no rain at all) and wet thunder (with measurable rain). This was achieved by comparing the column of rainfall amount with that of weather. In an event when a thunderstorm occurred in the evening, as is the case in West Africa (Omotosho, 1987; 2008), but its rainfall extends to the early hours of the following days, the rainfall was added against the day during which the storm occurred, in as much as the rainfall did not last beyond 0600Z. Such a day was not a rainy day, unless another thunderstorm with rain occurred later in the evening/night of the same day.

In order to study the frequency of occurrence of thunderstorm, the total monthly number of thunderstorm followed by the total annual number of thunderstorm were computed. But in order to compare the degree of variation of the frequency of occurrence of thunderstorm, the coefficient of variation was calculated using:

$$C.V. = \frac{\delta}{\sigma} X\ 100$$

Where, C.V. is the coefficient of variation, δ is the standard deviation, while σ is the mean of the frequency.

RESULTS AND DISCUSSION

Spatial distribution of thunderstorms with time

Thunderstorm activities were only recorded in the Sahelian region of Maiduguri between July and August (Figures 2g and h) which coincides with the period of northernmost position of the Inter-tropical Discontinuity (ITD) and the time of Little Dry Season (LDS) in the south. The cores of the thunderstorm activities are stronger from the coast up to 9°N (around Abuja) in the summer months of April-June and September-October (Figures 2d-j), but with thunderstorm occurrence ranging from 2-3 times in November (Figure 2k). These findings are in agreement with Anne-Duncan (2010), who asserted that the months of May to October, which is the

months of the rainy season are mostly characterized by thunderstorms and line squalls with its attendant turbulence, micro bursts and lightning. The effect and/or possible implication of LDS which leads to some areas having double maxima rainfall (10°W-9°E up to 10°N) (Omotosho, 1988), started exhibiting its feature of no activity in July but become prominent in the month of August as it spans to about 8°E and within south of 10°N. The beginning of thunderstorm activities always starts from the southwest through the south-south at the beginning of the summer month of March but later migrates to the centre of the study area in the other summer months till October as seen in Figure 2d-j.

The position of the ITD in the month of August implied that the thunderstorm activities are more predominant in the Sudan and Sahel region of the country at latitude 11°N upward. But such strong activities were also experienced around Enugu axis (lat. 6.28°N and long. 7.33°E) as was observed over Owerri (lat. 5.29°N and long. 7.00°E) as revealed by Enete et al. (2012), which is well below 10°N (transition zone) when other stations south of the same latitudinal position are experiencing lesser activities of the system. This situation can be attributed to orographic influences such as the presence Obudu hill and Cameroon Mountain.

In the month of August, the existence of a shift of the maximum isoceraunic lines from the coast up to the extreme north was observed as seen in Figure 2h, which could be as a result of the availability of more moisture which favours the development of cumulonimbus (CB) clouds as well as the position of the ITD. Together with the existence of an area of More Thunderstorm Activities (MTA) over Enugu, there is a latitudinal belt of reduced thunderstorm activities (RTA) which is between 7-10°N in August (Figure 2h). However, this belt has been observed to be between 6 and 8.5°N (Omotosho, 1988).

Furthermore, when a baseline of 5 numbers of thunderstorm was used, it was observed that the onset of agriculturally viable rainfall, which has been postulated to be lagging behind thunderstorm (Balogun, 1981), begins in March (Figure 2c), over the tropical rainforest regions of Ikeja and Port Harcourt, April (Figure 2d) over Abuja, May (Figure 2e) over Yola and Ilorin, and June (Figure 2f) over the Sahel region of Kano. This is in line with the findings of (Balogun, 1981) that rainfall over Nigeria follows the meridional migrations of the ITD from around 5°N in January to a maximum position of about 22°N in August. There is a drastic reduction in the number of thunderstorm over the areas lying between 2-7°E and 6-10°N as witnessed between the months of July and August (Figures 2g and h, respectively), which confirms the existence of the anomalous “little dry season”. This is in line with the findings of Ireland (1962), who gave the northern and eastern limits of this LDS as 9°N and 5°E, respectively. In confirming the existence of this “anomaly”, Adefolalu (1972) and Adekoya (1979) showed that the LDS extends to 12°W and 7°E.

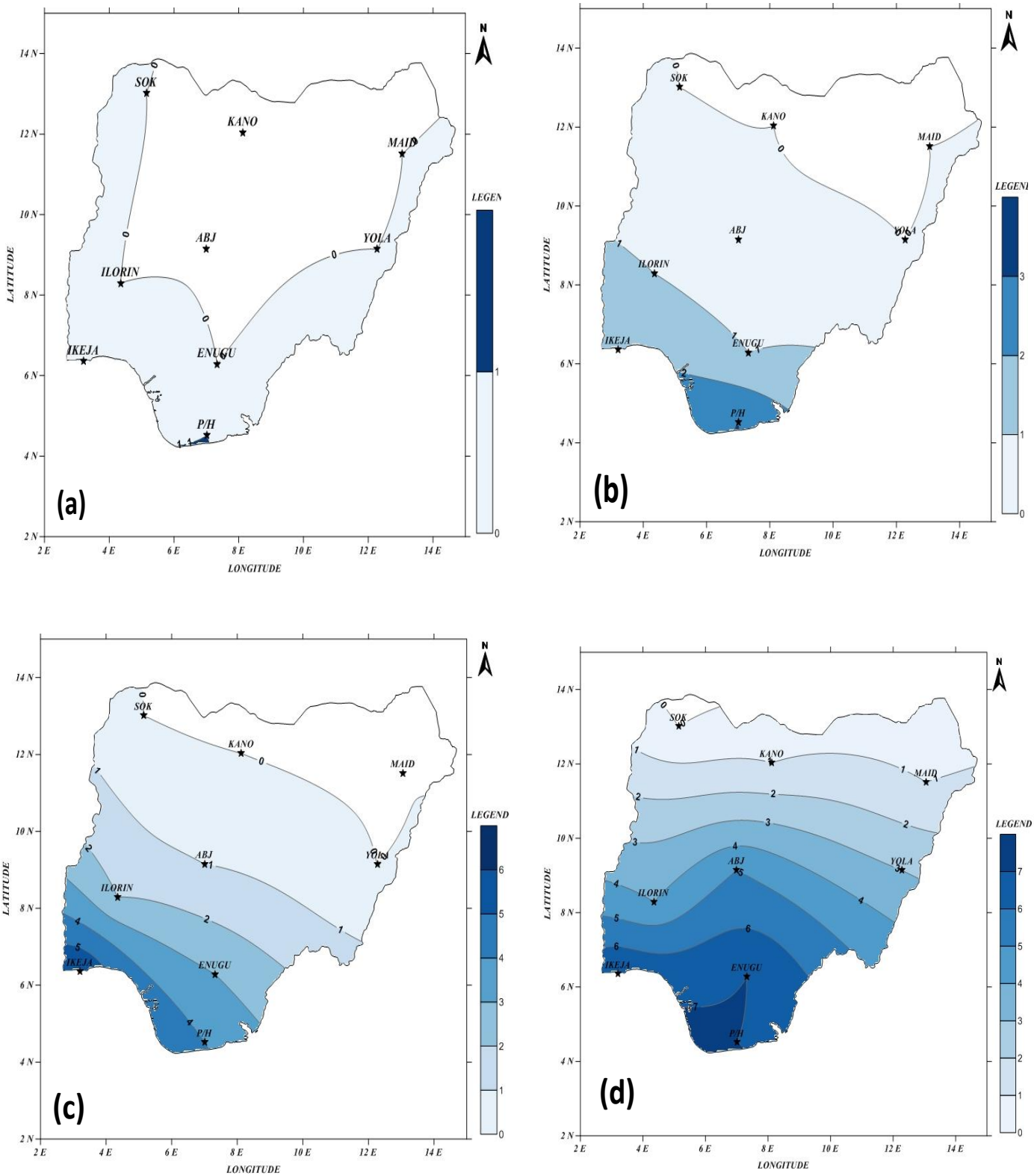
The isoceraunic lines of maximum thunderstorm activities were found over areas that are occupying the central states of the country but there exist reduced numbers of thunderstorm activities over areas to the extreme left (west) and right (east) of the country as seen at Ilorin and Yola stations (Figures 2d-f and i-j). This ‘centralized shape’ could be attributed to the movement and position of the weather producing wave (ITD) that is prevalent over the country; wherein the trough falls on, as in the central Nigeria (longitudinally) receives maximum thunderstorm activity, while the area under the crest of this wave experiences reduced thunderstorm activity. This can also be seen over the Sahel region, where the occurrence of thunderstorm tends to be greatly reduced over Maiduguri more than over Sokoto, with Kano (at the centre) receiving MTA. This severe RTA over Maiduguri (Figure 9c, d, g, h, i and j) could be the reason for the existence of more severe desert encroachment from this side of the country than it is over Sokoto, and this is particularly noticeable in September (Figure 2i) but reflected little in other months.

Mean inter-seasonal variation

It can be seen from Figure 11a that the average number of thunderstorm remains constant between 3 and 4 thunderstorms (TS) per year for stations north of 9°N while Abuja has the highest number of thunderstorm occurrence of 8 TS in 1992 and 7 TS in 1996. However, there is generally a very low thunderstorm occurrence over Ilorin and Yola, which implies the dominance of the other rain producing systems such as monsoon and squall line. The same cannot be said of the stations south of 9°N where the range of the average thunderstorms recorded were between 4 and 9 TS per years with the least number of 2 TS of thunderstorm per years (Figure 11b) experienced over Ilorin station in 1992. While Port Harcourt, Ikeja and Enugu were experiencing a downward trend in the average number of thunderstorms from 1991-1998, Ilorin on the other hand was experiencing an upward trend.

Five year mean inter-seasonal variation

Between the first and second pentads on the inter-seasonal basis; the five year mean is to determine the variability in the frequency of occurrence of thunderstorms within the ten years period by comparing the first pentad and the second pentad (Figures 3a-k). Hence, the pentad spatio-temporal graphs will give a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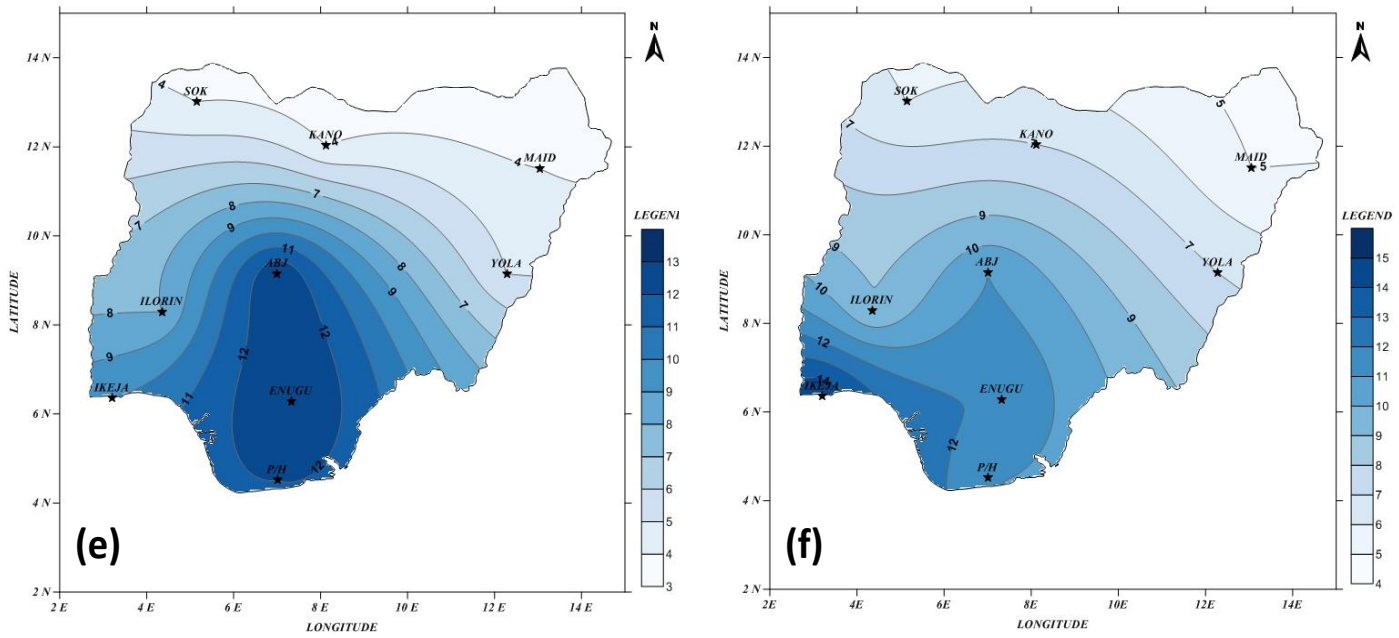


Figure 2. The mean monthly variations of thunderstorm frequency in Nigeria; (a) January, (b) February, (c) March, (d) April, (e) May, (f) June, (g) July, (h) August, (i) September, (j) October, (k) November, (l) December.

better representation on an average than on an annual basis.

There is an increase in the number of thunderstorm occurrences inland in the second pentad between 1996 and 2000. This increase is more prominent over Ilorin and Yola in the second pentad when compared with the first 5 years (1991-1995) as seen in Figure 10a and b. Maximum thunderstorm occurrence in the first and second pentads was highest in the coast, but reduces inland, as latitude increases.

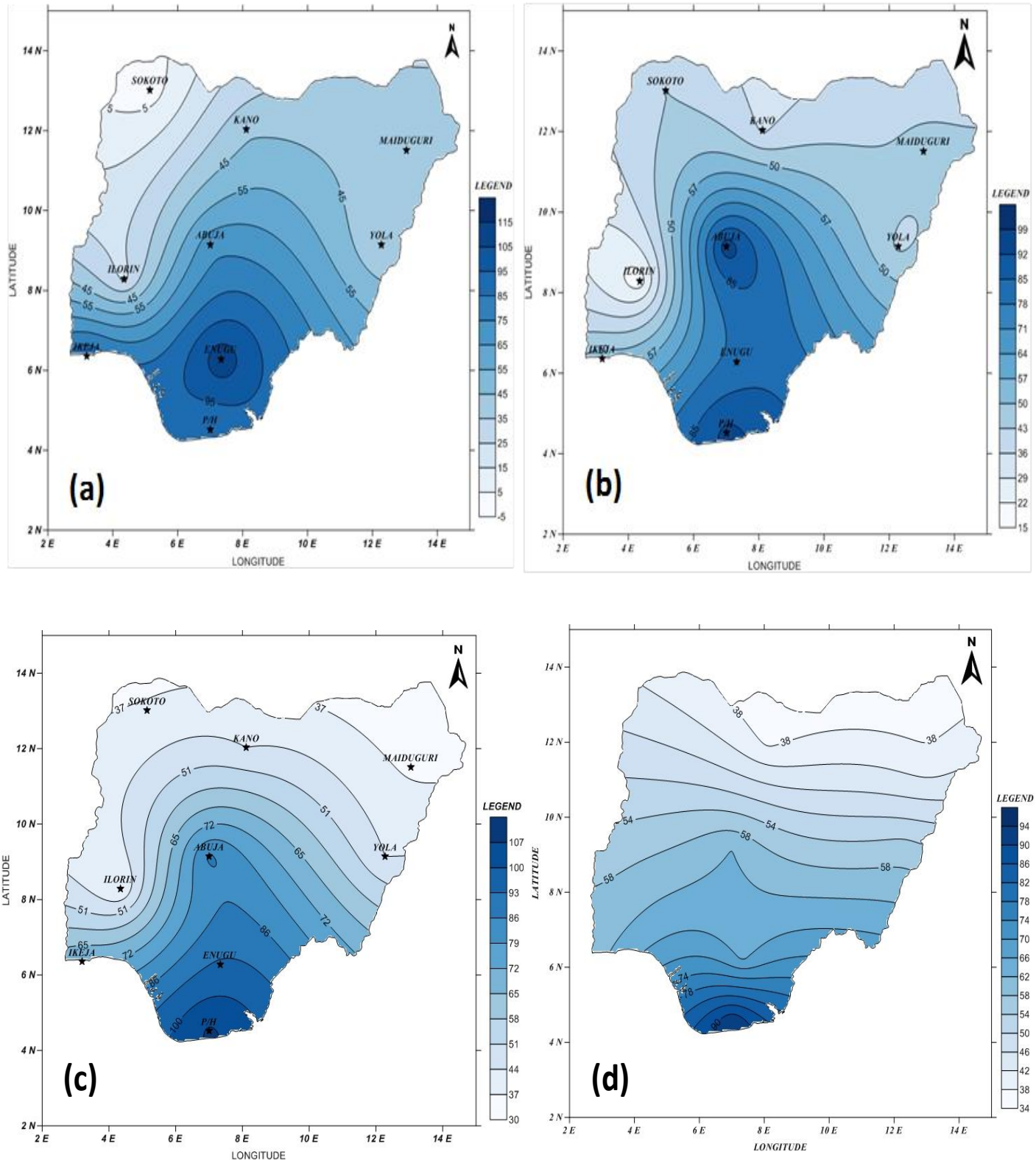
However, on the seasonal basis; the five-year monthly average of the frequency of thunderstorms showed that January, February, March, June and September (Figure 13a, b, c, f and i) of the second 5-year mean (1996-2000) recorded an improvement in the system compared to the previous (1991-1995) 5-year mean monthly frequency of thunderstorms. In the second pentad, there was an improvement in the spatial coverage of thunderstorm activity in the country which was more predominant over the south-western region of the country with a marked reduction over Sokoto and Maiduguri in the Sahel region while the first 5-year average experienced most of the activities over the south-south region.

July and October (Figure 13g and j) of 1996-2000 recorded a reduction in the frequency of thunderstorm from what was obtainable in the previous pentad of 1991-1995, but the month of August showed a shift in the maximum thunderstorm activity (MTA) from the south-eastern region (Figure 12h) between 1991 and 1995 to the extreme northern part of the country (Figure 13h) within 1996 and 2000. However, there was no significant change in the frequency of thunderstorms in November and December of the two pentads considered.

Temporal and seasonal variation

In August, double maxima could be seen over all the stations that are south of 9°N except Enugu (lat. 6.28°N and long. 7.33°E) which experiences a reduced thunderstorm activity that is not significant enough to have shown the feature of double maxima of thunderstorm activities like other stations within the defined latitude (Figure 4b). Also all stations north of 9°N have been observed to be experiencing a single maximum of thunderstorm activities except Abuja (lat. 9.15°N and long. 7.00°E) whose thunderstorm activities show double maxima (Figure 4a). This is in line with results of (Balogun, 1981 and Okuma, 2001) who however, made use of a bench mark of 7°N to delineate the nation, while Omotosho (1988) used 10°N to delineate the country.

Over all the stations in the Sahel region, the total number of thunderstorms ranges between 35 and 45, except in 1995 and 1997, when Sokoto and Kano experienced a sudden decline and increase in the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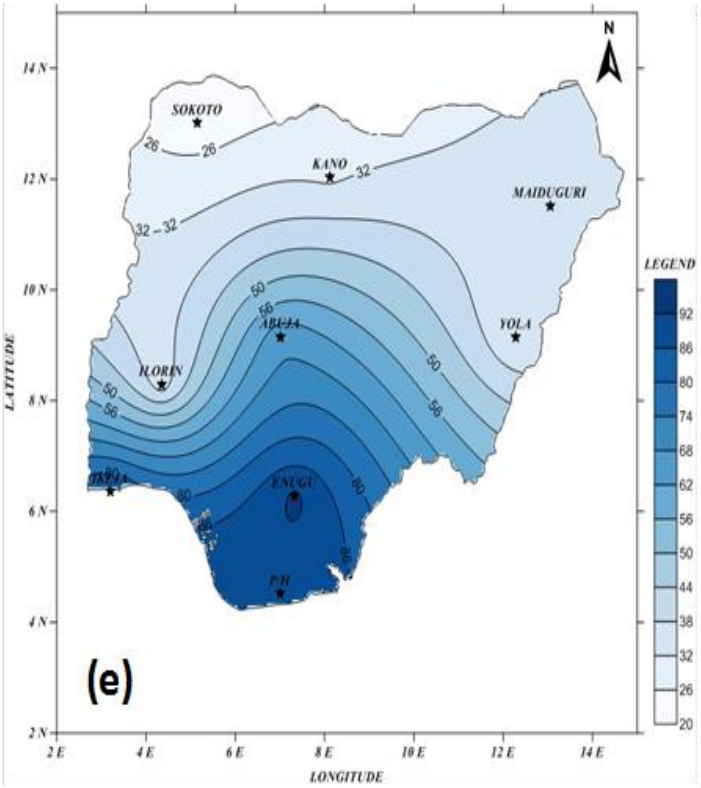
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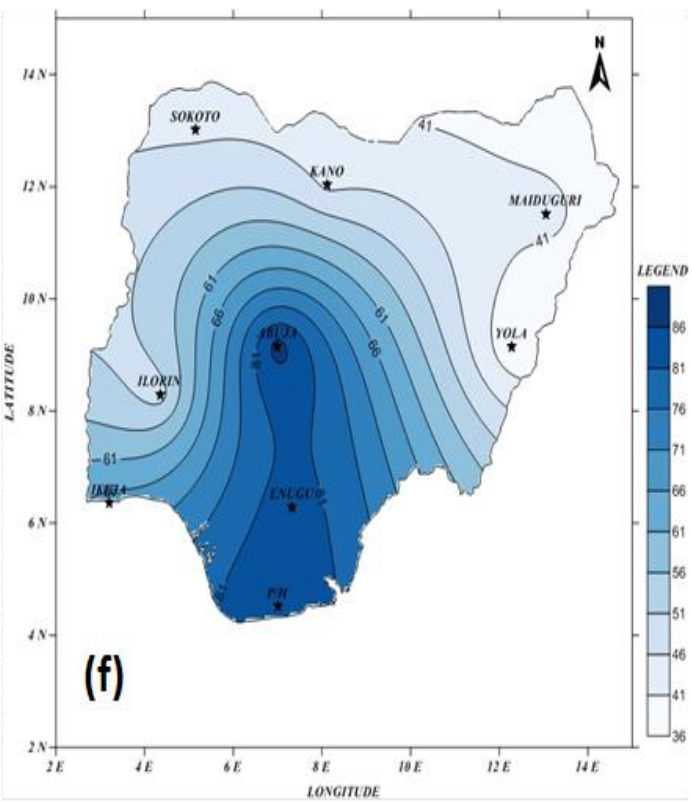
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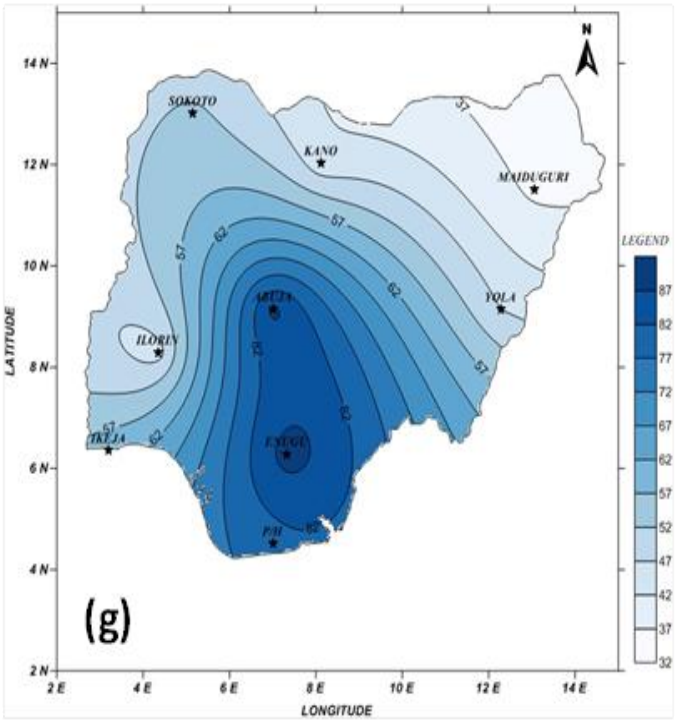
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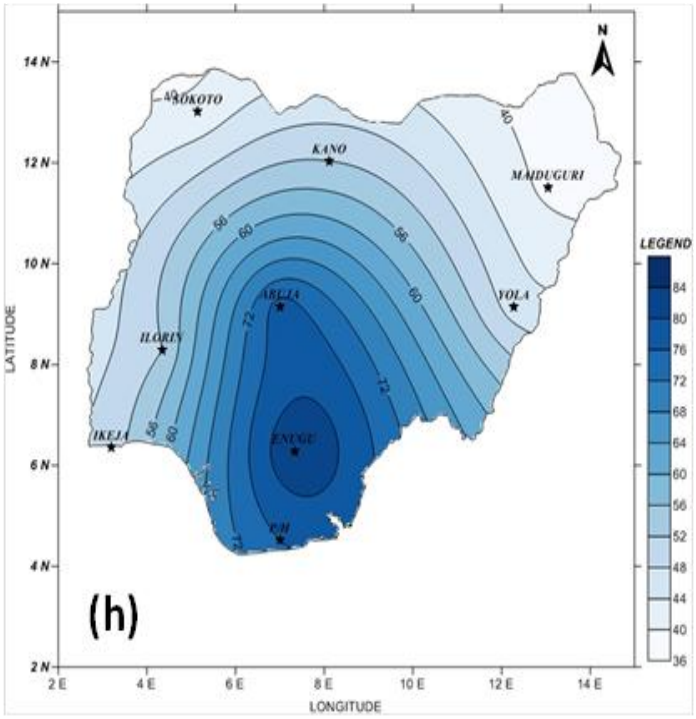
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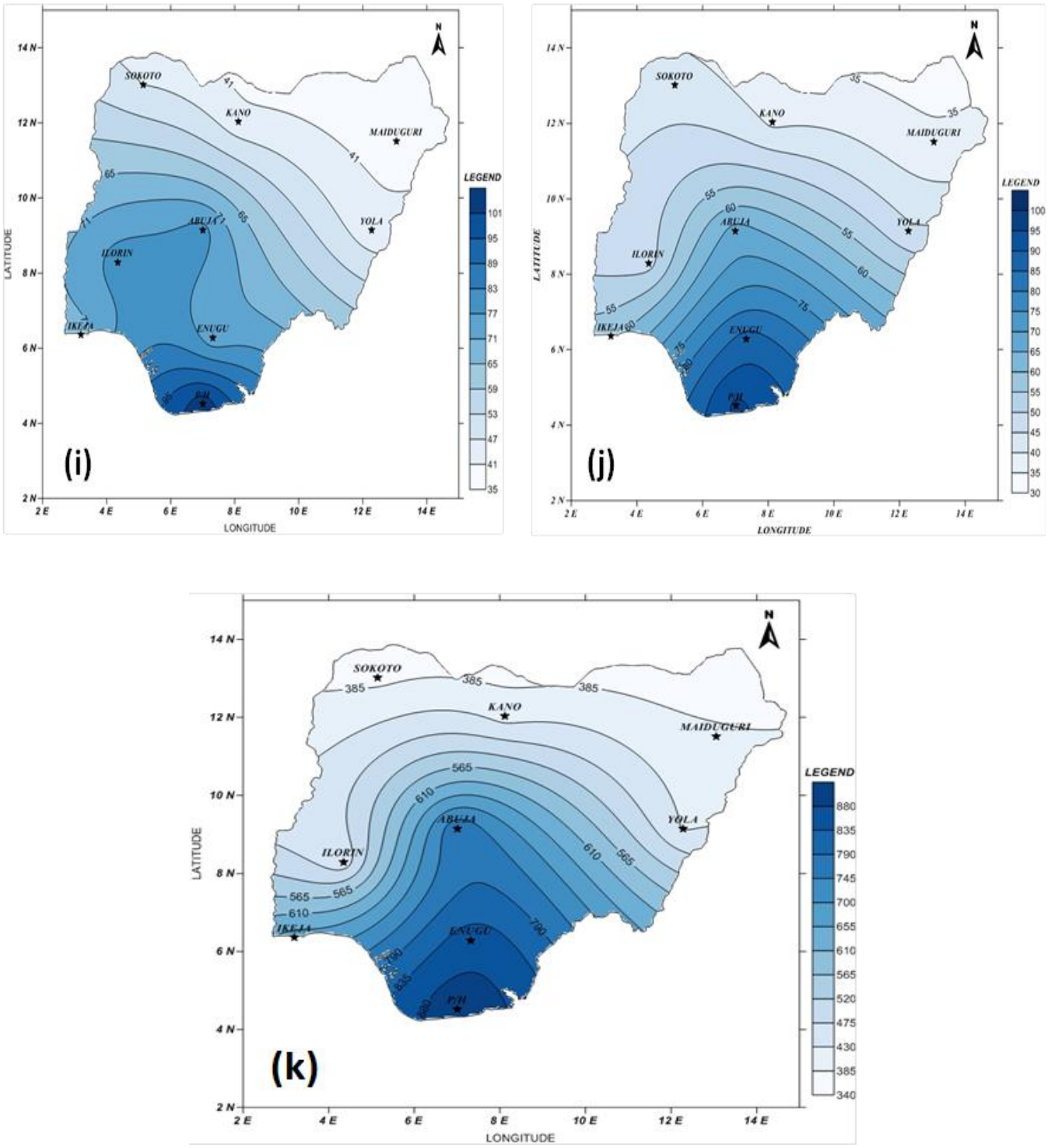
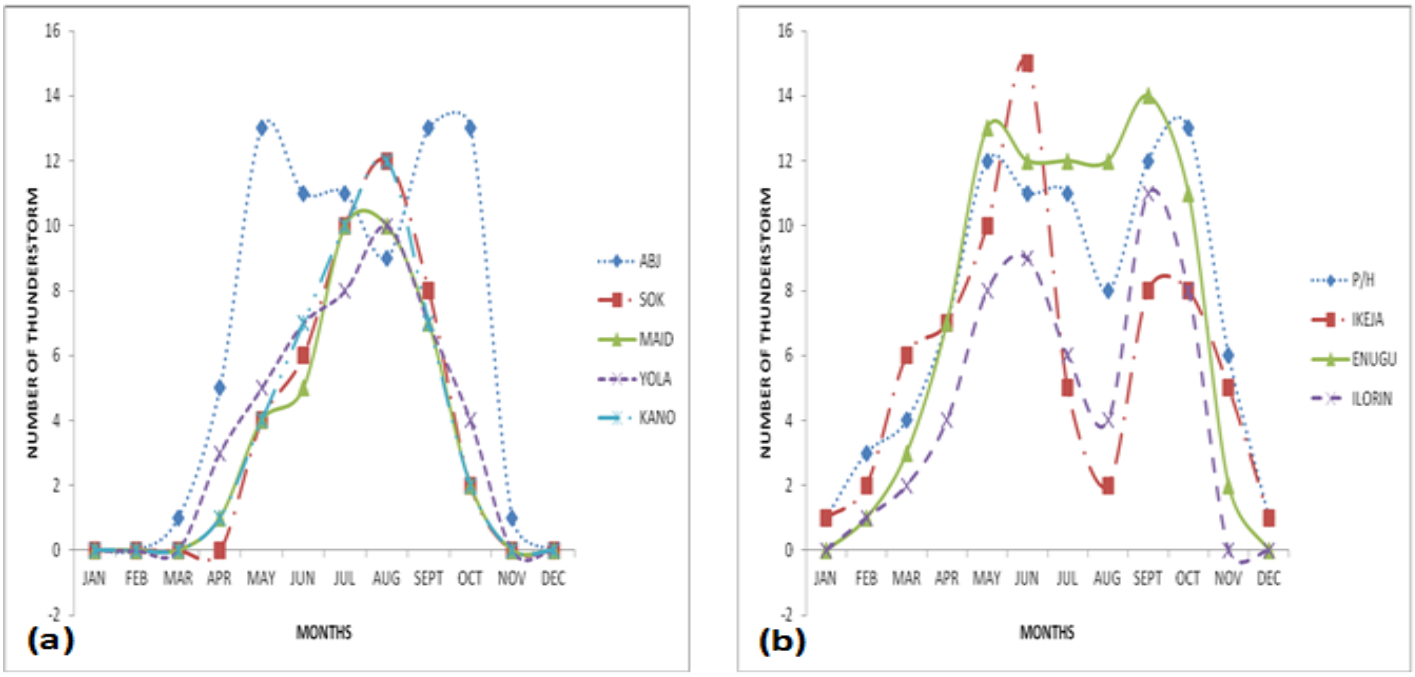


Figures 3. Total annual variation of thunderstorm over Nigeria; (a) 1991, (b) 1992, (c) 1993, (d) 1994, (e) 1995, (f) 1996, (g) 1997, (h) 1998, (i) 1999, (j) 2000, (k) 1991-2000.



Figures 4. Monthly variation of thunderstorm over stations; (a) above 9°N and (b) below 9°N.

number of thunderstorm, respectively (Figure 5a). However, over the rainforest region, all the stations show a gradual reduction in the total number of thunderstorm activities until 1998 when Ikeja and Port Harcourt started increasing, while Enugu started experiencing increase in thunderstorm activities in 1999 (Figure 5b).

Over the Savannah region, it can be deduced that Yola and Ilorin are having the same increasing thunderstorm trend; and this can also be seen on the spatial distribution maps, whereas, Abuja was observed to be having a decreasing trend (Figure 5c).

Inter-seasonal variation

With Abuja (above 9°N) experiencing double maxima and Enugu (below 9°N) experienced a single minimum, it can be seen that the weather over tropical Nigeria does not strictly follow latitudinal divides. And it is safe to say that there are other local factors that influence its formation.

Dry thunderstorm

Inter-seasonal variation

While both Enugu and Port Harcourt are experiencing a gradual reduction in the number of dry thunderstorm occurrence, Ikeja had a sudden increase from 1997 to 1999 (Figure 6a). The number of dry thunderstorm activity is more predominant over the western part of the country than over the eastern part when viewed longitudinally (Sokoto, Ilorin, Ikeja and Abuja) (Figures 6a-c). There is a general decreasing trend in the number of dry thunderstorm occurrence over the Savannah region until in 1999, when there was a sudden increase in the dry thunderstorm frequency in all the stations (Figure 6b). All the stations over the Sahel region showed decreasing trends from 1991-1995 and 1997-2000, but there was an increase in the frequency of occurrence of thunderstorm activities in 1996, over Kano and Maiduguri (Figure 6c).

Comparison between thunderstorm and dry thunder frequency

Stations north of 9°N showed a single maximum in thunderstorm frequency while the dry thunderstorm showed a double maximum (though, not really significant). Also, it can be seen that stations that are south of 9°N have double maxima both by thunderstorm and dry thunder frequencies (Figure 7a and b).

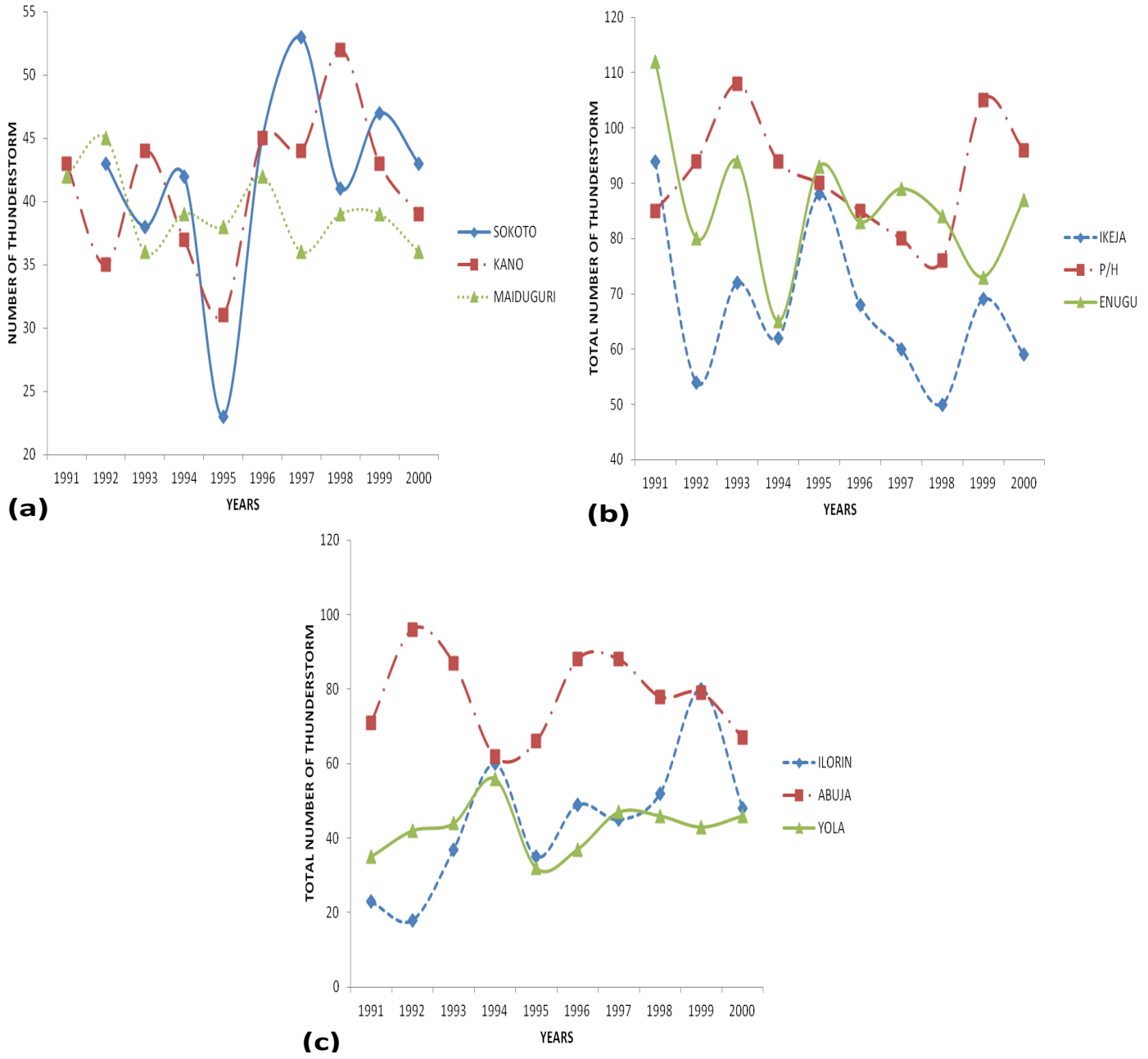
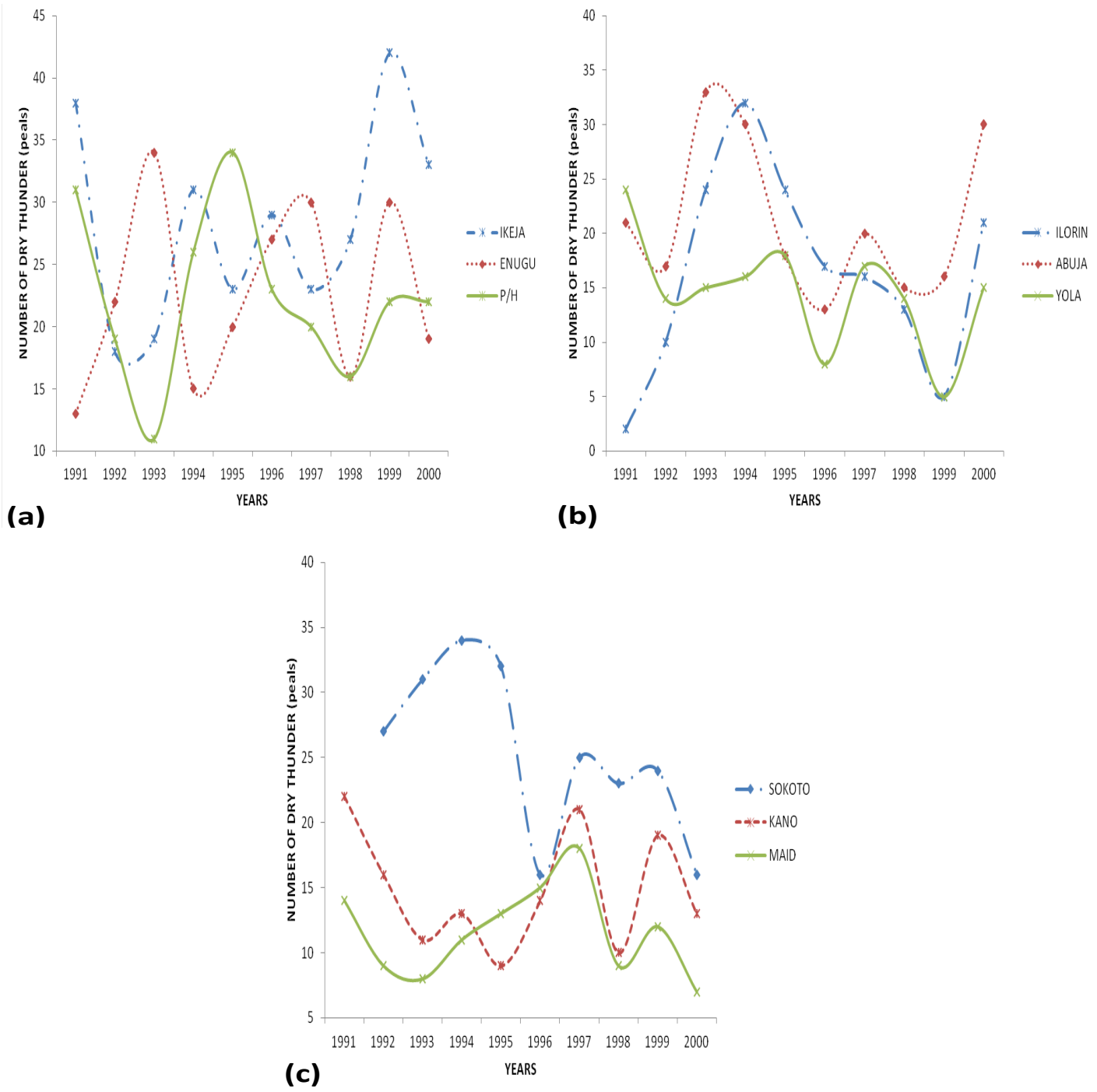


Figure 5. Total annual variation of thunderstorm over stations at the; (a) Sahel regions, (b) Rainforest region and (c) Guinea Savannah region.



Figures 6. Total annual variation of dry thunder over stations at the; (a) Rainforest region, (b) Guinea Savannah region and (c) Sahel region.

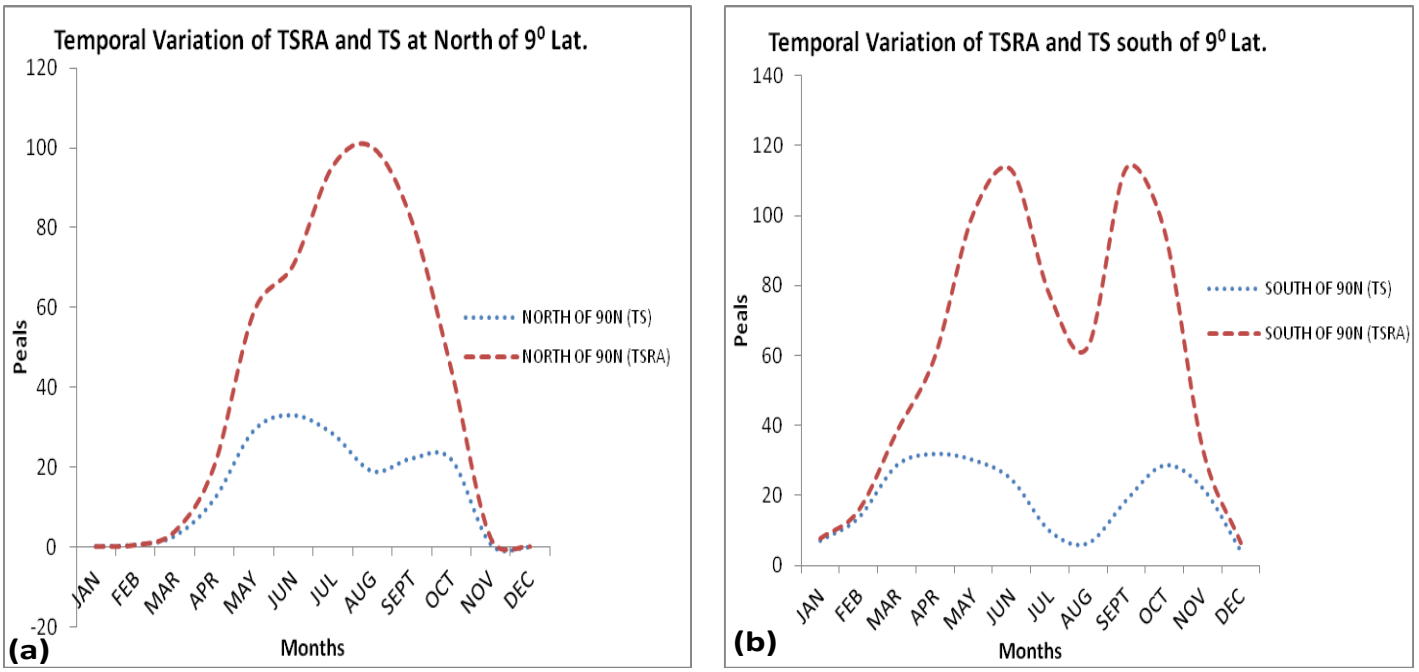
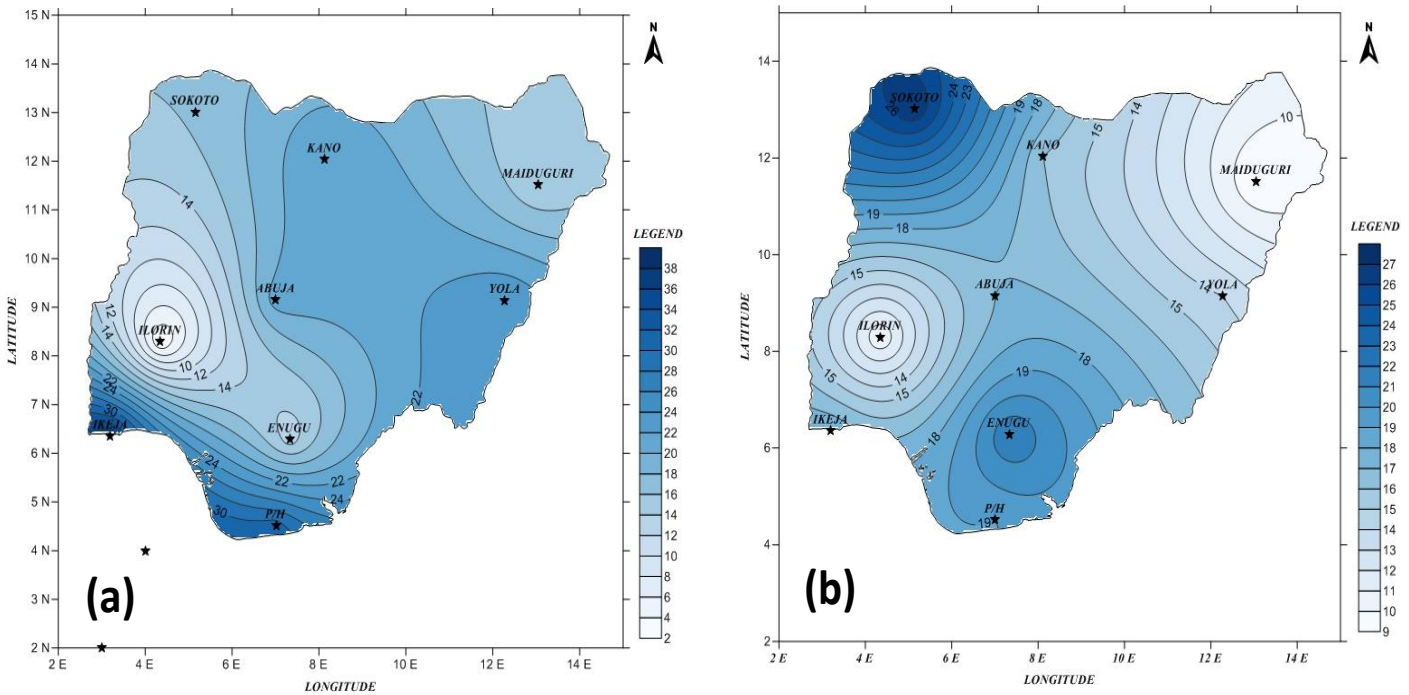
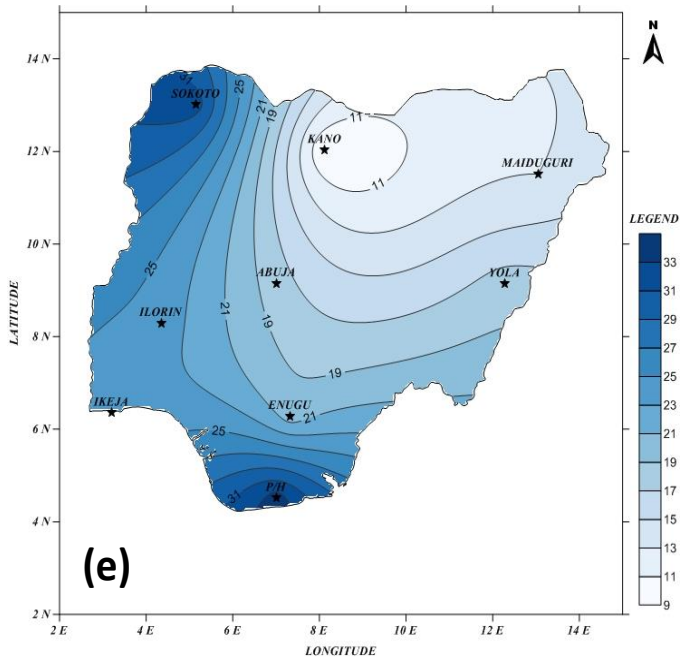


Figure 7. Comparisons of the temporal variations of thunderstorm and dry thunder over stations; (a) north of 9°N and (b) south of 9°N.

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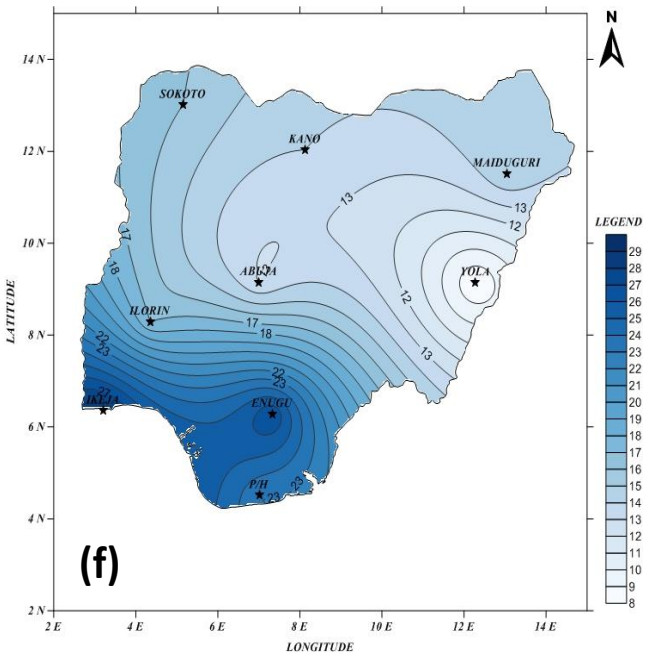
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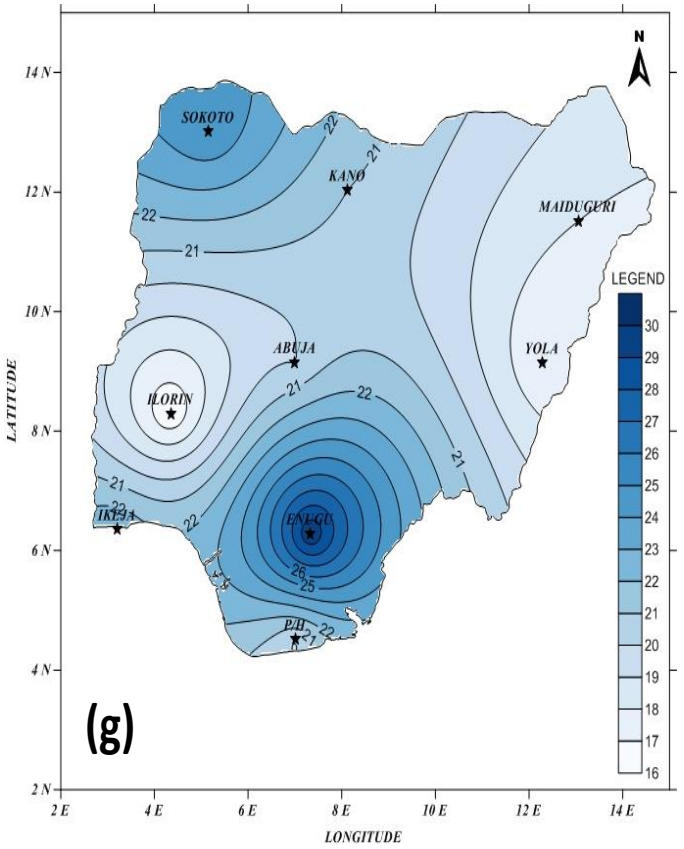
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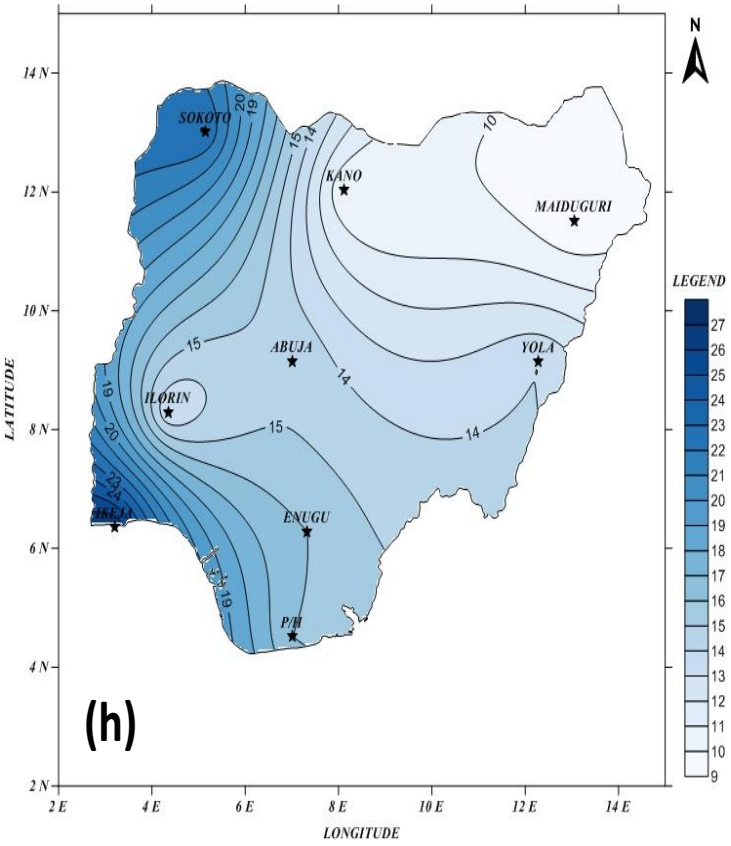
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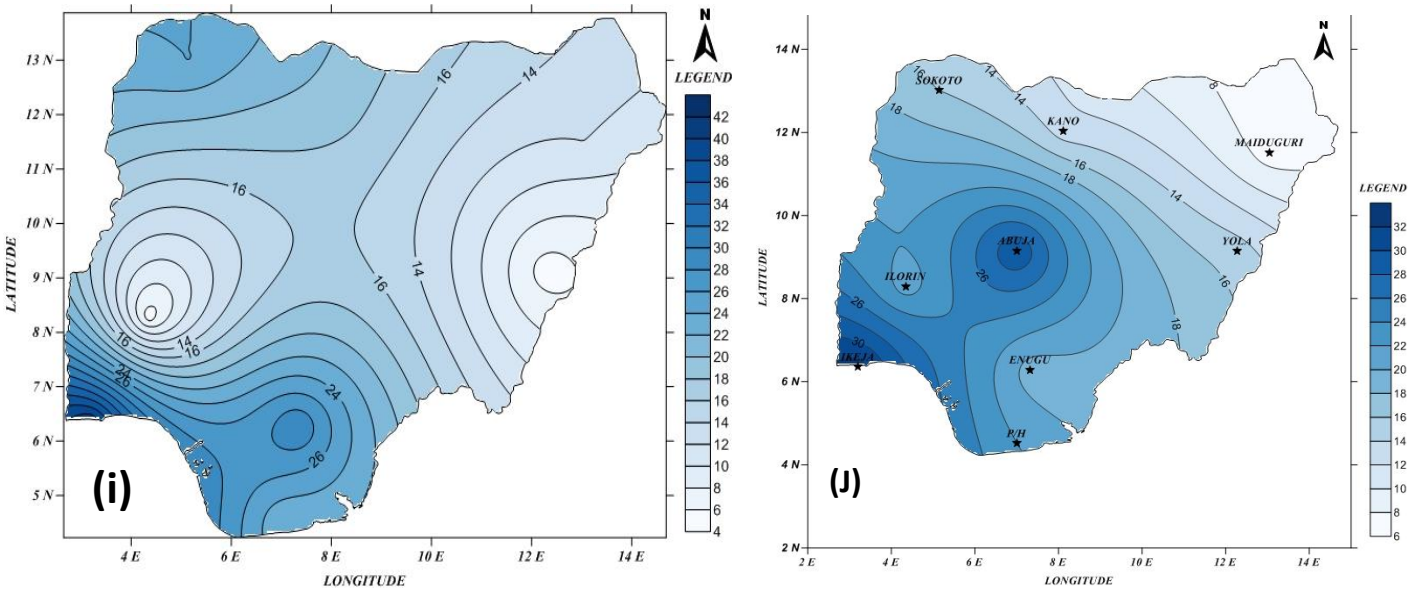
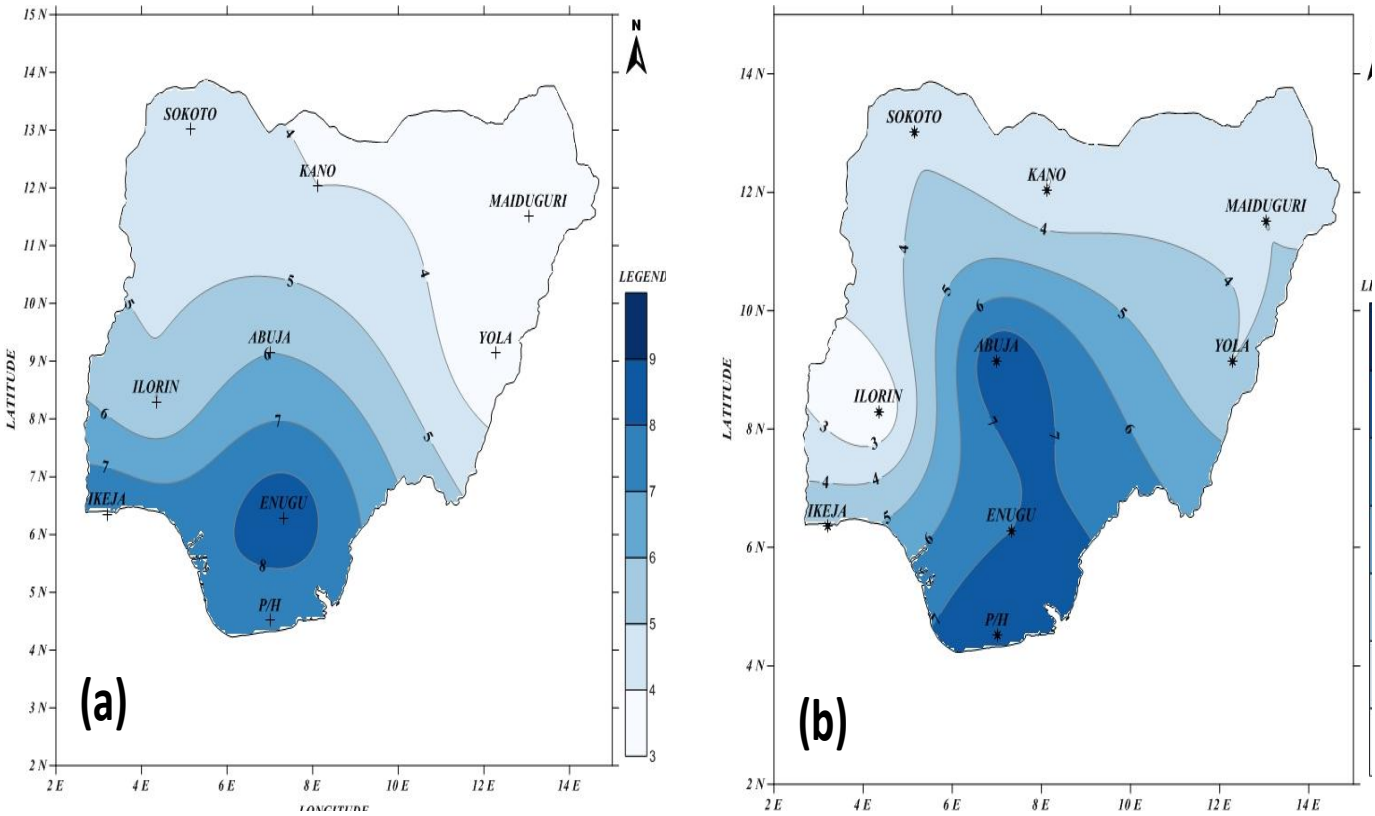
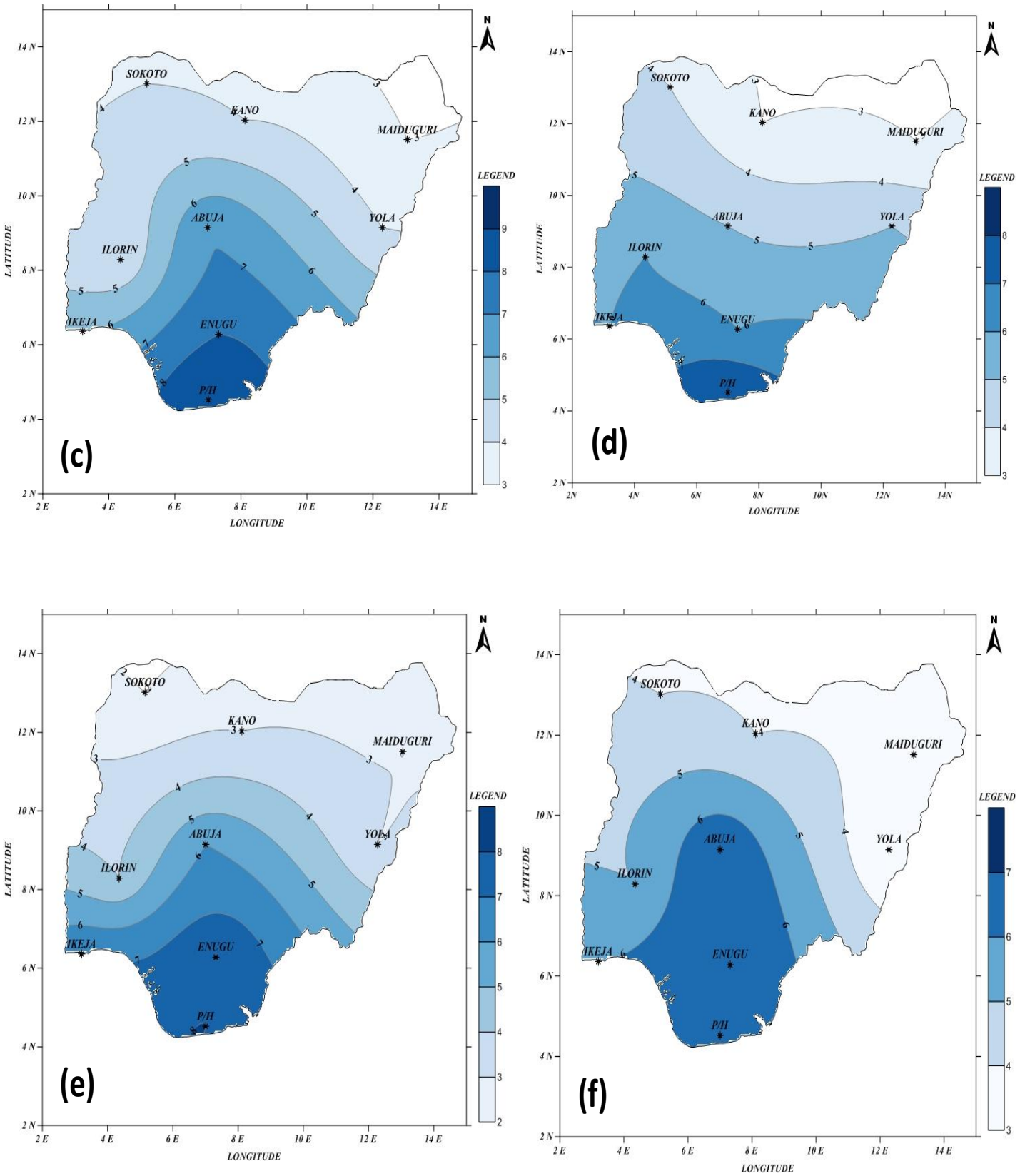


Figure 8. Annual variation of the total number of occurrence of dry thunder over Nigeria; (a) 1991, (b) 1992, (c) 1993, (d) 1994, (e) 1995, (f) 1996, (g) 1997, (h) 1998, (i) 1999, (j) 2000.

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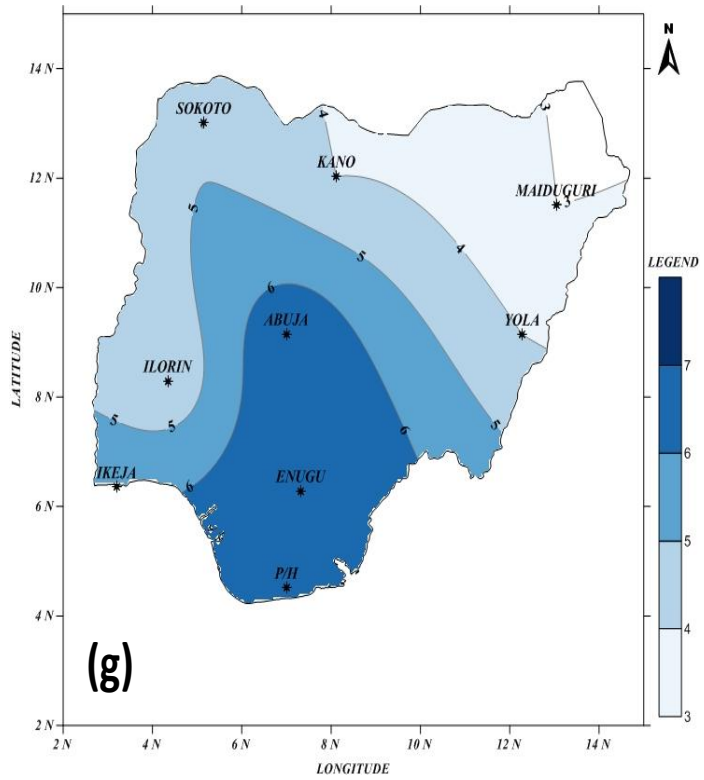
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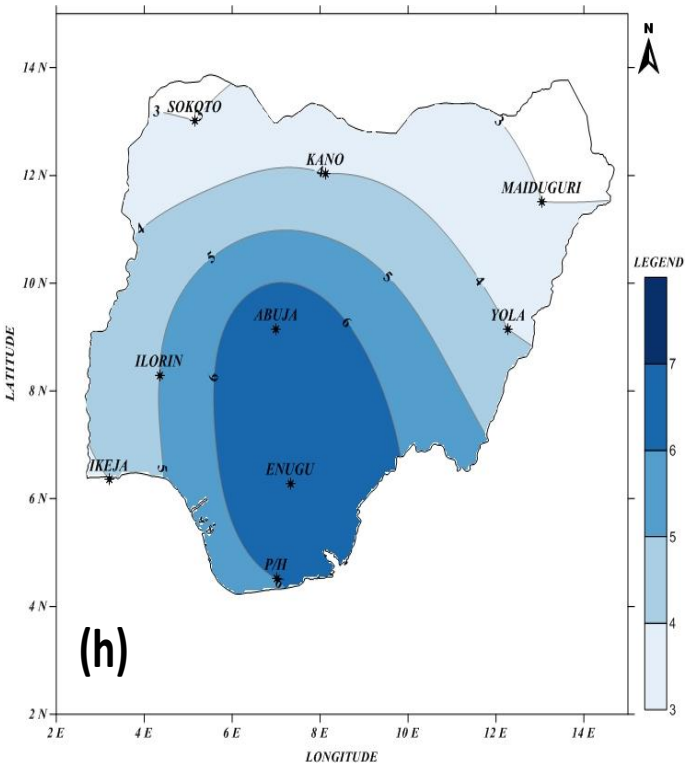
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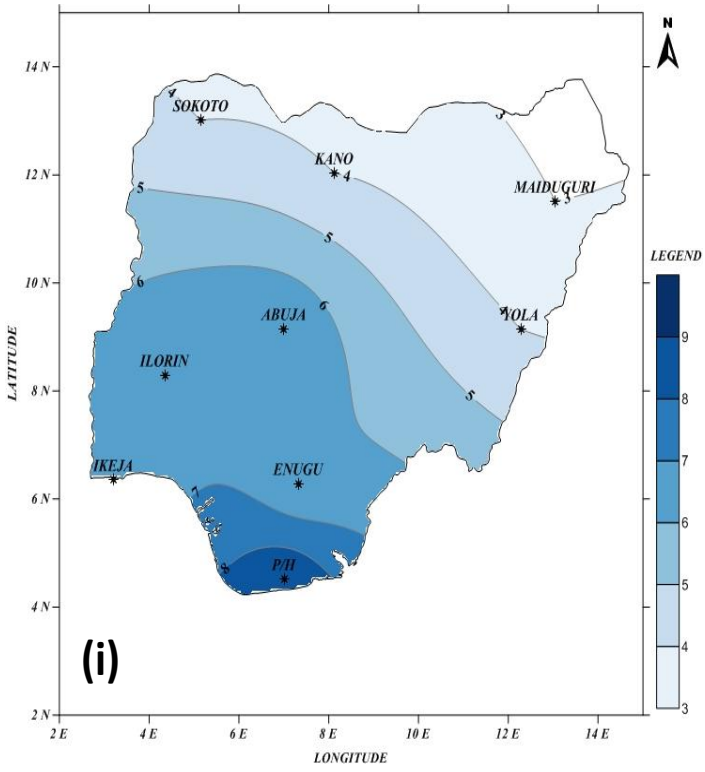
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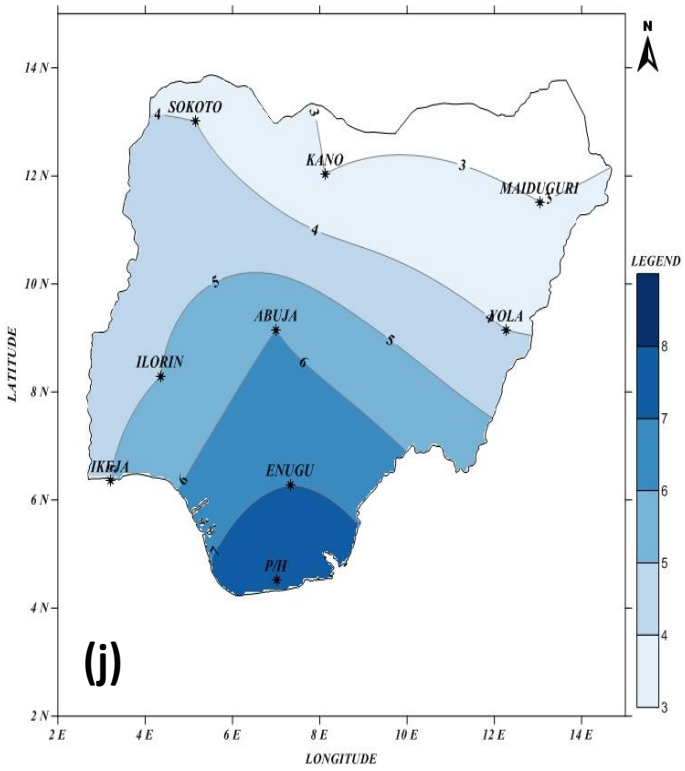
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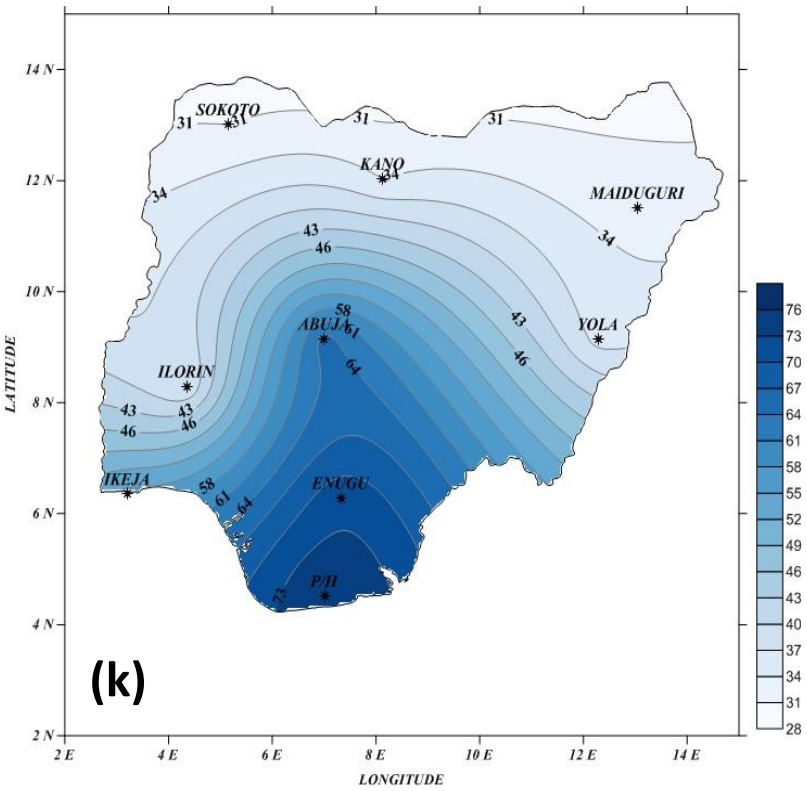
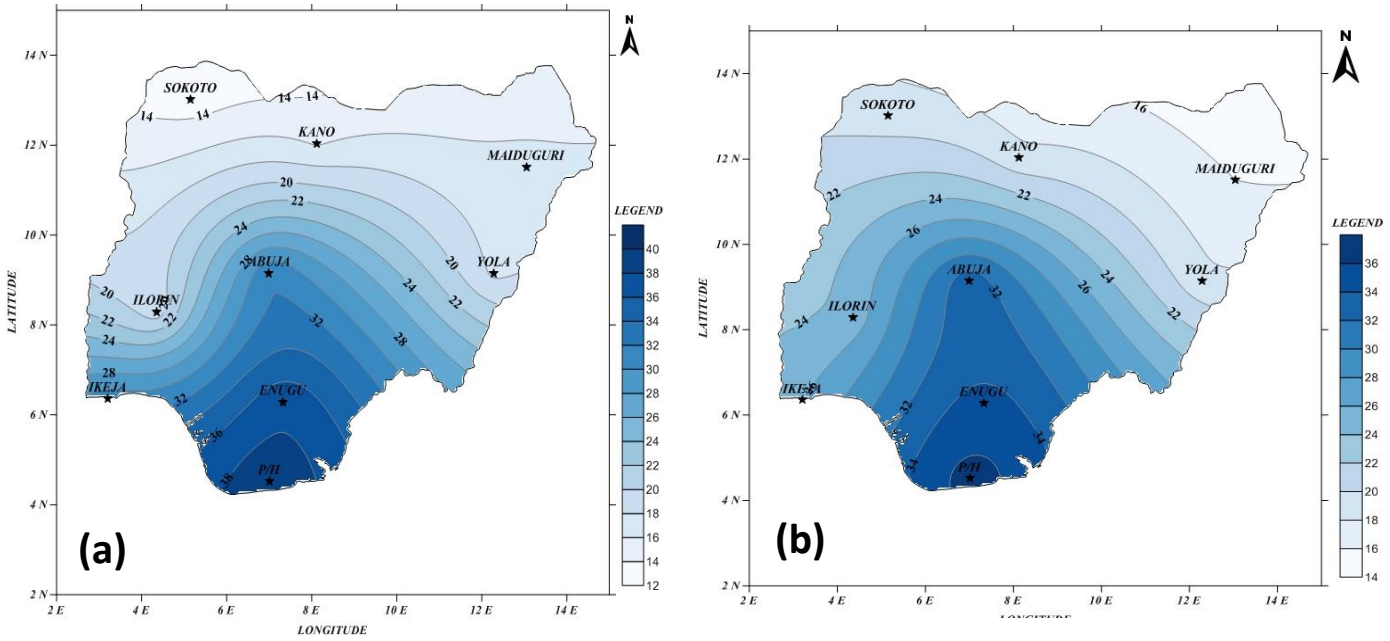
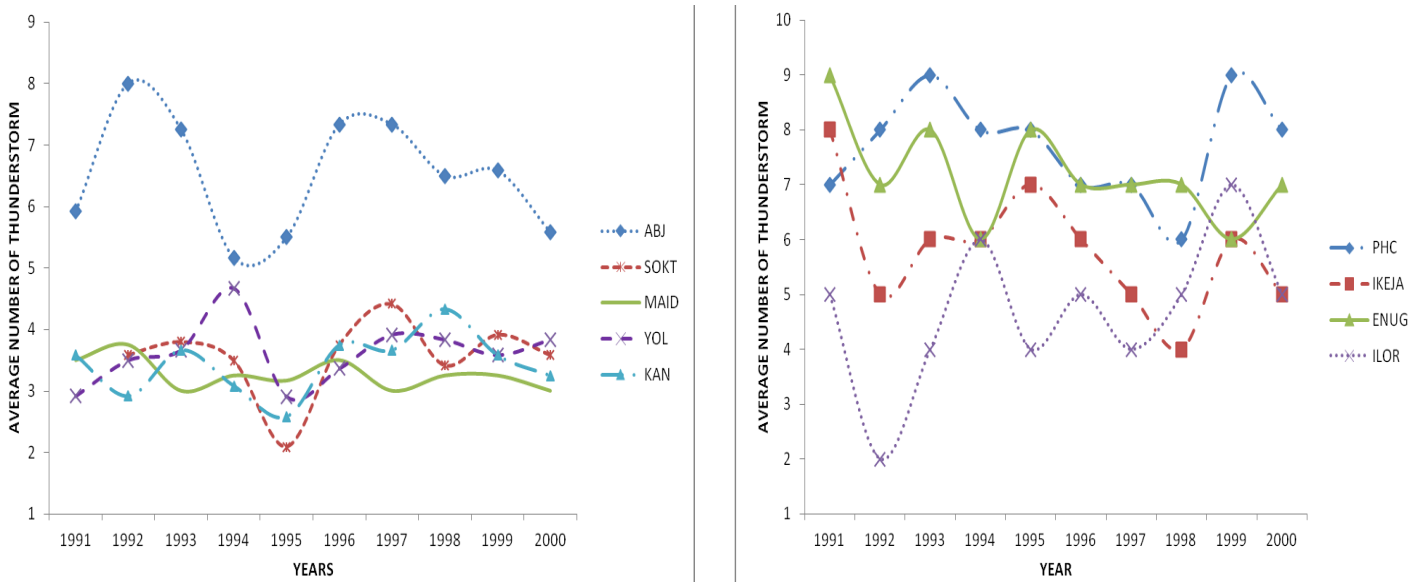


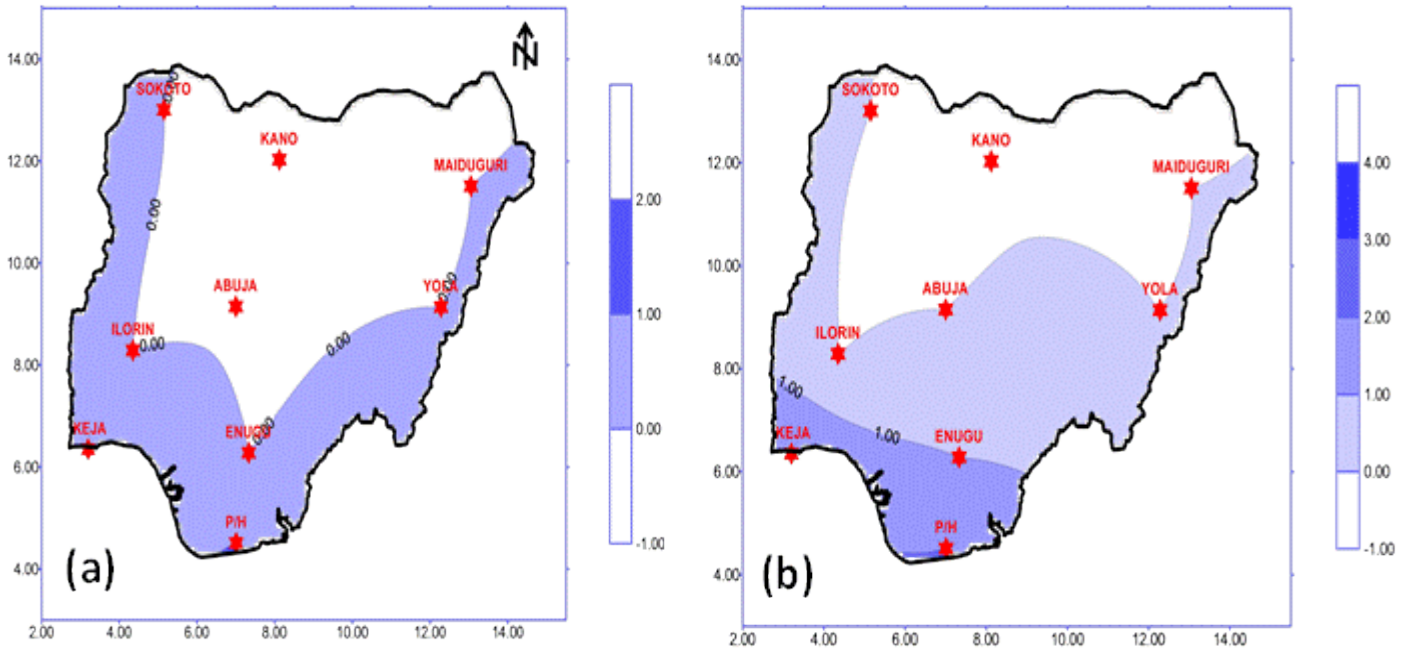
Figures 9. Mean annual thunderstorm occurrences over Nigeria for; (a) 1991, (b) 1992, (c) 1993, (d) 1994, (e) 1995, (f) 1996, (g) 1997, (h) 1998, (i) 1999, (j) 2000, and (k) 1991-2000.

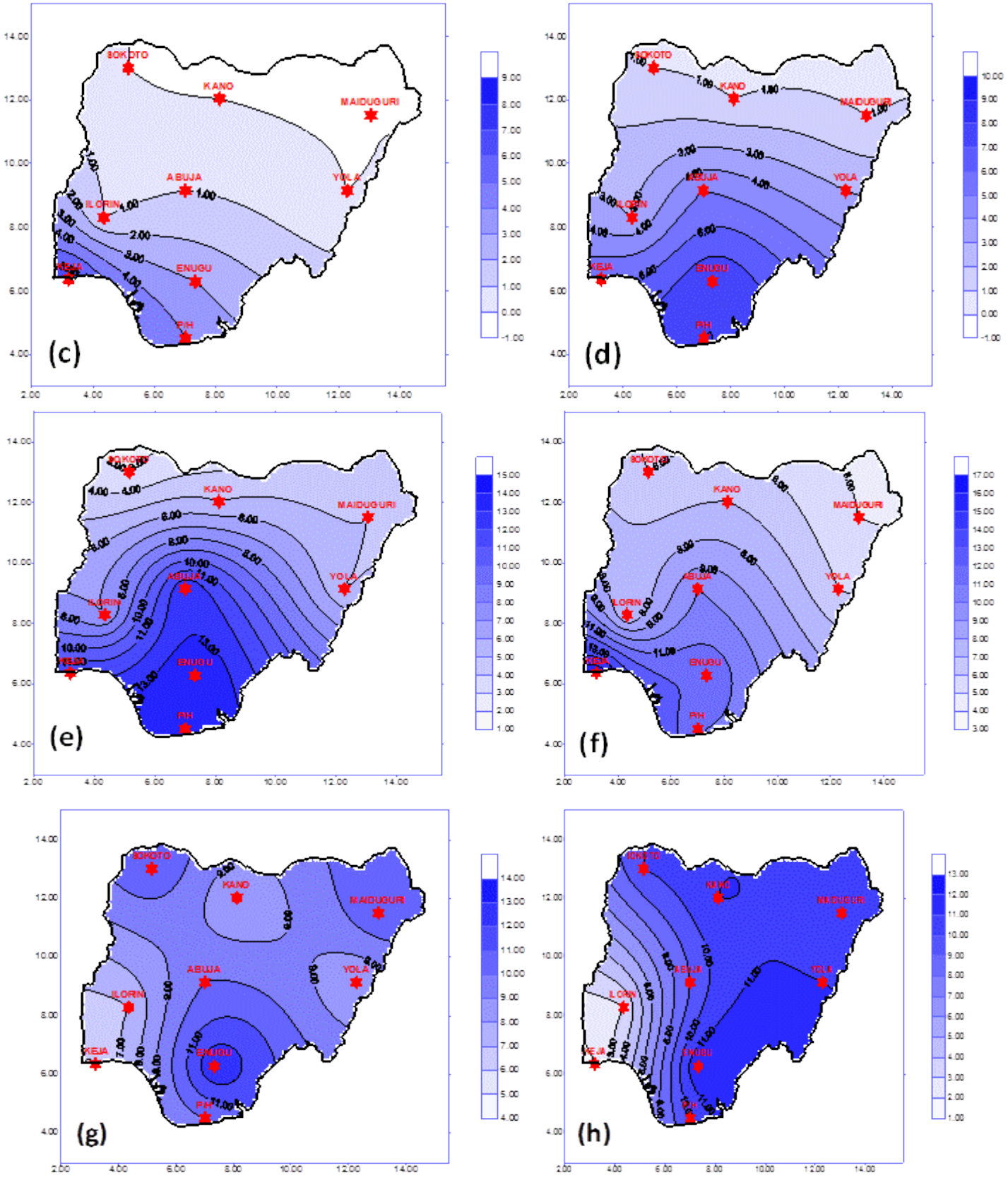


Figures 10. 5-year mean annual spatial variations of thunderstorms over Nigeria, from; (a) 1991-1995, and (b) 1996-2000.



Figures 11. The mean annual number of thunderstorm over stations; (a) North of 9°N and (b) South of 9°N.

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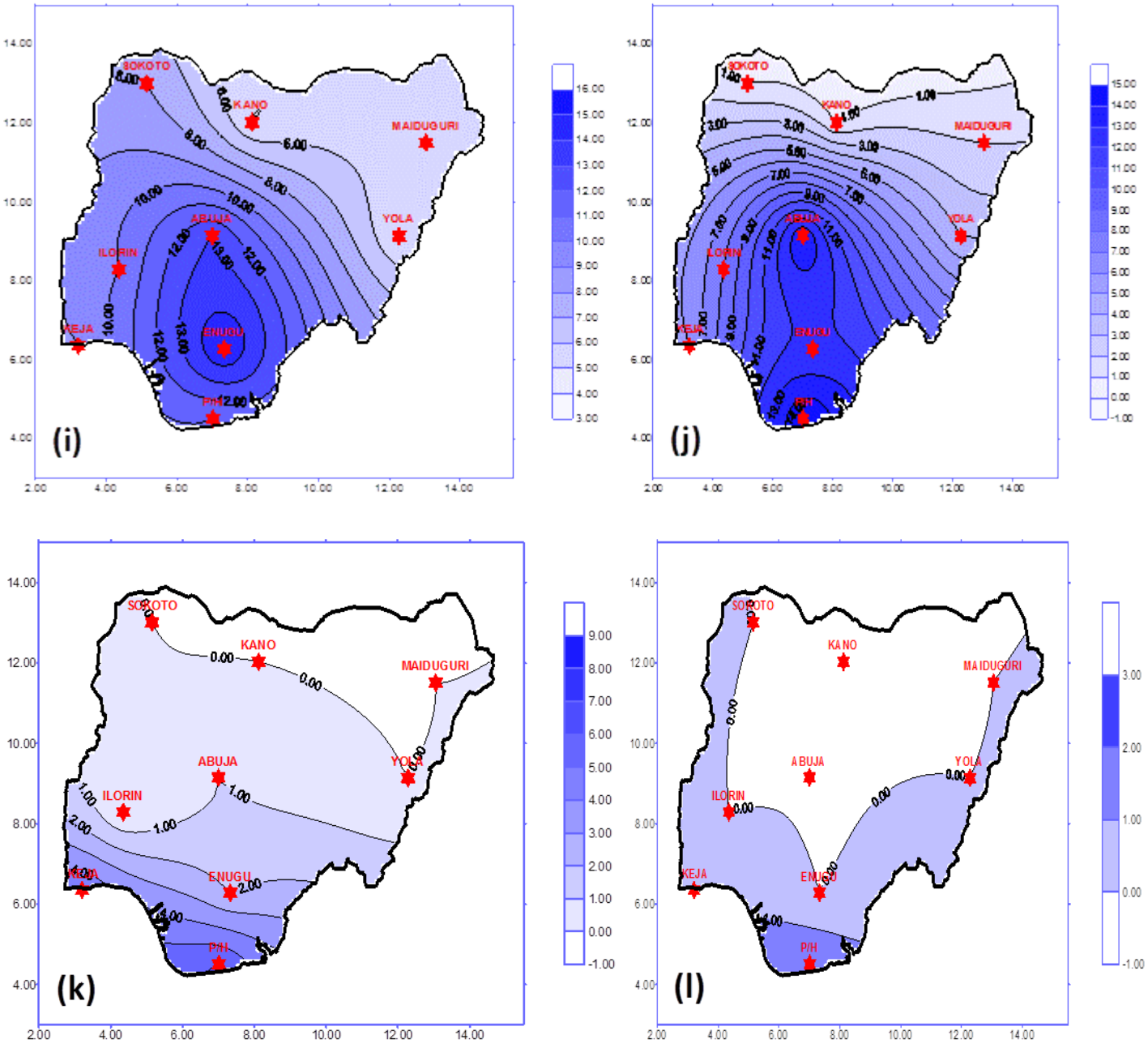
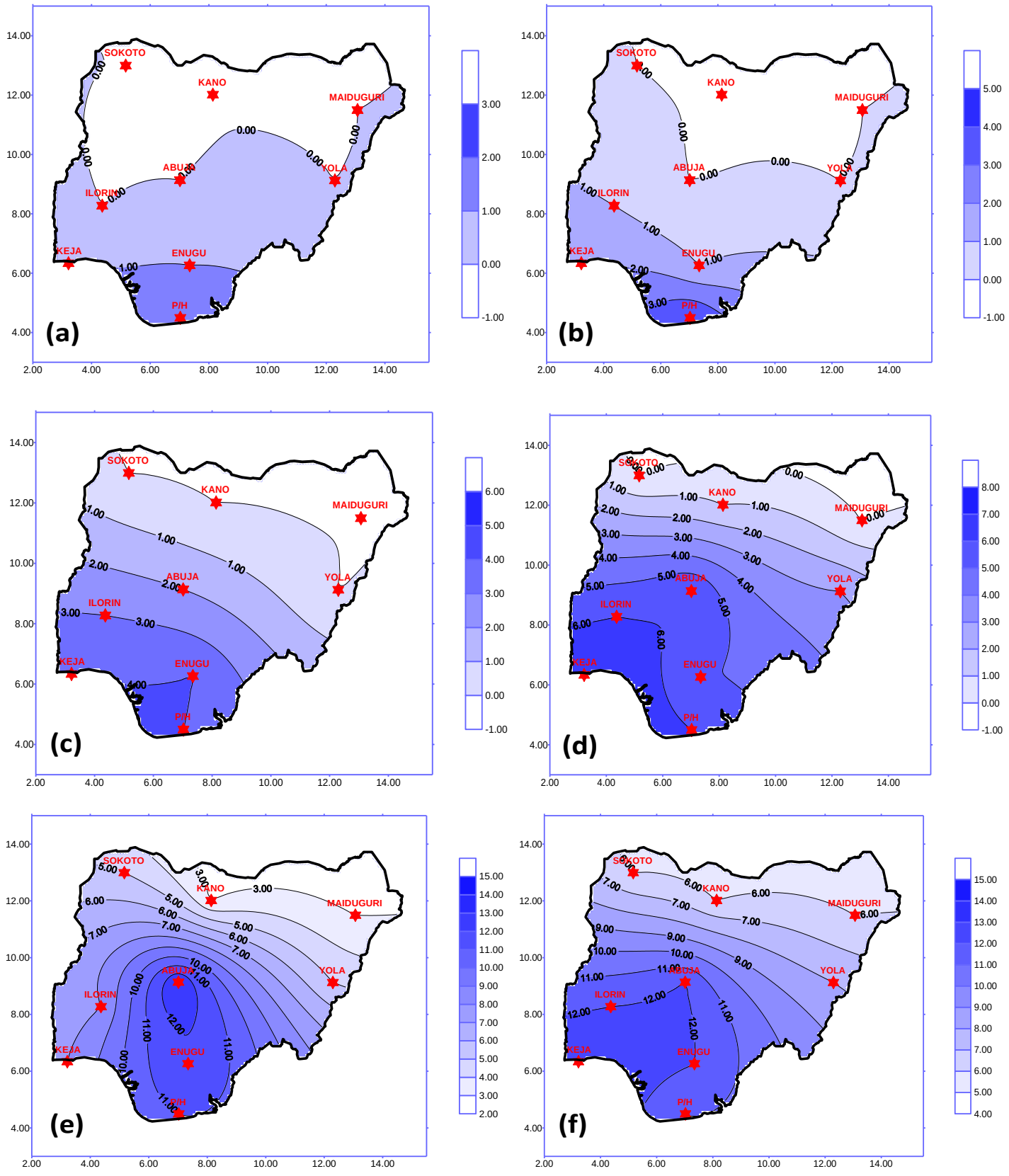


Figures 12. The 5-year mean monthly thunderstorm occurrence over Nigeria from 1991-1995 for; (a) January, (b) February, (c) March, (d) April, (e) May, (f) June, (g) July, (h) August, (i) September, (j) October, (k) November, (l) December.

Conclusion

In this study, the seasonal, inter-seasonal and spatial variations of thunderstorm frequency over a tropical region, Nigeria, was investigated. It was observed that the maximum thunderstorm and dry thunder frequencies are predominant over the central and western parts of Nigeria, respectively. However, while the isoceraunic lines of maximum dry thunder activities show no well defined pattern, the isoceraunic lines of maximum thunderstorm activities (MTA) decreases from the coast towards the inland regions as latitude increases. During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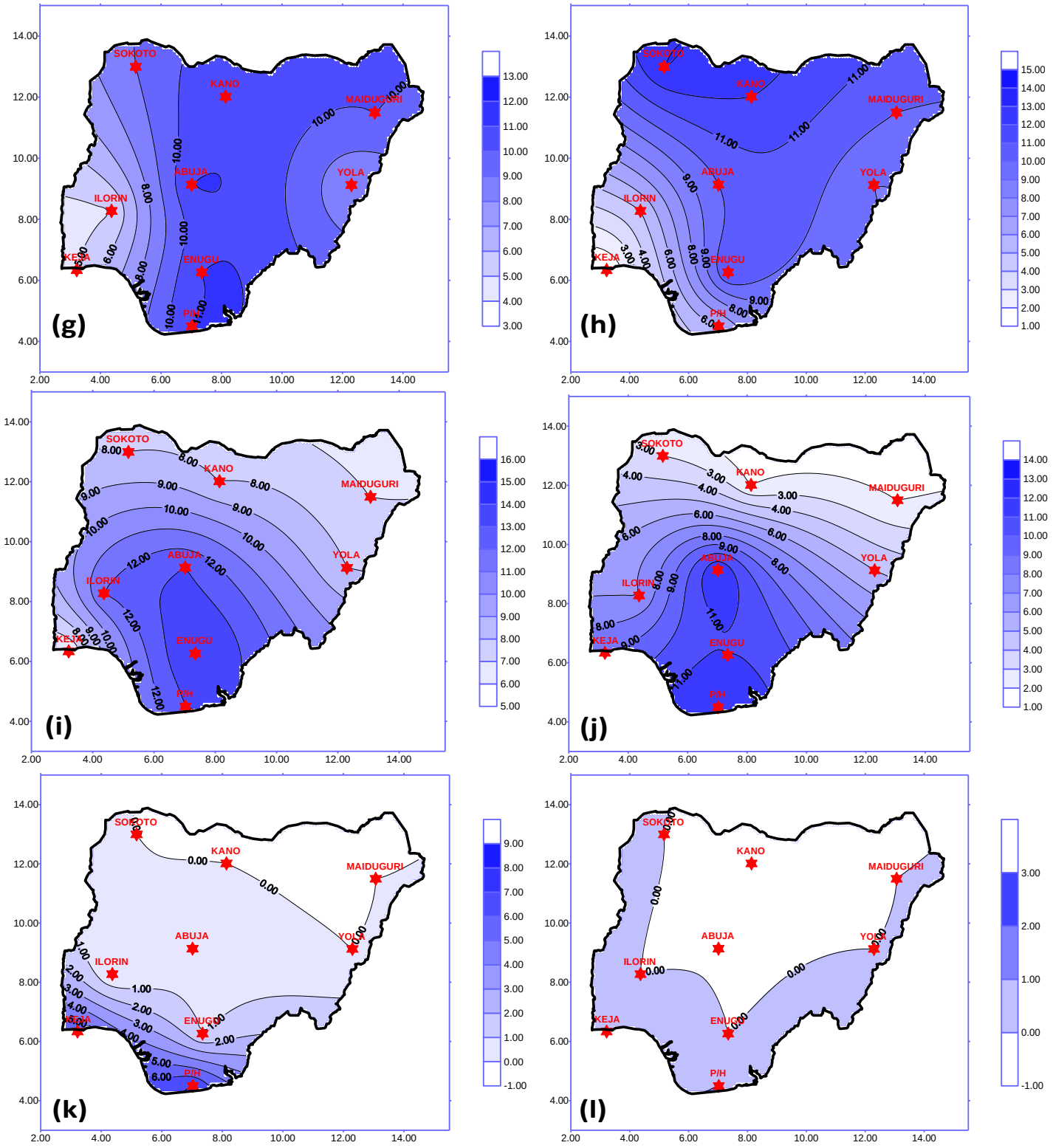

Figures 13. The 5-year mean monthly thunderstorm occurrence over Nigeria from 1996-2000 for; (a) January, (b) February, (c) March, (d) April, (e) May, (f) June, (g) July, (h) August, (i) September, (j) October, (k) November, (l) December.

July/August months, two areas of MTA were observed; Enugu and Kano, which are sandwiched by a belt of reduced thunderstorm activities (RTA; 8- 10°N).

Furthermore, over the Sahel region, it has been observed that the occurrence of thunderstorm tends to be greatly reduced over Maiduguri than over Sokoto, which could be the reason for the existence of a more severe desert encroachment from the north-eastern side of the country than it is over the north-western side. The existence of a latitudinal belt of reduced thunderstorm activities has been observed to be between 7.6-10.4°N in August, while the little dry season belt which was earlier stated to be between 10°W-9°E has been found to be limited to 7°E.

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