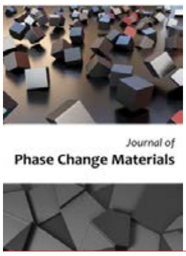
Journal of Phase Change Materials

J-PCM



Article

Check for updates

Published from the Department of Computer Engineering, Modeling, Electronics and Systems - DIMES, Italy by Royallite Global UK

Volume 2, Issue 2, 2022

Article Information
Submitted:
Accepted :
Published:

Additional information is available at the end of the article

https://creativecommons.

How to Cite:

Giwa, A., & Yusuf, A. (2022). Desert encroachment and the temporal trends of precipitation in Nigeria's climate zones. Journal of Phase Change Materials,

DOI:

Desert encroachment and the temporal trends of precipitation in Nigeria's climate zones

Adewale Giwa[1] Ahmed Yusuf[1]

[1] Department of Chemical Engineering, Khalifa University, United Arab Emirates

E-mail: adewale.giwa@ku.ac.ae

Abstract

Desertification in Nigeria is the southward spread of desert from Northern Nigeria caused by both climatic changes and human influence. The areas being exposed to desertification at the greatest level in recent years are in parts of North of Nigeria, extending from about latitude 8 °N to 12 °N or Savanna zone. The Sahara Desert advances from extreme North of Nigeria southwards at an estimated rate of 600 m per annum. This study was aimed at investigating the relationship between desert encroachment from the Sahara and the trend in Nigeria's precipitation time series for the time period 1900 – 2010. Computer codes were used to identify the zone with the most substantial reduction in mean monthly precipitation; the trend and periodicity in the precipitation time series were obtained for this zone. Results obtained show that the decrease in precipitation in Nigeria over the time period is most prominent in parts of the Savanna vegetation zone – the zone that is mainly influenced by movement of sand dunes southwards from the Sahara Desert and Sahel region. The change in mean monthly precipitation between the pre-1950 and post-1950 periods in the Savanna zone is the greatest among the three climate zones in Nigeria. Phase change materials are proposed to regulate the precipitation and temperature variability arising from this change.

Keywords: Desertification; Precipitation trend; Nigeria; Savanna vegetation; Sahara Desert.

Public Interest Statement

While many of the advances in materials science have been driven by breakthroughs in material design and fabrication, understanding the changes that occur in a material during its utilization or operation in devices is of immense importance for its successful integration. Considering these aspects and the continued growth in materials research, there is a clear need for new topical journals which can serve researchers to understand the phase transitions and exploit the phenomena to current, state-of-the-art research in the field of materials science, moreover with full accessibility.

1. Introduction

Nigeria has a tropical climate with sharp variances of precipitation across the climate zones. The climate of Nigeria is more varied than that of any other country in West Africa because of the extensive length from south to north which covers virtually all the climatic belts of West Africa (Abdulhamid, 2011). The climate in some parts of the country is also being affected by the Sahara Desert which borders Nigeria in the North (Obioha, 2009). According to United Nations Framework Convention on Climate Change (UNFCCC, 2003), the vegetation zones in Nigeria can be broadly classified into six: the saltwater (mangrove) swamp, freshwater swamp, tropical lowland rainforests, Guinea savanna, Sudan savanna, and Sahel savanna. These zones can be generally classified into three climate zones based on latitude – Guinea, Savanna and Sahel zones (Oguntunde and Abiodun, 2012). The rainy season in Nigeria is almost all-year round in the Guinea zone. This zone includes the parts of the coast, which receive more than 2,000 mm of precipitation each year. The Guinea zone lies between 4 °N to 8 °N. The Savanna zone lies between 8-11° N and includes most parts of the middle belt that receive 1,000-1,500 mm of precipitation annually. However, within this zone, the Jos Plateau receives more precipitation due to its higher elevation (Blench, 1999). In the dry savanna regions, precipitation is especially variable over distance and time. The Sahel zone is the zone along Nigeria's northeastern border and extreme north. It receives less than 500 mm of precipitation per year, and the rainy season here hardly lasts for three months (Oguntunde and Abiodun, 2012).

The precipitation patterns in Nigeria are influenced by the movement of the Inter-tropical Discontinuity (ITD) (Ilesanmi, 1971; Ogolo and Adeyemi, 2009; Omogbai, 2010). ITD is a zone where warm, moist air from the Atlantic meets with dusty, dry and hot air known as Harmattan from the Sahara (Bello, 1996; Olaniran, 1988). ITD trails the sun northward during the summer, therefore the influence of the moist Atlantic air on many parts of Nigeria is pronounced during this period (Adejuwon and Odekunle, 2004). As the summer declines, ITD moves southwards, thereby bringing an end to the rainy season (Olaniran, 2002). Desertification in Nigeria is the southward spread of desert from the north caused by both climatic changes and human influence (Abdulhamid, 2011; Audu, 2013; Nzeh and Eboh, 2001). The human factors which contribute to desertification in Nigeria include deforestation, overgrazing and land abuse, bush burning and declining groundwater resources (Oladipo, 1993). Nigeria loses about 350,000 ha of her total land area annually to desert as a result of sand dunes approaching from the Sahara Desert (Ekpoh and Nsa, 2011; Obioha, 2009; Onyenechere, 2010). The areas mostly affected by desertification are in the Sudano-Sahelian region in the Northern parts of the Savanna zone (Oladipo, 1993). The southward movement of the desert occurs at an estimated rate of 600 m per annum (UNDP, 2011).

As a result of the loss of vegetation due to the covering of soil by sand dunes approaching from the Sahara Desert, soil evaporation has increased over time (Emeka, 2013). The increase in soil evaporation has been reinforced by the irregularities in the north-south movement of the ITD experienced in the last couple of years (Adeonipekun and John, 2011). Another effect of desert encroachment from the Sahara is increased temperature variability. Temperatures in Nigeria are relatively high throughout the year because of its tropical location, averaging about 26-29 °C. In the higher elevations of the Jos Plateau, mean annual temperature is lower (Oguntunde et al., 2012). However, greater temperature extremes are experienced in Northern Nigeria than the

South (Dummar, 2002). Nigeria's average temperature rose by 1.7 °C between 1901 and 2005, with higher increase in the arid regions (Oguntunde et al., 2012). Other effects include changes in biodiversity and displacement of local population, annual decrease in farm yields, extreme weather and poverty for many Nigerians in the North (Farauta et al., 2013; Odjugo, 2010).

Aside from the aforementioned effects, the relationship between temporal variability of precipitation and desert encroachment needs to be examined. Previous studies on trends and oscillations in the precipitation time series of the three climate zones in Nigeria have shown a downward trend in annual mean precipitation over the last century (Odjugo, 2010; Oguntunde and Abiodun, 2012). The declining precipitation trends offer an opportunity to determine the adverse effects of ecological conditions such as increasing southward movement of sand dunes on the climate of Nigeria. This study is aimed at investigating the relationship between desert encroachment from the Sahara and the trend of precipitation in the climate zone that is mostly influenced by the encroachment. Two precipitation time series, i.e. 1900-1949 and 1950-2010, were considered in this study. For each series, the mean precipitation in each month of the year across Nigeria was estimated. The difference between the mean monthly precipitation for the two series was computed and analyzed. The zone with the most substantial reduction in mean monthly precipitation was identified. This study also ensured the analysis of the differences in the rainfall patterns in Nigeria's vegetation zones between 1900-2010.

2. Methodology

The monthly precipitation time series data for the grids in Nigeria with a resolution of 0.5° was obtained from the University of Delaware monthly precipitation series (Willmott and Matsuura, 2012). The study area was 4–14° N and 3–15° E. For each of two precipitation time series, 1900-1949 and 1950-2010, the maps of the mean precipitation for each month of the year across Nigeria were plotted using MATLAB computer code. The differences between the mean monthly precipitation estimated from the two series were analyzed for the three climate zones using descriptive statistics. The code is provided as follows.

```
nyears=110;
load('precipitation_Nigeria.mat');
lat1=find(latcut==8.75);
lat2=find(latcut==12.25);
long1=find(longcut==5.25);
long2=find(longcut==11.25);
%Guinea
%lat1=find(latcut==4.75);
%lat2=find(latcut==7.75);
%long1=find(longcut==3.75);
%long2=find(longcut==12.25);
%dlat=21;
%dlong=27;
%Edit long and lat for Savanna and Sahel
nigeriacut=nigeriacut(lat1:lat2,long1:long2,:);
latcut2=latcut(lat1:lat2);
longcut2=longcut(long1:long2);
nseries=size(nigeriacut,1)*size(nigeriacut,2);
%%% putting data in an array with a time series in each row
```

```
Ttransition=zeros(nseries,nyears*12);
coordnew=zeros(nseries,2);
k=1;
for i=1:dlat
   for j=1:dlong
      Ttransition(k,:)=squeeze(nigeriacutT(i,j,:));
      coordnew(k,:)=[latcut2(i),longcut2(j)];
      k=k+1;
   end
end
for i=1:12*nyears
 T(i)=nanmean(nanmean(nigeriacut(:,:,i)));
end
subplot(2,1,1);
plot(T);
T=T';
Tmat=reshape(T,12,[]);
Tmat=Tmat';
Tave=nanmean(Tmat);
for i=1:12
   Tmat(:,i)=Tmat(:,i)-Tave(i);
end
Tmat=Tmat';
Tanomaly=reshape(Tmat,[],1);
subplot(2,1,2);
plot(Tanomaly,'r');
```

The zone with the most significant decrease in precipitation was identified from descriptive statistics. A parametric method (linear regression analysis) was used to estimate the regression coefficients of the trend of the whole precipitation time series (1900-2010) for this zone and entire Nigeria. The trend was observed from a simple linear regression using Eq. (1).

$$Y = Ax + B \qquad (1)$$

Y is precipitation in mm, x is time in months, and A is regression coefficient. A periodogram or spectral plot was obtained for the entire time series to observe the periodic signals for the zone that is most significantly impacted by reduction in mean precipitation.

Descriptive statistics of the monthly precipitation across the three zones were used to summarize the climatic differences between the zones. Using the precipitation time series data for all spatial grids in each zone, the mean monthly precipitation during each time interval was computed for an entire zone. The maximum, maximum, coefficient of variation, skewness and kurtosis of the mean monthly precipitation for each zone were also computed.

3. Results and Discussion

3.1 Desert encroachment and temporal precipitation trends

The spatial variability of mean monthly precipitation across Nigeria during the time period 1900-1949 and 1950-2010 is shown in Fig. 1 and Fig. 2, respectively. The maps in the first rows in Fig. 1 and Fig. 2 show the mean monthly precipitation across Nigeria from January to April; those in the second rows are for May to August, while those in the third row are for September to December. Fig. 1 and Fig. 2 show visible differences in the mean monthly precipitation estimated from the two precipitation time series, particularly in parts of savanna vegetation zone.

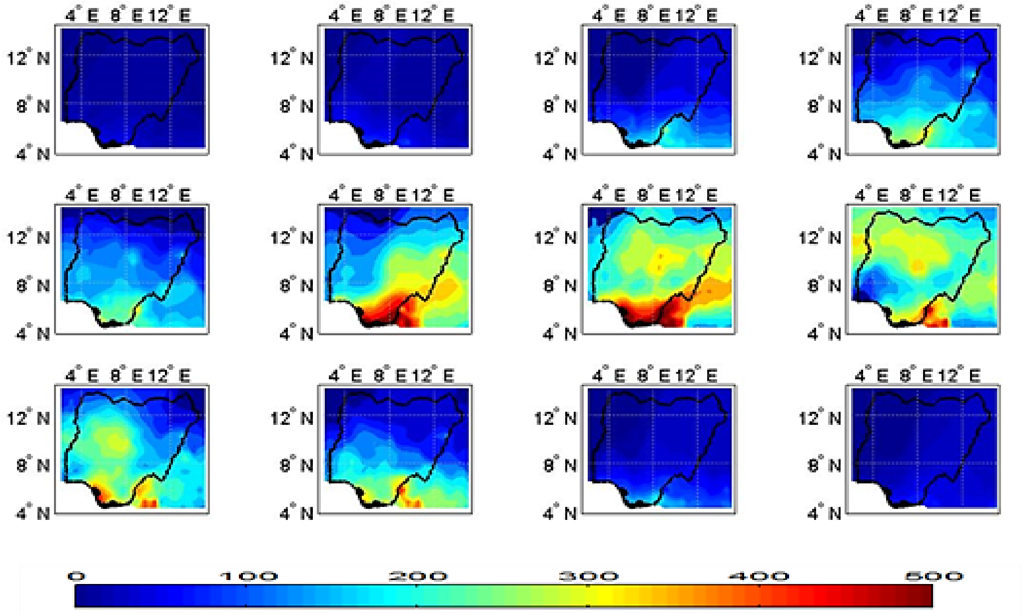


Fig. 1 Mean monthly precipitation (mm) across Nigeria (1900-1949).

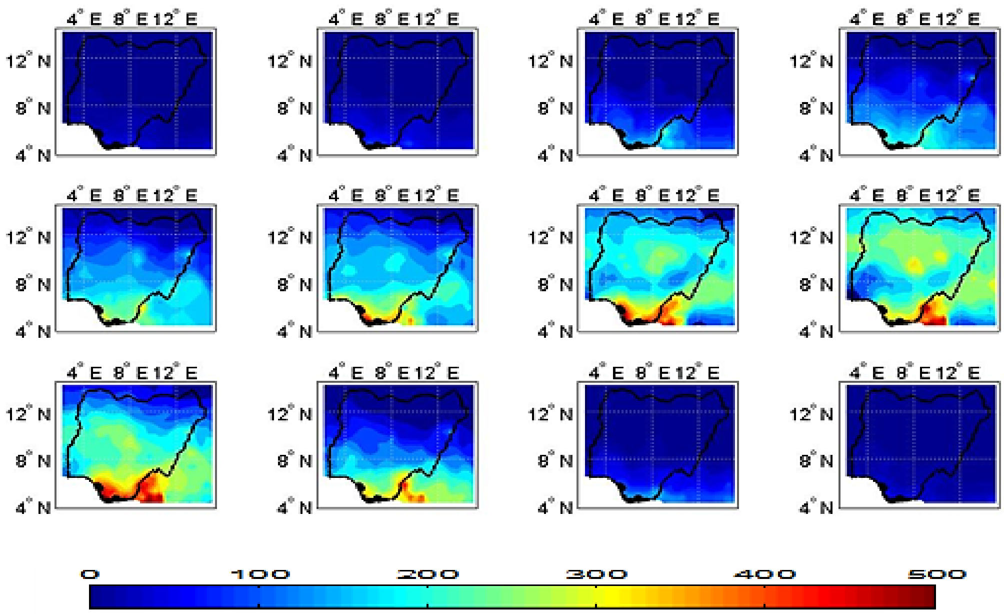


Fig. 2 Mean monthly precipitation (mm) across Nigeria (1950-2010).

The differences are more noticeable in months spanning from April to July, or during the rainy season in the North. In June and July especially, the maps show more observable changes in precipitation as the yellow and reddish-brown spots noticed in the maps begin to vanish in 1950–2010 series (indicating variability in precipitation between the two precipitation time series).

The descriptive data for the two precipitation time series are shown in Table 1. The most pronounced decrease in the mean monthly precipitation occurred in the Savanna zone, by about 6 mm during the time period 1950-2010, when compared to the time period 1900-1949. The Guinea zone, with areas close to the Atlantic coast, experienced the highest average and maximum precipitation among the three zones. The two series for the Savanna zone are both positively skewed with a tail extending to the right which means that the mean is greater than the median, and a negative kurtosis indicating flat distributions. The highest differences in coefficient of variation, skewness and kurtosis estimated from the two precipitation time series were obtained for the extreme parts of Nigeria in the Sahel region, indicating that the region had been strongly affected by desertification in the past because it is the closest to the Sahara. However, the precipitation decrease in the Savanna zone was more pronounced than that experienced in the other zones. This observation might be connected to the increasing encroachment of the vegetation in this zone by the Sahara sand dunes that migrate from the neighboring Sahel zone. The Savanna zone showed the most pronounced decline in maximum precipitation.

Table 1. Descriptive statistics of mean monthly precipitation in the zones.

	Savanna		Guinea		Sahel	
	1900-1949	**1950-2010**	**1900-1949**	**1950-2010**	**1900-1949**	**1950-2010**
Mean (mm)	91.60	85.15	161.10	157.33	55.09	51.11
Minimum (mm)	1.98	0.81	18.82	14.50	1.03	0.39
Maximum (mm)	274.06	255.07	312.48	308.62	224.28	207.44
Coefficient of variation (mm)	1.02	1.05	0.64	0.66	1.28	1.31
Skewness	0.74	0.74	-0.17	-0.13	1.44	1.39
Kurtosis	-0.94	-1.00	-1.69	-1.69	1.28	0.90

Meanwhile, the decline in minimum precipitation was mostly experienced in the Guinea zone as a result of the irregularities in the movement of ITD southwards. These irregularities were observed in recent decades (Adeonipekun and John, 2011). The descriptive statistics for the Savanna zone were then compared with those of the entire Nigeria for the entire time series 1900–2010, as shown in Table 2.

Table 2. Comparison between the mean monthly precipitation in the Savanna zone and entire Nigeria during the time period 1900-2010.

	Savanna	Entire Nigeria
Mean (mm)	88.05	98.03
Coefficient of variation (mm)	1.04	0.81

Skewness	0.74	0.34
Kurtosis	-1.00	-1.51

As shown in Table 2, the mean monthly precipitation in the Savanna zone is about 10 mm less than that of the entire Nigeria during 1900-2010. This means that the climatic conditions in the Savanna zone have a noticeable influence on the drop in precipitation in Nigeria. The trend of the precipitation time series 1900–2010 for the Savanna zone is shown in Fig. 3.

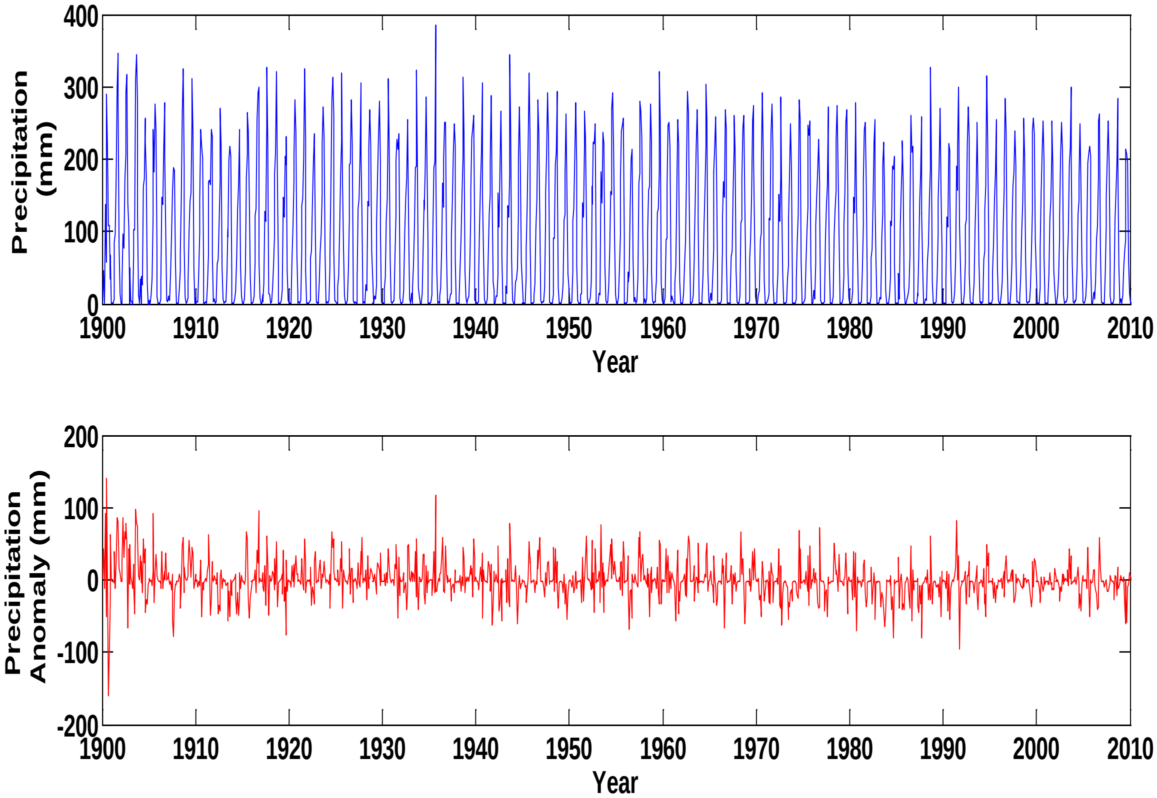


Fig. 3 Precipitation trend and anomaly in the Savanna zone between 1900 and 2010.

The regression coefficients obtained from Eq. (1) were -0.0098 and -0.011 for the Savanna zone and entire Nigeria, respectively. B was obtained as 110 and 96 for the Savanna zone and entire Nigeria, respectively. The negative regression coefficients indicate decreasing precipitation over the Savanna zone and Nigeria. The time series data for the Savanna zone shows a linear trend with a slope that is about 10 times more negative than that of the entire country. The precipitation variability in the Savanna zone over 1900-2010 can be analyzed using the anomalies shown in Fig. 3. The precipitation anomalies or detrended precipitation time series can be employed to analyze the cyclic structure of a time series in the frequency domain because they show the variability or cycles of monthly precipitation more clearly than the actual precipitation data. The periodic behavior of the time series for the Savanna zone can be observed from the spectral plot or periodogram, shown in Fig. 4. There are stronger periodic components at low frequencies in the spectral plot, in accordance with the monthly cycles. This reveals that there is more variability in the latter half of the time series shown by the lower frequencies for the zone i.e. during 1950-2010, than in the former half.

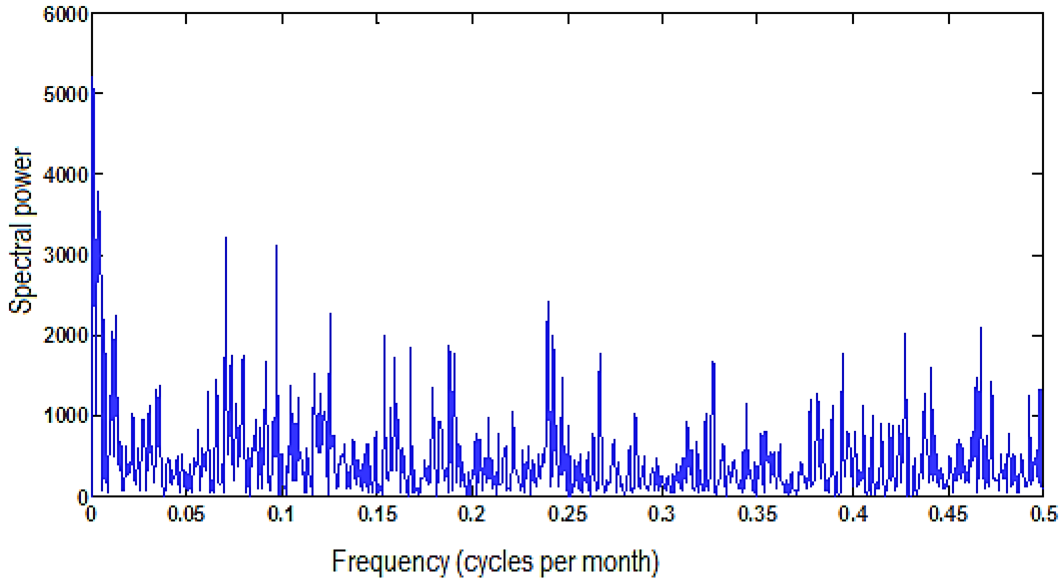


Fig. 4. Spectral plot of precipitation time series (1900-2010) for Savanna zone.

3.2 Influence of phase change materials

Phase change materials (PCMs) may be used as one of the materials/approaches to stem the tide of desert encroachment arising from the movement of Sahara sand dunes from the Sahel to the Savanna (and resulting in precipitation reduction and temperature increase/extremes in Northern Nigeria). PCMs are heat storage compounds that undergo a phase transition between liquid and solid states upon a temperature change. The phase transition occurs isothermally upon melting (heat storage) or solidifying (heat recovery). PCMs store heat as latent heat involved in breaking the PCM's inter-molecular bonds, during transition from solid to liquid. The stored heat can then be released when the material is cooled back to a solid.

PCMs can be applied in solving many heat related problems in the desert, including desertification. Some organic PCMs and low melting metal alloys have been developed well tuned to desert cycle. PCMs can absorb the heat due to temperature differential and therefore, regulate the precipitation patterns, as an initial solution. The heat can be absorbed during the day and dispensed at night. Of course, other approaches including trees or shelterbelt plantings across the path of the sand dunes would still need to be put in place for a permanent solution. The melting points of the selected PCMs will be a critical factor for their effectiveness; their melting points should correspond to the ambient temperature range. Sugars, alcohols, fatty acids, low-fusion metal alloys (eutectic compositions of Bi-Pb-In-Cd-Sn-Zn multicomponent system), polymers and their composites have been tested as PCMs. Many international companies like BASF, Climator, Cristopia, EPS Ltd., Mitsubishi Chemical Corporation, Rubitherm GmbH, TEAP, Witco., etc were marketing PCMs and PCM products. Over 50 PCMs are commercially available.

Most commercial PCMs were based on modified compositions of salt hydrates, paraffins and eutectic salt water solutions, with agents for nucleating, gelling, and thickening added in the base. Apart from micro- or macro-encapsulated PCMs, these companies were also marketing different PCM products like PCM wallboards, PCM-polymer or PCM-silica dry composite powders by Rubitherm. Dupont Energain panels containing a copolymer and paraffin compound had been launched. Garmisch Partenkirchen introduced pocket heaters for mountain-rescue teams. Outlast Thermocules was marketing fiber and fabric-containing microencapsulated PCMs. Other products for human comfort are underwears to reduce sweating, gloves, shoes, jackets, kidney belts, sleeping bags, etc. Various types of transportation containers to carry medicines and food items to field conditions had been marketed by various companies. PCM products for heat therapy were also marketed by Lavatherm GmbH (Kumar et al., 2011).

4. Conclusion

The decrease in precipitation in Nigeria over the time period 1900–2010 is most pronounced in the Savanna vegetation zone. The change in mean monthly precipitation between the 1900-1949 and 1950-2010 time periods in the Savanna zone is the highest among the three climate zones in Nigeria. This observation might be attributed to the encroachment of desert or movement of sand dunes southwards from the Sahara Desert into the Savanna zone. Although other climatic effects might have also been partly responsible for this observation, the intrusion of Sahara into this zone has been observed within the same time interval. The use of PCMs is proposed as an initial solution. Shelterbelt plantings for protection of lands against sand dunes from the Sahara and better land use are recommended to prevent further movement of sand dunes southwards.

Acknowledgements

Khalifa University of Science and Technology (Masdar Institute), Abu Dhabi, United Arab Emirates is appreciated for this work.

References

Abdulhamid, Y., 2011. The impact of climate change in Nigeria. Comput. Eng. Intell. Syst. 2, 14–17.

Adejuwon, J.O., Odekunle, O.O., 2004. Skill assessment of the existing capacity for extended range weather forecasting in Nigeria.

Adeonipekun, P.A., John, M., 2011. Palynological investigation of haze dust in Ayetoro-Itele Ota, Southwest Nigeria. J. Ecol. Nat. Environ. 3. https://doi.org/10.5897/JENE11.082

Audu, E.B., 2013. Fuel wood consumption and desertification in Nigeria. Int. J. Sci. Technol. 3, 1–5.

Bello, N.J., 1996. An investigation of the characteristics of the onset and cessation of the rains in Nigeria. Theor. Appl. Climatol. 54, 161–173. https://doi.org/10.1007/BF00865159

Blench, R., 1999. Traditional Livestock Breeds: Geographical Distribution and Dynamics in

Relations to the Ecology of West Africa. Overseas Dev. Inst. Portl. House Stag Place London, SW1E 5DP Working Pa, 1–69.

Dummar, F.C., 2002. The history of the Nigerian army and implications for the future of Nigeria. U.S. Army Command and General Staff College.

Ekpoh, I.J., Nsa, E., 2011. Extreme climatic variability in north-western Nigeria: An analysis of rainfall trends and patterns. J. Geogr. Geol. 3. https://doi.org/10.5539/jgg.v3n1p51

Emeka, E.E., 2013. Drought and desertification as they affect Nigerian environment. J. Environ. Manag. Saf. 4, 45–54.

Farauta, B., Egbule, C., Agwu, A., Idrisa, Y., Onyekuru, N., 2013. Farmers' adaptation initiatives to the impact of climate change on agriculture in Northern Nigeria. J. Agric. Ext. 16. https://doi.org/10.4314/jae.v16i1.13

Ilesanmi, O.O., 1971. An empirical formulation of an ITD rainfall model for the tropics: A case study of Nigeria. J. Appl. Meteorol. 10, 882–891. https://doi.org/10.1175/1520-0450(1971)010<0882:AEFOAI>2.0.CO;2

Ravindra, K., Manoj, K.M., Rohitash, K., Deepak, G., Sharma, P.K., Tak, B.B., Meena, S.R., 2011. Phase change materials: Technology status and potential defence applications. Def. Sci. J. 61, 576-582. https://doi.org/10.14429/dsj.61.363

Nzeh, E.C., Eboh, O.R., 2001. Study of technological and farming systems adaptation to climate change in farming communities of Enugu state, Nigeria. African Technol. Policy Stud. Netw. Res. Pap. 5 3.

Obioha, E.E., 2009. Climate variability, environment change and food security nexus in Nigeria. J. Hum. Ecol. 26, 107–122.

Odjugo, P.A.O., 2010. Regional evidence of climate change in Nigeria. J. Geogr. Reg. Plan. 3, 142–150.

Ogolo, E.O., Adeyemi, B., 2009. Variations and trends of some meteorological parameters at Ibadan, Nigeria. Pacific J. Sci. Technol. 10, 980–987.

Oguntunde, P.G., Abiodun, B.J., 2012. Analysis of trend and periodicity in long-term annual rainfall time series of Nigeria, in: Hydrological Time Series Analysis: Theory and Practice. Capital Publishing Company, New Delhi, pp. 249–272.

Oguntunde, P.G., Abiodun, B.J., Lischeid, G., 2012. Spatial and temporal temperature trends in Nigeria, 1901-2000. Meteorol. Atmos. Phys. 118, 95–105. https://doi.org/10.1007/s00703-012-0199-3

Oladipo, E.O., 1993. A comprehensive approach to drought and desertification in Northern Nigeria. Nat. Hazards 8, 235–261. https://doi.org/10.1007/BF00690910

Olaniran, O.J., 2002. Rainfall anomalies in Nigeria: The contemporary understanding.

Olaniran, O.J., 1988. The July-August rainfall anomaly in Nigeria. Climatol. Bull. 22, 26–38.

Omogbai, B.E., 2010. An empirical prediction of seasonal rainfall in Nigeria. J. Hum. Ecol. 32, 23–27.

Onyenechere, E.C., 2010. Climate change and spatial planning concerns in Nigeria: Remedial measures for more effective response. J. Hum. Ecol. 32, 137–148.

UNDP, 2011. Territorial approach to climate change in Delta State (Long-term planning for low emission, climate-resilient development in Delta State, Nigeria).

UNFCCC, 2003. Nigeria's first national communication. Abuja.

Willmott, C., Matsuura, K., 2012. University of Delaware Precipitation Data set (Monthly-V3.01). Univ. Delaware 100, 729–739.