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# RAINFALL HARVESTING, A SUSTAINABLE WATER MANAGEMENT ALTERNATIVE FOR FOOD SECURITY IN NIGERIA

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## ABSTRACT

Nigeria with her expanse of land is greatly endowed with potentials of first class food producing nation. Weather information of thirty six states including the Federal Capital Territory: Altitude (AT), population density (PD), average annual rainfall (AR), land mass (LM), latitudes (LT), longitudes (LG), relative humidity (RH), maximum and minimum temperatures (MX, MN) and average daily wind run (WR) were collated, processed and analyzed.

Isotherm, isobaths, isohyetal, isotach and isohume maps were constructed. Weighed rainfall of the states was evaluated. Frequency of exceedence based on frequency analysis model was determined. Empirical model generated by NIHORT using $28m^2$ roof surface area obtained through daily rainfall was used to evaluate the rainfall harvesting potentials of thirty six states of Nigeria including federal capital territory (FCT).

Exceedance frequency was highest for Katsina with average annual rainfall of 552mm , altitude 464m, latitude 12°12'N, longitude 7°30'E and population density, 160.3/$km^2$, while Minna recorded the highest weighted rainfall of 116.2mm with average annual rainfall of 1400mm, altitude 299m, latitude 10°00'N, longitude 6°0'E, showing the highest potentials for rainfall harvesting at 129.3$km^3$, though 18th in ranking respect to the actual amount expected based on the average annual rainfall and $28m^2$ roof surface area.

**KEYWORDS:** Rainfall Harvesting, A Sustainable Water Management Alternative for Food Security

## INTRODUCTION

Nigeria exhibits such an intimidating and frightening demographic feature that call for holistic approach to forestall future outburst of crisis while taking cognizance of the basic needs of the downtrodden. The agricultural labour force of the country stands at 70% with population growth of 3.5%. However, one noteworthy feature of the nation is the extent of her natural resources endowment. The state with the least average annual rainfall (Katsina , 552mm) is higher than the average highest annual rainfall in Israel, notwithstanding Israel is ranked the second world largest producer of agricultural products worldwide. Nineteen states in Nigeria have geographical terrain in terms of land mass far greater than the state of Israel of only 20,000$km^2$. Food production index of this country greatly supersedes that of Nigeria regardless of the global conviction that food accounts for a large and increasing volatile share of most family budgets (Robert, 2011). Therefore, neglect of Nigeria government in meeting the food requirements of the populace amounts to breeding communal crisis, mass protest and youth restiveness thereby resulting into militancy.

Similarly, reports indicated that Asian countries are injecting about 25% of their annual budget on development of agriculture unlike their counterparts in Africa especially Nigeria that is struggling with less than 5% against the 10% stipulated by Maputo declaration. (EKI NEWS, 2010).

Consequent upon the lapses obtained in Africa, foreign nations are seriously taking over the lands in developing countries though not by military force but by the power of cheque books (www.rural21.com). Other reports (EKI NEWS, 2010) signified that about 50,000,000 ha of land, more than 54% of the land size of Nigeria is being acquired for agricultural development by the developed rich nations for food production. This trend constitutes threat to Nigeria's economy because these investors are not only driven by profits but also put the food needs of the export market above the local demands thereby further impoverishing the already depleted resources of the region.

Nigeria, popularly known as the giant of Africa must invest massively into water

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management to increase her agricultural productive land area and guarantee food security. Rural 21, 2010 re-iterated that about 13,300km$^3$ of water is required annually globally for supplemental irrigation instead of the current 8,800km$^3$. The report further stated that 10 out of the 93 developing countries have exceeded more than 40% of their available renewable water resources for food production. The deficit of 4,500km$^3$ is therefore urgently needed for mobilization in order to meet the expected target (FAO, 2003). Similarly, the situation in Nigeria cannot be too far from what obtains internally. For example, Nigeria is ranked the highest importer of rice in the world at 2.1 metric tons annually translating to N 356 billion yearly (Akinwumi, Adesina, 2012) However, notwithstanding the current water scarcity, depletion and imminent water crisis, rainwater harvests are at presently below the expected level. Moreover, great pressure is continually observed on the existing water supplies due to population growth, increasing competition between food, fibre production and fuel crops. Rainwater harvesting therefore becomes an indispensable water management alternative to bridge the gap between the available water resources and daily water demands in view of the fact that water is assuming a dominant resource on demand in the next ten decades. Moreover, harvesting of rainwater before reaching the land surface has been reported to affect groundwater recharge thereby preventing possible flooding as result of overloaded recharge (Doll and Florike, 2005) in conformity with the reports of Avenge et al., (2008) and Sutcliffe and Peterson (2007) that the fall observed in level of Lake Victoria was attributed to low rainfall during the short rains of 2003 as evident in major cities of Nigeria during the raining season. Taylor and Howard (1996), Magnus and Adinda (2011) also confirmed that un harvested rainfall reaching the soil encourages high soil moisture deficit thereby activating greater groundwater recharge with resultant effect on flooding. Therefore rainwater harvesting before reaching the land surface becomes an indispensable option especially where rainfall intensity has the capability of inducing flooding. Interestingly, water management handling in Nigeria has negatively relegated citizens to adopt a subsistence level of water utility compared to other countries. For example, Nigeria is rated 20$^{th}$ among the 28 surveyed nations of the world based on basic water needs per person per day. Generally, US, Australia, Italy, Japan, Mexico, Spain, Norway, France, Austria, Denmark, Germany, Brazil, Peru, Uk, India, China, Bangladesh, Kenya, and Ghana's exhibit basic water needs of 21.3, 18.3, 14.3, 13.9, 11.9, 11.1, 10.6, 9.3, 7.8, 7.2, 6.9, 6.4, 5.5, 5.0, 3.2, 1.7,1.7, 1.3 % higher than their counterparts in Nigeria respectively ( Peter and Iwra, 1996).

This scenario pictures Nigeria as a free nation without regard for resource data bank unlike Europe with documented information of 53%, 32% and 15% of their available water resources being used for agriculture, industry and domestics respectively (EKI NEWS, 2010).

This study however aims at determining the potentials of the states in Nigeria for rainwater harvesting based on the average annual rainfall and co-ordinates.

## MATERIALS AND METHODS

Average annual rainfall and seven other weather elements of the states in Nigeria were generated for the study using internet facilities. These include average annual rainfall, maximum and minimum temperatures, latitudes and longitudes, altitude, relative humidity and wind speed with their corresponding land mass and population density.

Exceedance frequency and weighted rainfall for the thirty seven states were determined using the model developed by Oosterbaan (1994). Isotherm, isobaths, isohyetal, isohume, and isotach topographic contours were constructed using the model developed by Jansen (2003). Mean values of minimum and maximum temperatures were obtained from the internet weather site (Wikipedia, 2005). Reference evapotranspiration (mm/day) of the states were calculated using Blanney-Criddle empirical model, $ET_o = p\ (0.46T_{mean} + 8)$, where p= mean daily percentage of annual day time hours.

$$T_{mean} = \frac{T_{max} + T_{min}}{2}$$

$T_{mean}$ = mean daily temperature ($^oC$), $T_{max}$ = the ratio of the sum of all $T_{max}$ values during the month to the number of days of the month, $T_{min}$= ratio of the sum of all $T_{min}$ values during the month to the number of days of the month. Empirical equation generated from rainfall harvesting structure of 28m$^2$ roof surface area, 7.5m gutter length and 0.7m head loss developed by Afolayan et al., 2010 was used as the basis for the estimation of potential rainwater harvests of the states in Nigeria. Average annual rainfall considered as the most important weather element of agricultural production and dependent variables was regressed with other weather elements as independent variables using multiple linear regression analysis (Gomez and Gomez, 1976). This is based on the accepted perception of

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the interdependence between rainfall and increasing steady rise in other weather elements such as temperatures, relative humidity, and wind run. The combined linear effects of these weather elements on rainfall were evaluated using multiple correlation coefficients (Gomez and Gomez, 1976). Similarly, principal component analysis of the weather elements was carried out using multivariate analytical system (Mareia, et al, 2005) to identify the discriminative or weighted capacity of the weather elements to rainfall profile at the states and possibly use same to develop empirical ecological models for rainfall harvesting.

## RESULTS AND DISCUSSION

Table 1 shows the climate data comprising average annual rainfall (mm), maximum temperature (°C), minimum temperature (°C), latitude (°N), Longitude (°E), altitude (m), relative humidity (%) and wind run (km/hr) for thirty six states of Nigeria and the Federal Capital Territory. Three states (Niger, Borno, and Taraba) recorded the highest land mass of 76,363, 70,898 and 54,473 $km^2$ respectively, thereby accounting for about 21.8% of the total land mass of the country with minimum population density at 32.5, 36.6 and 27.2/$km^2$ compared with Imo (784.7/$km^2$),Kano (664.8/$km^2$) , Anambra (837.1/$km^2$), Ebonyi (784.8/$km^2$), Rivers (603.9/$km^2$), Kaduna (731.7/$km^2$) and Abuja (1,088.70/$km^2$) showing possibility for higher water demands and more initiatives for water harvesting to supplement the existing water resources.

Frequency analysis showing exceedance frequency, weighed rainfall and potential rainwater harvest is presented in Table 2. The highest weighed rainfall indicated some measure of proportionality with the landmass seeing that Niger state exhibited the highest landmass, also recorded the highest weighed rainfall at 116.2mm and the potential rainwater harvesting at 129.3$km^3$, incidentally, the second highest average monthly evapotranspiration demand at 6.6 mm. Similarly, Bayelsa state recorded the least frequency of exceedance (0.03) followed by Akwa-Ibom (0.05) and Katsina, the highest (0.97). This trend is of course expected because average annual rainfall amounts were highest in the states with lower exceedance frequency thereby indicating that that states with higher exceedance frequencies require greater financial capability to enhance sustainable rainwater harvesting in the region.

Fig 1 present the isohume map representing the average relative humidity of the states ranging from 33% typical of Sahel savannah of Borno state with average annual rainfall of 553 mm to 97% of rainforests zone of Bayelsa with average rainfall of 3200 mm. This wide range puts Nigeria in a vantage position of potentials for diversities of crops and possibilities of water sufficiency if wisely assessed.

The isohyetal contour map of the states is shown in Fig. 2. The minimum average annual rainfall was recorded for Katsina at 552mm and the maximum for Bayelsa at 3200 mm. notwithstanding the wide gap between the states, there is possibility of harvesting sufficient amount of water capable of turning the horticultural ventures of the states around if sustainably harvested by farmers.

Figs 3, 4 and 5 showed the isotherm (maximum temperatures, minimum temperatures,) isotach and the isobaths maps indicating states above latitudes, 10°N exhibiting low average annual rainfall, states between latitude 8°N and 9°N with medium average annual rainfall and states between 3°N and 7°N producing highest average annual rainfall . This trend is pronounced in Bayelsa with latitude 4°45'N recording the highest mean annual rainfall. This confirms the assumption that rainfall amount in a particular region is proportional to its closeness to the equator and by extension the possibility of higher potentials for rainfall harvest with landmass remaining constant.

Table 3 summarizes the interaction between average annual rainfall and some other weather elements. The highest $R^2$ value was obtained from mean latitudes at 79.4% showing that rainfall pattern can be explained by 79.4% of its association with latitudes, while the standard regression coefficients reveals that rainfall increases with decrease in latitude to the tune of 89.1% with the eigenvector of 57.9%. This observation confirms the explanation made in Table I. However, the general results obtained showed that based on average annual rainfall, Bayelsa state with 3200 mm had the highest potential for rainfall harvest at 18,598$m^3$, while on weighted rainfall, Niger state of 1400 mm had the highest potential for rainfall harvest at 129.3$km^3$. Overall results indicated that the minimum amount of rainfall harvest obtainable in Nigeria was 1.96$km^3$ and the highest at 129.3$km^3$ showing average rainfall harvesting potentials of 37.38$km^3$ greater than the annual world water demands of 13,300$km^3$ (Rural 21,2010).

## CONCLUSIONS

Nigeria as a nation is greatly endowed with abundance of resources which remained untapped thereby impoverishing the citizens. For example, Nigeria flares 23 billion gases, representing 11% of the global annual emission (Wikipedia, 2005), destroys 3.5 % of its forest recourses annually that could immensely contribute to carbon sequestration, neglected the enormous groundwater reservoir management coupled with complete abandonment of rainfall harvesting capable of turning the agricultural landscape into profitable venture and 3,557 km railroad wasted. However, with minimum investment in rain water harvesting, horticultural production in Nigeria will attain its peak with corresponding control on seasonal flooding ravaging the country.

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**TABLE 1** :CLIMATE DATA FOR 37 CITIES IN 36 STATES INCLUDING THE FCT

| annrf(mm) | max(oc) | min(oc) | ldnms( km2) | lat(0N) | LONG(0N) | alt(m) | relh(%) | windr(km/hr) |
|---|---|---|---|---|---|---|---|---|
| 2730 | 29 | 24 | 17,698.0 | 5°30' | 6°00' | 21 | 80 | 7 |
| 1560 | 31.6 | 22.9 | 15,500.0 | 7°10' | 5°05' | 277 | 66 | 7 |
| 1400 | 34 | 30 | 76,363.0 | 10°00' | 6°01' | 299 | 53.5 | 8 |
| 1850 | 30.9 | 23.8 | 5,530.0 | 5°29' | 7°2' | 350 | 75 | 10.1 |
| 1875 | 35 | 23 | 9,251.0 | 7°30' | 4°30' | 305 | 79 | 14.5 |
| 1180 | 37 | 24 | 36,825.0 | 8°30' | 5°00' | 290 | 81 | 12 |
| 1130 | 35.8 | 31.2 | 36,919.0 | 9°20' | 12°30' | 456 | 79 | 5 |
| 1280 | 29 | 20 | 30,913.0 | 9°10' | 9°45' | 1208 | 53 | 14 |
| 1190 | 33 | 25 | 34,059.0 | 7°20' | 8°45' | 104 | 53 | 6 |
| 620 | 37 | 30 | 25,973.0 | 13°05' | 05°5' | 265 | 45 | 19 |
| 552 | 38 | 30 | 24,192.0 | 12°15' | 7°30' | 464 | 36 | 7 |
| 920 | 38 | 24 | 49,119.0 | 10°30' | 10°00' | 616 | 53 | 14.5 |
| 3000 | 28 | 26 | 7,081.0 | 5°00' | 7°50' | 189 | 76.5 | 7 |
| 696.4 | 38 | 28 | 20,131.0 | 11°30' | 8°30' | 481 | 54 | 16 |
| 1316 | 30 | 22 | 28,454.0 | 8°00' | 4°00' | 239 | 66 | 2 |
| 1838 | 30 | 26 | 3,475.1 | 6°35' | 3°45' | 34 | 59 | 6 |
| 1950 | 31.2 | 23.8 | 4,844.0 | 6°35' | 7°30' | 117 | 87.9 | 9 |
| 1811 | 30 | 24 | 7,161.0 | 6°35' | 7°30' | 248 | 80 | 6 |
| 2718 | 32 | 25 | 604.0 | 5°45' | 8°30' | 63 | 94 | 8.05 |
| 2600 | 29.2 | 21.2 | 5,530.0 | 6°15' | 8°05' | 116 | 87.6 | 9.5 |
| 553 | 40 | 30 | 70,898.0 | 11°30' | 13°00' | 300 | 33 | 13 |
| 2400 | 33 | 25 | 17,400.0 | 4°51' | 7°01' | 468 | 95 | 2 |
| 2400 | 31 | 24.5 | 6,320.0 | 5°25' | 7°30' | 112 | 90.2 | 8 |
| 2074 | 30 | 24 | 17,802.0 | 6°30' | 6°0' | 80 | 80 | 3 |
| 846.8 | 35.3 | 21.8 | 39,762.0 | 12°10' | 6°15' | 420 | 56.2 | 14 |
| 1324 | 34 | 22 | 46,053.0 | 10°20' | 7°45' | 614 | 58 | 6 |
| 859.7 | 34 | 23 | 7,135.0 | 9°40' | 7°29' | 400 | 53 | 6 |
| 3200 | 37 | 10 | 10,773.0 | 4°45' | 6°08' | 206 | 97 | 6 |
| 650 | 35 | 19 | 23,154.0 | 12°00' | 11°6'40'' | 428 | 50 | 7.1 |
| 1179 | 34.7 | 19 | 54,473.0 | 8°00' | 10°30' | 1800 | 52.1 | 9 |
| 2200 | 27 | 23 | 6,353.0 | 7°40' | 5°15' | 458 | 98.6 | 7 |
| 900 | 30 | 28 | 36,800.0 | 11°30' | 4°00' | 230 | 40 | 10.4 |
| 1270 | 35 | 20 | 29,833.0 | 7°30' | 6°42' | 1022 | 67 | 12.9 |
| 1450 | 31 | 24 | 16,762.0 | 7°00' | 3°35' | 530 | 85 | 5 |
| 630 | 37 | 34 | 45,502.0 | 12°00' | 11°30' | 473 | 60 | 12 |
| 1500 | 34.8 | 18.4 | 27,117.0 | 8°32' | 3°4' | 153 | 84.7 | 15 |
| 877 | 33.3 | 21.8 | 18,768.0 | 10°15' | 11°10' | 775 | 56 | 10 |

**Table 2**: Frequency analysis and potential rainfall harvest in Nigeria

| Rainfall (mm) | ETo (mm) | Exceedance frequency | Area (%) | Weighted rainfall ($^o$C) | Mean temperature $^o$C) | Potential rainwater harvest | |
|---|---|---|---|---|---|---|---|
| | | | | | | **m3** | **km3** |
| 3200 | 4.9 | 0.03 | 1.2 | 38.4 | 23.5 | 18.6 | 41.5 |
| 3000 | 5.7 | 0.05 | 0.8 | 24.0 | 27.0 | 17.5 | 25.4 |
| 2730 | 5.6 | 0.01 | 1.9 | 51.9 | 26.5 | 15.9 | 57.4 |
| 2718 | 5.7 | 0.11 | 0.1 | 2.7 | 28.5 | 15.9 | 57.8 |
| 2600 | 5.1 | 0.13 | 0.6 | 15.6 | 25.2 | 15.2 | 2.0 |
| 2401 | 5.8 | 0.16 | 0.7 | 16.8 | 27.8 | 14.0 | 18.2 |
| 2400 | 5.6 | 0.18 | 1.9 | 45.6 | 29.0 | 14.0 | 50.0 |
| 2200 | 5.1 | 0.21 | 0.7 | 15.4 | 25.0 | 12.9 | 16.8 |
| 2074 | 5.9 | 0.24 | 1.9 | 41.5 | 27.0 | 12.1 | 44.3 |
| 1950 | 5.8 | 0.26 | 0.5 | 9.8 | 27.5 | 11.2 | 11.4 |
| 1875 | 5.8 | 0.29 | 1.0 | 18.8 | 29.0 | 11.0 | 20.9 |
| 1850 | 5.8 | 0.32 | 0.6 | 11.1 | 27.4 | 10.8 | 12.3 |
| 1838 | 5.6 | 0.34 | 0.4 | 7.4 | 28.0 | 10.8 | 7.7 |
| 1811 | 5.7 | 0.37 | 0.8 | 14.5 | 27.0 | 10.6 | 15.5 |
| 1560 | 5.8 | 0.40 | 1.7 | 26.5 | 27.3 | 9.2 | 31.1 |
| 1500 | 5.7 | 0.42 | 3.0 | 45.0 | 26.6 | 8.8 | 40.1 |
| 1450 | 5.6 | 0.45 | 1.8 | 26.1 | 27.5 | 8.5 | 29.4 |
| 1400 | 6.6 | 0.47 | 8.4 | 116.2 | 32.0 | 8.3 | 129.3 |
| 1324 | 5.6 | 0.50 | 5.0 | 66.2 | 28.0 | 7.8 | 73.9 |
| 1316 | 5.0 | 0.53 | 3.1 | 40.8 | 26.0 | 7.8 | 45.5 |
| 1280 | 4.8 | 0.55 | 3.4 | 43.5 | 24.5 | 7.6 | 48.0 |
| 1270 | 5.8 | 0.58 | 3.3 | 41.9 | 27.5 | 7.5 | 46.0 |
| 1190 | 5.8 | 0.61 | 3.7 | 44.0 | 29.0 | 7.0 | 49.2 |
| 1180 | 6.4 | 0.63 | 4.0 | 47.2 | 30.5 | 7.0 | 52.8 |
| 1179 | 5.7 | 0.66 | 6.0 | 70.7 | 26.9 | 7.0 | 78.1 |
| 1130 | 5.9 | 0.68 | 4.0 | 45.2 | 28.5 | 6.7 | 50.8 |
| 920 | 6.0 | 0.71 | 5.4 | 49.7 | 31.0 | 5.5 | 55.4 |
| 900 | 5.0 | 0.74 | 4.0 | 36.0 | 24.0 | 5.4 | 40.6 |
| 877 | 6.0 | 0.76 | 2.1 | 18.4 | 27.6 | 5.2 | 20.2 |
| 459 | 5.7 | 0.79 | 0.8 | 6.9 | 28.5 | 5.1 | 7.5 |
| 846.8 | 5.7 | 0.82 | 4.4 | 37.3 | 28.6 | 5.1 | 41.4 |
| 696.4 | 5.7 | 0.84 | 2.2 | 15.3 | 33.0 | 4.2 | 17.4 |
| 650 | 5.9 | 0.87 | 2.5 | 16.3 | 27.0 | 3.9 | 18.7 |
| 630 | 5.8 | 0.90 | 5.0 | 31.5 | 27.5 | 3.8 | 35.7 |
| 620 | 6.8 | 0.92 | 2.8 | 17.9 | 33.5 | 3.8 | 20.1 |
| 553 | 7.0 | 0.95 | 7.8 | 43.1 | 35.0 | 3.4 | 49.2 |
| 552 | 6.9 | 0.97 | 2.7 | 14.9 | 34.0 | 3.4 | 16.8 |

**Table 3**: Principal Component Analysis over Rainfall

| Weather element | Regression coefficient ($R^2$) | Standard Regression Coefficients | Eigen vectors |
|---|---|---|---|
| **Latitude ($^o$N)** | 0.794 | -0.891 | 0.579 |
| **Longitude ($^o$E)** | 0.097 | -0.311 | 0.291 |
| **Maximum temperature ($^o$C)** | 0.342 | -0.585 | 0.483 |
| **Minimum temp. ($^o$C)** | 0.150 | -0.385 | 0.108 |
| **Relative humidity (%)** | 0.660 | 0.812 | -0.261 |
| **Wind run (km/hr)** | 0.170 | -0.412 | -0.517 |

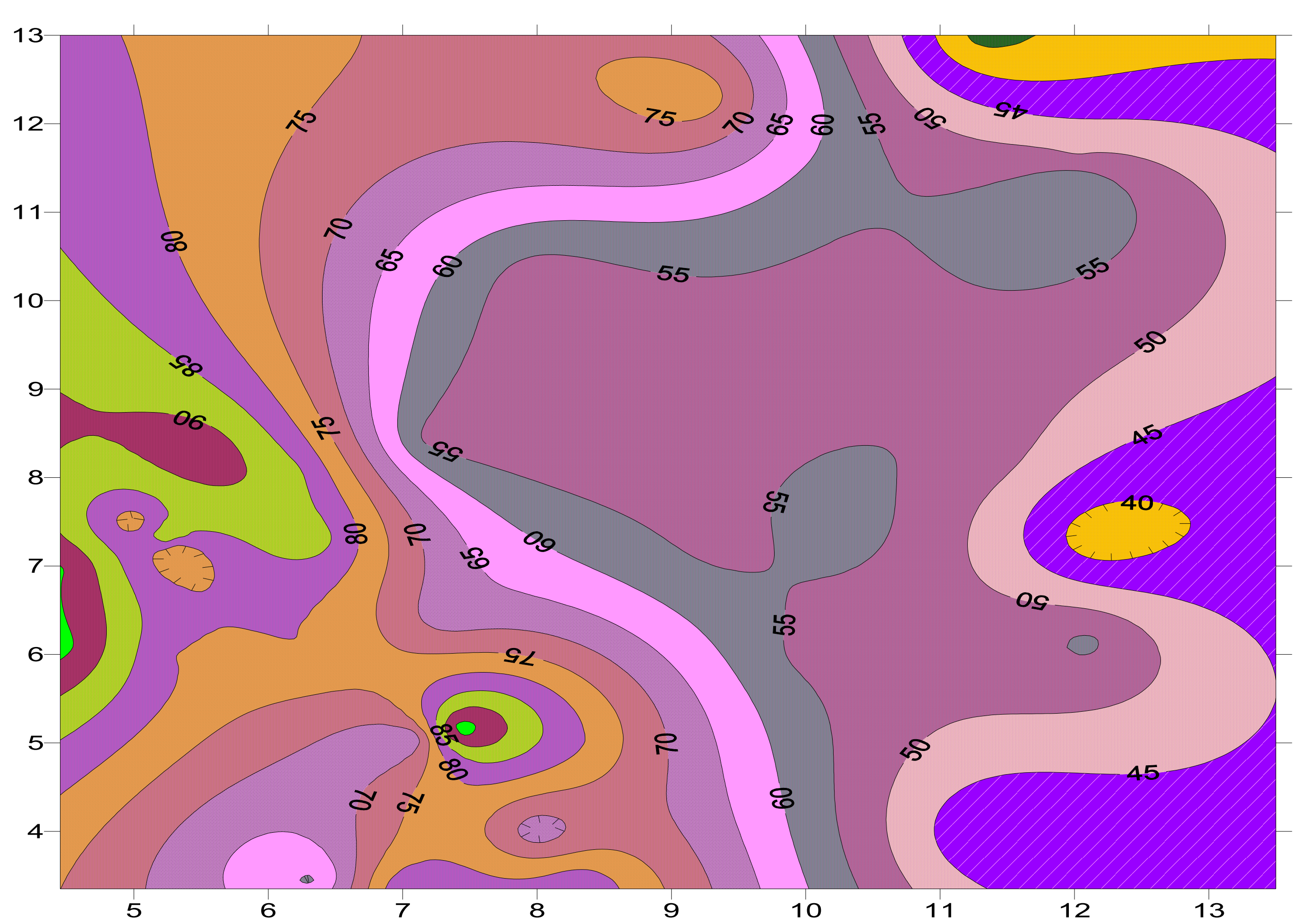


**Fig 1**: Isohume (Lines of equal relative humidity) map

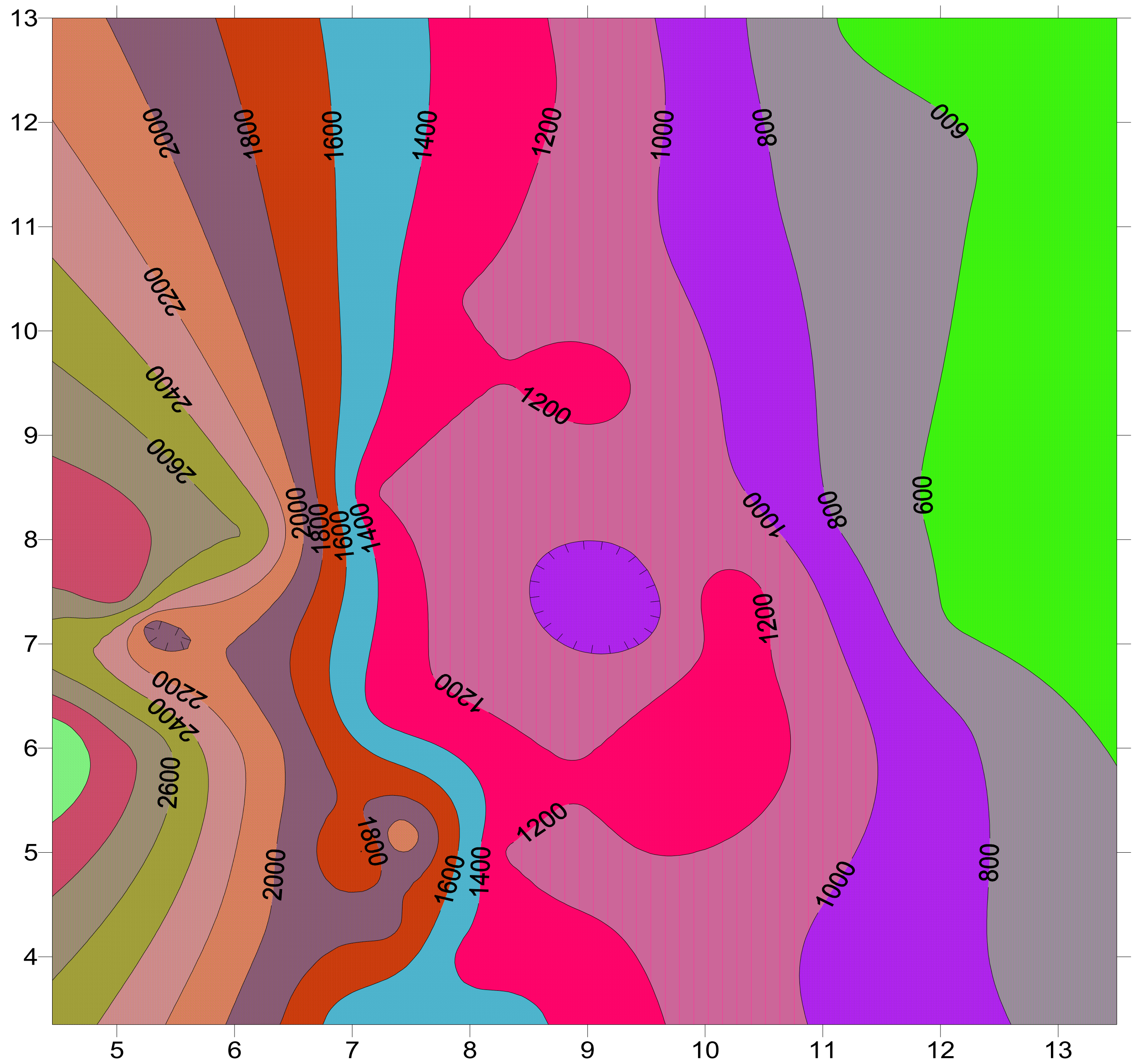


**Fig 2**: Isohytetal Map of 36 states of Nigeria including FCT, Abuja

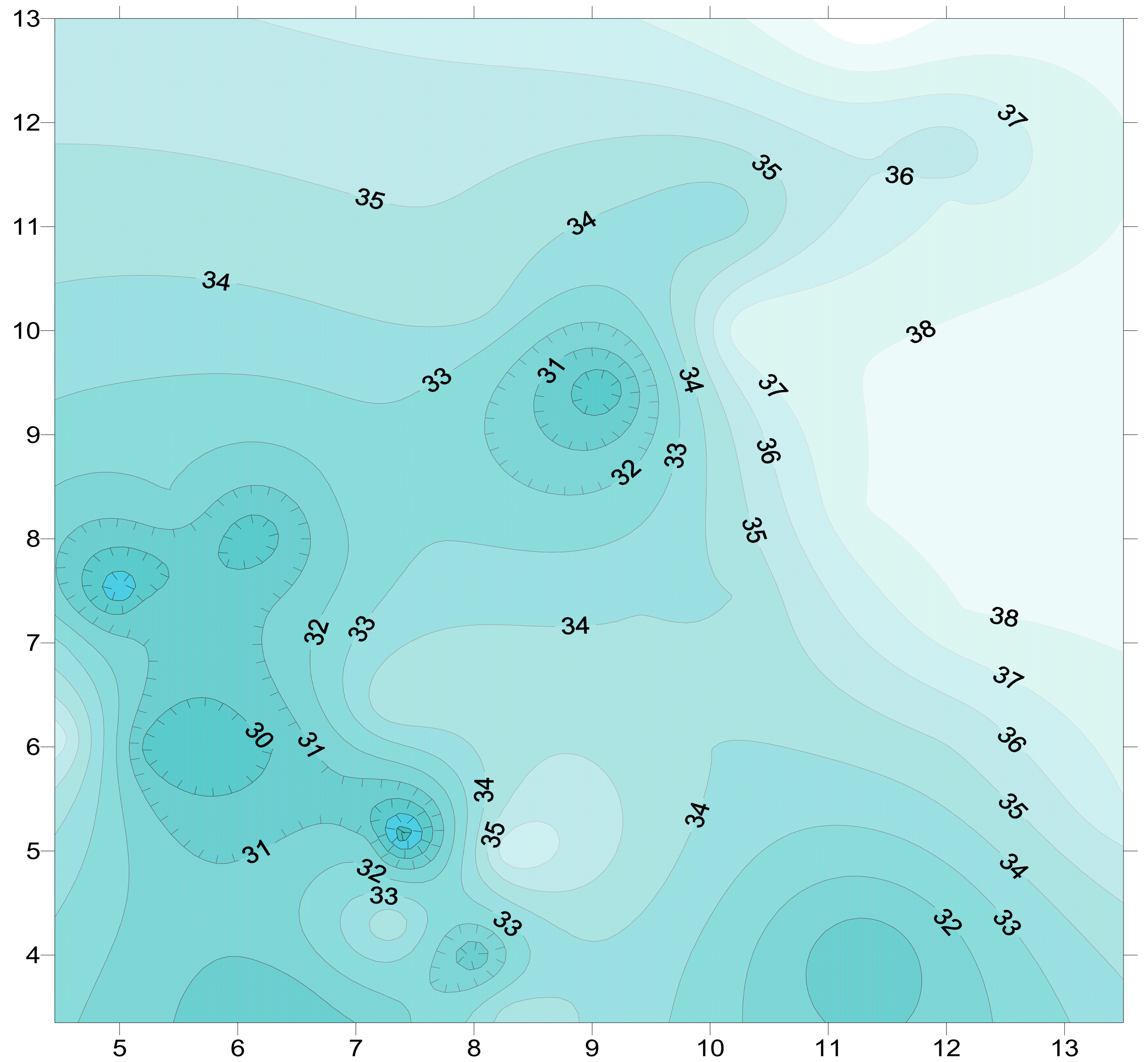


**Fig 3** : Isotherm (maximum temperature)map

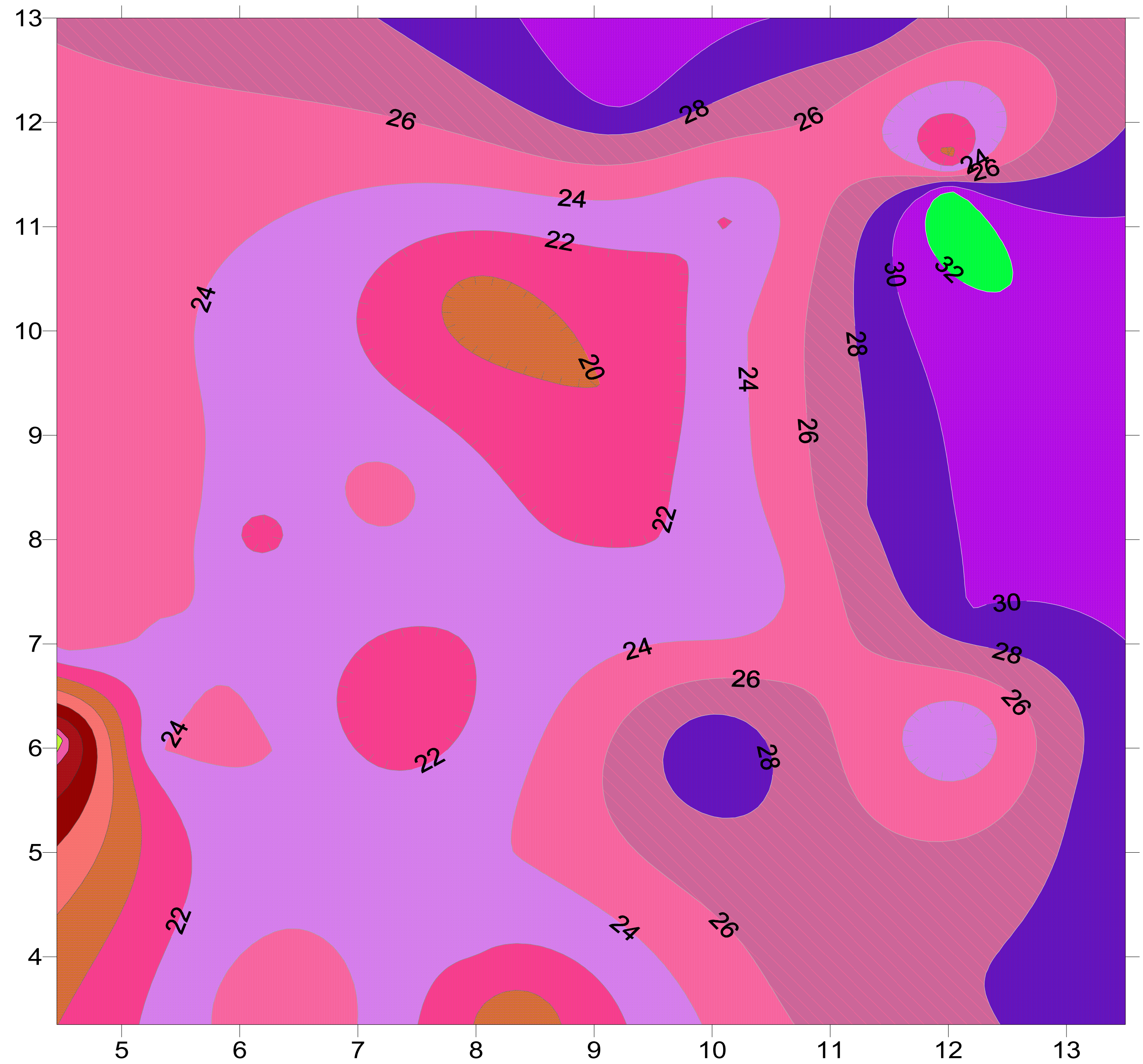


**Fig 4** :Isotherm(minimum Temperature)map

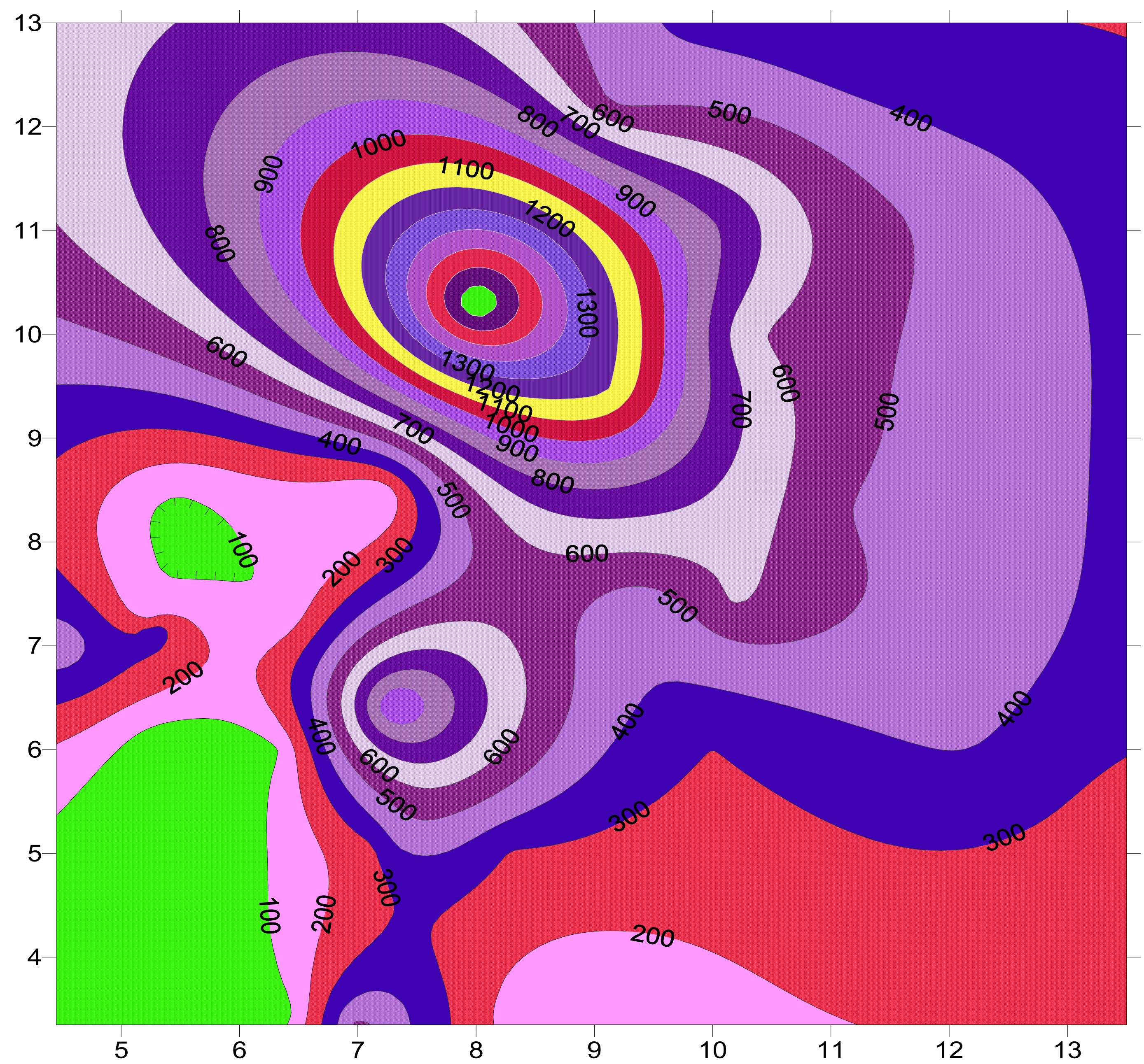


**Fig 5**: Isobaths (altitude) map