Iranica Journal of Energy & Environment

Journal Homepage: www.ijee.net

IJEE an official peer review journal of Babol Noshirvani University of Technology, ISSN:2079-2115

An Investigation on Effects of Harmattan Dust (aerosols) on Horizontal Visibility Deterioration over Bauchi, North- eastern Nigeria

F. O. Anjorin[1*], E. U. Utah[2], D. Buba[3]

[1]Department of Science Laboratory Technology, University of Jos. Plateau State. Nigeria
[2]Department of Physics, University of Uyo, Uyo. Akwa Ibom State. Nigeria
[3]Department of PRE- ND, Federal Polytechnic, Bauchi. Bauchi State. Nigeria

PAPER INFO

Paper history:
Received 6 January 2015
Accepted in revised form 15 Feburary 2015

Keywords:
Visibility
Harmattan dust
Extinction coefficient
Scattering
Absorption

ABSTRACT

In this paper, the effects of harmattan dust (aerosols) on visibility deterioration over Bauchi, a town in North-eastern Nigeria was investigated. The data of visibility readings for a period of ten (10) years were obtained by human identification of target objects and landmarks, most especially hills and buildings at known distances in a full 360 degrees circle around the observation point. The annual cycles of visibility in Bauchi for daily and monthly averages for ten years (1998-2007) were obtained. This enabled us to determine atmospheric extinction coefficient ($\beta_{ext.}$), which results in the scattering and absorption due to dust particles by using the Koschmieder relationship for the study area. Bauchi recorded a maximum visibility value of about 35000.0m in April/May 2005. The minimum visibility value of nearly zero was recorded on November/December 2000. However, during the months of June-September, the maximum atmospheric extinction coefficient value of 0.230 was recorded in 2007 and the minimum atmospheric extinction coefficient value of 0.164 was recorded in 1999. For the months of harmattan season (November to February), the maximum atmospheric extinction coefficient value of 0.689 was recorded in 2000/2001 and the minimum atmospheric extinction coefficient value of 0.270 was recorded in 2005/2006.

***doi**: 10.5829/idosi.ijee.2015.06.02.03*

INTRODUCTION

The measurement of atmospheric transmittance of visibility deterioration due to the presence of hydrometeors or lithometeors within specified accuracy to pilots, air-traffic controllers and motorists has great importance, most especially with the advent of high speed, high altitude jet and supersonic aircrafts. Visibility is defined as the maximum distance that an object or details of a complex pattern can be observed [1]. This definition is however subject to the limitations in the goodness of sight and interference between object and observer [2]. Visible light extinction, one of the most obvious effects of air pollution, is mainly due to absorption and scattering effects of aerosols in the atmosphere. The degree at which aerosol scattering and absorption contribute to the total aerosol visible light extinction can be determined and the aerosol impact on aerosol visibility degradation and its variation can be quantified. Sources of aerosols include soil dust during the harmattan season, bush burning [3], anthropogenic aerosols particularly sulfate aerosols from fossil fuel combustion, which exist all year round, aerosols from substances such as silica, asbestos, and diesel particulate matter sometimes found in the workplace. In Bauchi, a town in North-eastern Nigeria, aerosols concentration due to harmattan is prevalent since other sources of aerosol such as emissions from industrial activities are limited. Harmattan season soil aerosols are mainly transported by the North Easterly Winds from the Bilma plain (18°N, 12°E) in Niger Republic and Faya Largeau (18°N, 19°E) in the Chad basin, particularly from the Bodele depression to different parts of West Africa [3-8].

In Bauchi, effective rainy season starts from mid-May or sometime in early June and ends late October. The dry season starts in October and ends in May. This

* Corresponding author: F. O. Anjorin
E-mail: frankanj@yahoo.com

Please cite this article as: F. O. Anjorin, E. U. Utah, D. Buba, 2015. An Investigation on Effects of Harmattan Dust (aerosols) on Horizontal Visibility Deterioration over Bauchi, North- eastern Nigeria, Iranica Journal of Energy and Environment 6 (2): 92-97.

period is characterized by dryness and the presence of harmattan dust haze especially between December and March of the preceding year. Although dust events are common in Nigeria as in most parts of West Africa [4, 9-12], only limited information is available for Bauchi on the phenomenon. It is obvious from environmental occurrences that airborne dust is likely to have the greatest impact on the radiative and optical properties of the atmosphere near its source, where mean particle size and particle density are greatest. For all forms of transportation, either on water, land or air, the safety of the journey lies mostly on how good the visibility of the path is to the traveler. It is difficult to determine a visibility that is representative for every one, but if users understand the performance of automated systems, or evaluation of human observers, they can successfully use the information to make proper decisions. In this paper, we present the effect of harmattan dust (aerosols) on horizontal visibility in Bauchi, during the months of November in one year to the month of February in the subsequent year, being the period when the atmosphere is loaded with a dry dusty air having a high concentration of fine dust particles . This is accomplished by taking measurement of visual ranges involving human identification of objects and landmarks, most especially hills and buildings at known distances in a full 360° circle around the observation point, determining the trend of visibility for the period of ten years, and obtaining the extinction coefficient ($\beta_{ext.}$), the scattering and absorption due to dust particles using the relationship [13].

Mathematical definition

The term visibility, is variously defined, but generally indicates the distance to which human visual perception is limited by atmospheric conditions. The physical mechanisms that influence visual perception during the night in distinguishing lights differ from those in the daylight.

The visual range is a function of the atmospheric extinction, the albedo and visual angle of the target, and the observer's threshold contrast at the moment of observation. Values of visual range usually are estimated from the appearance of buildings and special targets at differing distances against the skyline. The formula for the visual range R_V is given as follows [14]:

$$R_v = \frac{1}{\beta_{sc}} \ln\left(\frac{C}{\varepsilon}\right) \quad (1)$$

where C is the inherent contrast of the target against the background, and ε is the threshold contrast of the observer. To limit the subjective factors and the optional target choice involved in the formula, a black target is specified; its inherent contrast against the background is unity. The value of ε is selected as 0.02 from literature [14] contrast thresholds for the human eye. The use of β_{ext} rather than β_{sc} finds justification in that, the amount of attenuation in the atmosphere is often stated in terms of the quantity known as the transmittance T defined by the Lambert- Beer law as stated below:

$$T = \exp(-\beta_{ext} x) \quad (2)$$

where x is the path length and β_{ext} is the total extinction (scattering + absorption).

When β_{ext} is used in the equation (1), the relation becomes [13]:

$$R_v = \frac{3.912}{\beta_{\text{ext}}} \quad (3)$$

Geographical location of Bauchi

Bauchi, the capital of Bauchi State, lies on latitude 10.17° North and longitude 09.49° East of the equator and at altitude, 609.5m. It is bordered by seven states, Kano and Jigawa to the North, Taraba and Plateau to the south, Gombe and Yobe to the East, and Kaduna to the West. The State occupies a total land area of 49,359 square kilometers, representing about 5.3 percent of the land area of Nigeria.

Data and analysis

Visibilty data from the Bauchi Airport for a period of ten years, 1998-2007, were obtained and analyzed. The method that was used to obtain visibility readings for the period under review was human identification of target objects and landmarks, most especially hills and buildings at known distances in a full 360 degrees circle around the observation point.

The visibility ranges were measured every three hours daily by looking at the target objects and land marks such as: the Warenge hill runway (a location at a distance of 6km from the Bauchi Airport and height of 887m), Guru hill runway (2.47 km from Bauchi Airport and of height of 687m), Gudun hill runway (3.0 km from Bauch Airport and of height of 730m), Zaranda hotel runway (1.6km from Bauchi Airport and of height of 678m), and Central Bank of Nigeria building (0.5km and of height of 663m).

The atmospheric extinction coefficient ($\beta_{ext)}$, the scattering and absorption due to dust particles was obtained using the Koschmieder relationship as given by equation (3). The method of data analysis in this work is a common one usually applied to periodic variations of meteorological parameters to show cyclic variations, means and trends [15, 16]. The annual values of visibility for Bauchi were obtained from monthly averages which in turn were derived from daily data. To show the cycles in visibility values the data set was plotted as a time series. The harmattan season values of visibility were evaluated for comparison with those of the other season of the year. The extinction coefficient β_{ext} derived from the use of equation (3) was processed the same way as the visibility in terms of means, seasonal and annual means, and trends.

RESULTS AND DISCUSSION

The monthly mean visibility, the annual mean visibility, the standard deviation and the variance are summarized in Table 1. It can be seen that the year 2005 recorded the highest mean visibility of 20.2 $\pm$ 6.5km., while the lowest mean value of 11.4$\pm$ 5.4km was obtained in the year 2000 during the period of 10 years (1998-2007).

The annual cycles of visibility from 1998 to 2007 are shown in Figure 1.The average visibility values for the dry season months (November to February) for ten successive harmattan seasons (1997/98 to 2006/07) are plotted in Figure 2 to depict the variation over the period. Minimum visibility value below 1000m was recorded in 1998/1999 while the maximum visibility value of about 16000m was recorded in 2005/2006.The decadal mean visibility during the period is 10770m with a standard deviation of 2730m. Figure 3 shows the variation of extinction coefficient for the period under review while Figure 4 depicts the pattern of variation of atmospheric extinction coefficient (June-Sept.) in Bauchi (1998-2007). Figure 5 further shows the variation in harmattan season atmospheric extinction coefficient in Bauchi (1997/1998-2006/2007). The decadal mean extinction coefficient during the harmattan in the years 1998 to 2007 is 0.393 ± 0.133. On the other the visibility and the extinction coefficient in the months June to September during the period are $19550 \pm 3570m$ and 0.205 ± 0.036 respectively.

The trend analysis [15] which defines a long term change in the visibility mean level is given in figure 6. This shows that the change is increasing with time, indicated by the trend line with a positive slope. The fitted trend equation for the trend analysis of mean visibility the years 1998-2007 is given as follows;

$$Y(t)=13.87 +0.339*t \quad (4)$$

where Y represents the visibility and t, the year index. From this trend analysis, the accuracy measures for the Mean Absolute Percentage Error (MAPE), Mean Absolute Deviation (MAD) and Mean Standard Deviation (MSD) were 11.6394, 1.7196 and 4.8912 respectively. The forecasts of mean visibility (see Figure 6) for three (3) successive years after 2007 were respectively given as 17.5933, 17.9321 and 18.2709. These were obtained from the extrapolation of the line of best fits.

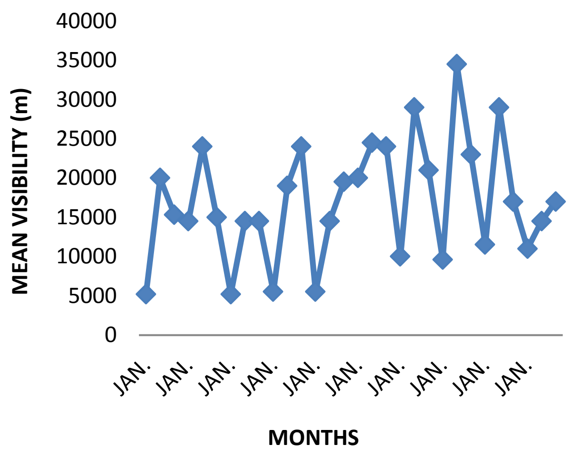

Figure 1. Annual Cycles of Visibility in Bauchi

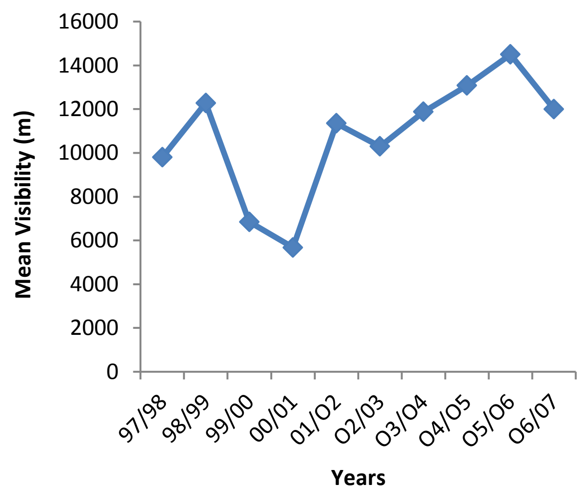

Figure 2. Variation of Visibility during Harmattan in Bauchi 1997-2007

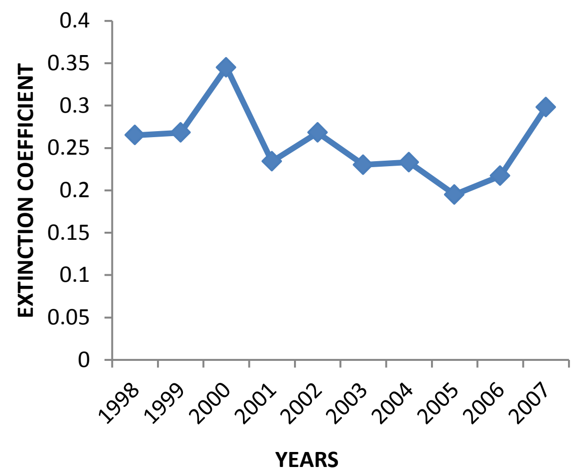

Figure 3. Variation of Atmospheric Extinction Coefficient in Bauchi (1998-2007)

Table 1. Mean Monthly Visibility for Bauchi in Kilometres (km), 1998-2007

Month	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Decadal monthly mean
JAN	5.20	14.5	5.20	5.50	5.50	20.0	10.0	9.60	11.5	11.0	9.8
FEB	10.5	10.5	5.50	5.20	10.4	9.70	9.50	9.70	11.0	10.5	9.3
MAR	10.5	14.5	6.00	9.80	10.5	9.70	9.70	24.5	9.70	10.0	11.5
APR	20.0	15.0	14.5	19.5	16.5	25.0	14.5	35.0	20.5	11.0	19.2
MAY	20.0	24.0	14.5	19.0	14.5	24.5	29.0	34.5	29.0	14.5	22.4
JUN	20.0	16.0	19.0	24.3	20.0	24.0	29.0	29.0	27.0	16.0	22.4
JUL	21.5	15.0	14.5	24.0	23.5	23.0	24.0	21.5	24.0	19.5	21.1
AUG	15.0	14.5	1.50	23.3	14.5	14.5	10.9	16.0	14.5	15.5	14.0
SEPT	15.3	15.0	14.5	24.0	19.5	24.0	21.0	23.0	24.5	17.0	19.8
OCT	15.0	19.5	19.5	16.3	19.0	19.5	19.5	20.5	19.5	11.5	18.0
NOV	14.5	11.5	0.60	16.5	11.0	17.5	20.5	20.0	16.0	10.5	13.9
DEC	9.60	5.20	0.60	16.5	10.5	10.5	15.0	16.5	10.5	10.3	10.5
Mean	14.8	14.6	11.4	16.7	14.6	17.0	16.8	20.2	18.1	13.1	15.7
Std. dev	5.1	4.6	5.4	7.0	5.2	5.8	6.0	6.5	7.0	3.2	5.6
Variance(S^2)	25.7	20.9	28.9	48.7	27.5	34.1	35.5	42.8	48.7	10.4	32.3

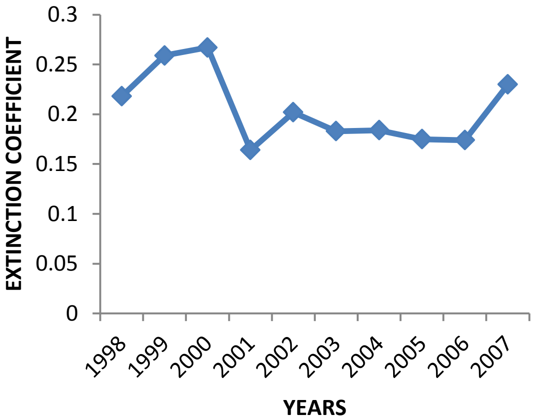

Figure. 4. Variation of Atmospheric Extinction Coefficient (June-Sept) in Bauchi (1998-2007)

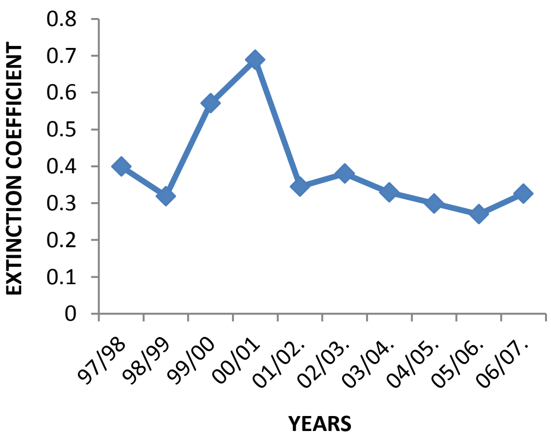

Figure 5. Variation of Harmattan Season Atmospheric Extinction Coefficient in Bauchi (97/98-06/07)

The annual cycles of visibility changes in Bauchi is also shown in Figure 2. The visibility changes are in conformity to the study carried out by Anuforum et al. [9]in Maiduguri which recorded a maximum visibility value of 30000m in June and the minimum visibility value of about 100m in January/February, compared to Bauchi with a maximum visibility value of about 35000m in April/May 2005 and the minimum visibility value of nearly zero in November/December 2000. The most observable phenomenon associated with these processes is the familiar harmattan haze that occurs during the months of November to February every year. The occurrence of low visibility in the months of November to February corresponds to the period when the entire Sahel region is under the influence of the dry dust-laden north-easterly winds. This indicates that dust aerosols transported from Sahara is the predominant cause of the low visibility in the Sahel region of Nigeria during the harmattan months. This is supported by the higher value of the attenuation coefficient of 0.393 compared to the value of 0.205 for other periods of the year when attenuation is caused by hydrometeors in the air.

The means and standard deviations of visibility, from 1998 to 2007 shown in table 2 and measure the spread of the deviations over the means. The minimum standard deviation was obtained in the year 2007 as 3.23, while the maximum standard deviation was obtained in the years 2001 and 2006 as 6.98.The standard deviation is less during the harmattan period. The minimum standard deviation or minimum spreading was observed in the harmattan season of 2000/2001 as 0.40 while the maximum standard deviation/maximum spread was observed in 2005/2006 as 4.56.

From tables 4 and 5, the average variance obtained for the whole period of ten (10) years is 32.3, while the average of variances obtained for the period of ten (10) years during harmattan is 8.06. This shows that the degree of freedom or spreading is more for the entire years, while the degree of freedom or spreading during the harmattan period is less.

The extinction coefficient of the atmosphere is proportional to the concentration of light absorbing and scattering aerosols in the atmosphere [17]. According to literature [18] the sizes of harmattan haze particle in Bauchi had average diameters of 7.5 ± 0.6μm with a range of 2 to 40μm and a concentration of 1.7mgm^{-3}.The plots of the values of extinction coefficients for the entire years, June-September period and November-February (harmattan season) are given in the graphs of Figures 3, 4 and 5 respectively. The mean maximum atmospheric extinction coefficient value of 0.345 was recorded in 2000 and the mean minimum atmospheric extinction coefficient value of 0.194 was recorded in 2005, while during the months of June-Sept., the maximum atmospheric extinction coefficient value of 0.267 was recorded in 2000 and the minimum atmospheric extinction coefficient value of 0.164 was recorded in 2001. For the months of the harmattan season (November to February), the maximum atmospheric extinction coefficient value of 0.689 was recorded in 2000/2001 and the minimum atmospheric extinction coefficient value of 0.270 was recorded in 2005/2006. These values show that atmospheric extinction coefficient is high during harmattan season than during June –September period.

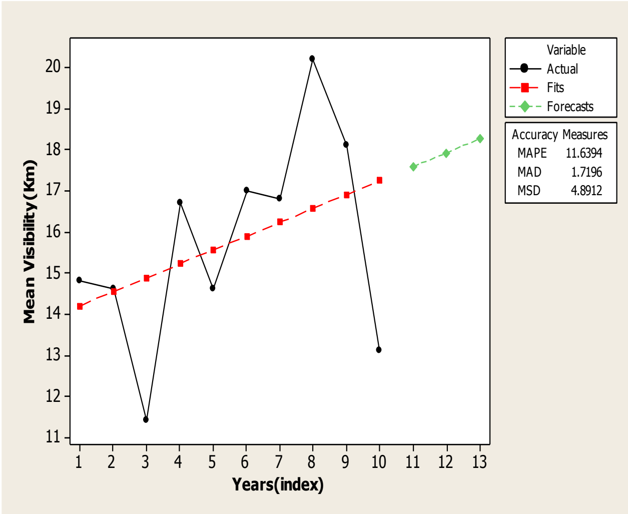

Figure 6. Trend analysis of visibility for Bauchi (1998-2007)

TABLE 2. June-September Mean Visibility and Standard Deviation

Year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Decadal Mean
Average (mean)	17.95	15.13	14.63	23.90	19.38	21.38	21.23	22.38	22.50	17.00	19.55
Standard Deviation(S)	3.29	0.63	3.47	0.42	3.71	4.53	7.63	5.34	5.49	1.78	3.57
Variance(S^2)	10.84	0.40	12.06	0.18	13.73	20.50	58.27	28.56	30.17	3.17	12.77

TABLE 3. November-February Mean Visibility and Standard Deviation

Year	97/98	98/99	99/00	00/01	01/02	02/03	03/04	04/05	05/06	06/07	Decadal Mean
Ave. mean	9.80	12.28	6.85	5.68	11.35	10.30	11.88	13.08	14.50	12.00	10.77
Standard Deviation (S)	3.62	2.60	3.10	0.04	4.45	0.57	2.64	4.14	4.56	2.68	2.84
Variance(S^2)	13.10	6.76	9.61	0.16	19.80	0.33	6.33	17.14	20.79	7.18	8.06

TABLE 4.Variability in Atmospheric Extinction Coefficient (June-Sept) in Bauchi (1998-2007)

Year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Decadal Mean
β_{ext}	0.218	0.259	0.267	0.164	0.202	0.183	0.184	0.175	0.174	0.230	0.205 ± 0.036

TABLE 5. Variation in Harmattan Season (November- February) Atmospheric Extinction Coefficient in Bauchi (97/98-06/07)

Year	97/98	98/99	99/00	00/01	01/02	02/03	03/04	04/05	05/06	06/07	Decadal Mean
b_{ext}	0.399	0.319	0.571	0.689	0.345	0.380	0.329	0.299	0.270	0.326	0.393 ± 0.133

CONCLUSION

The visibility recorded in the harmattan season (November-February) in Bauchi is about one half of that obtained in the raining season (June-September). The Saharan dust laden atmosphere during the harmattan attenuates visible solar radiation much stronger than do hydrometeors in the raining season.

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Persian Abstract

DOI: 10.5829/idosi.ijee.2015.06.02.03

چکیده

در این مقاله تاثیر گرد و غبار (آئروسل) ناشی از باد خشک زمستانی سواحل غربی آفریقا (Hartman) بر روی کاهش دید در شهر بوچی (در شمال شرقی نیجریه) مورد بررسی قرار گرفت. اطلاعات مربوط به مطالعات میدان دید از میزان تشخیص انسانی اشیا و نشان ها (به طور خاص تپه ها و ساختمان ها) در یک دور کامل ۳۶۰ درجه (حول نقطه ای که شاهد در آن و قرار دارد) و در یک فاصله مشخص بدست آمد. تغییر دوره ای سالانه متوسط میدان دید به صورت روزانه و ماهانه به مدت ۱۰ سال بدست آمد. ضریب خاموشی اتمسفری (β ext) از پراکندگی و جذب ناشی از ذرات غبار و با استفاده از رابطه Koschmieder برای ناحیه مورد مطالعه حاصل شد. شهر بوشی ماکزیمم میدان دیدی در حدود ۳۵۰۰۰ متر را در آپریل/ می ۲۰۰۵ ثبت کرد. میدان دید مینیممی در حدود صفر در نوامبر/ دسامبر ۲۰۰۰ ثبت شد. اما ماکزیمم میزان ضریب خاموشی اتمسفری ۰/۲۳۰ در طول ماه های ژوئن – سپتامبر ۲۰۰۷ و مینیمم میزان ضریب خواموشی اتمسفری ۰/۱۶۴ در سال ۱۹۹۹ ثبت شد. در فصل های که باد Hartman می وزد (از نوامبر تا فوریه)، ضریب خاموشی اتمسفری ماکزیمم ۰/۶۸۹ در سال ۲۰۰۰/۲۰۰۱ ثبت شد و میزان ضریب خاموشی مینیمم ۰/۲۷۰ در سال ۲۰۰۵/۲۰۰۶ ثبت شد.