

EVALUATING VALLEY SIDES SLOPE RECESSION USING EROSION PINS AND RAINFALL FACTORS AS DETERMINANTS

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Abstract

This research work attempted to evaluate the degeneration of valley side slope using some rainfall parameters in Ikpoba River Basin. The use of erosion pins involved monitoring erosion variables at the valley side slopes to determine advancement and retreat of the ground. There was also the monitoring of rainfall parameters as well as soil and slope characteristics. This was carried out for a span of three (3) years (2015-2017), with the installation of sixty (60) erosion pins along a transect line down the valley slope. And some rainfall parameters which included rainfall amount, kinetic energy and 15-minute intensity rainfall were measured using autograph rain gauge. Runoff amount was generated using an Ott-type-current meter and each velocity was taken at 60 seconds while antecedent precipitation index was also computed. The result indicate that most of the rainfall parameters studied are unsatisfactory as predictors of slope recession but suggested that standardized diagnostic rainfall parameters in slope degeneration and recession are of value only within clearly defined environment. However the study revealed that the level of slope recession may be predicted with some degree of accuracy, on the basis of relatively few rainfall parameters. It was also discovered that rainfall amount, rainfall duration and 15-minute intensity were significantly related to slope degeneration.

Key Words: *Ikpoba River, Rainfall parameters, Slope recession, Erosion pins, Valley side slopes*

Introduction

The most important geomorphic process affecting the earth's surface today is soil erosion by rain drop impact and overland flow in both the humid tropical and temperate regions. The two geomorphic processes has led to the degeneration of most land surfaces rendering them unproductive (Morgan, 2005). However, the accurate measurement of soil erosion has proven to be laborious, time

consuming, and often expensive. Several techniques has been used to measure soil erosion which include experiments on particulate and soluble yield at basin outlet, hydrologic processes. Various experiments have been directed at understanding slope degeneration including slope failures, flow phenomenon and rapid mass movement (Okuda, Okimura and Mizutani, 1976).

Channel changes as well as laboratory and theoretical studies have been employed over time with the intention of understanding slope degeneration through erosion processes Dietrich, (1982). However, within the context of this work, erosion pins was utilized because it is the simplest and most effective methods used in monitoring the changes which occur in the altitude of ground surface which result from erosion and deposition Haigh, (1977); Lawler, (1993). According to Boardman and Favis-Mortlock, (2016), erosion pins are simple, robust and relatively cheap. The advantages of this method are still very noticeable and better when compared to the expensive field/laboratory techniques such as ^{137}Cs and ^{210}Pb tracers, installation of flumes and laser scanning.

According to Pal (2016), valley side slopes are the very steep surfaces between the valley floor and summits of adjacent uplands. He went further to describe slopes as the angular inclination of terrain between hill slope (crest) and valley bottom.

It is for the above reason, that the researcher decided to carryout onsite investigation of valley sides degradation from Ikpoba river basin in Benin City and environs using erosion pins.

2.0 Materials and Methods

2.1 Study Area

The study was carried out at Ikpoba river valley sides slopes which lies between latitudes $6^{\circ}4^1$ and $6^{\circ}7^1$ North and longitudes

$5^{\circ}4^1$ and $6^{\circ}1^1$ East (Fig. 1). The Ikpoba river drains approximately 730.2km^2 (Odemerho, 1992). The river has a maximum discharge of 320cm and a minimum of 191cm (Owena River Basin Authority, 1996). The topography of the basin is mainly an undulating plain with a relief of 12 metres (Odemerho, 1992). The slopes ranges between 1.5° and 3° . Most relief feature in the basin is attributable to fluvial processes that has led to the dissection of the flat-lying sedimentary unit. The basin experiences the tropical moist climate (Ogidiolu, 1996). The annual rainfall in the area exceeds 2000mm with the first-peak which occurs in July with precipitation of 344.7mm. The second peak monthly precipitation of 457.2mm occurs in September. Most of the storm are convective and have high short term intensities (Ogidiolu, 1996). The basin experiences both the dry and wet season which is controlled by the position of the Inter-Tropical Discontinuities (ITD). The wet season begins in March and reaches its first maximum in July and the second in September. Both maxima are separated by a brief spell known as the "August Break". The dry season is short and may last from November to February. In any case, rainfall is experienced in all the months of the year with January and December being the driest. Temperature are fairly uniform with the highest mean monthly temperature of 29.1°C recorded in March and the lowest 24.4°C in the month of June.

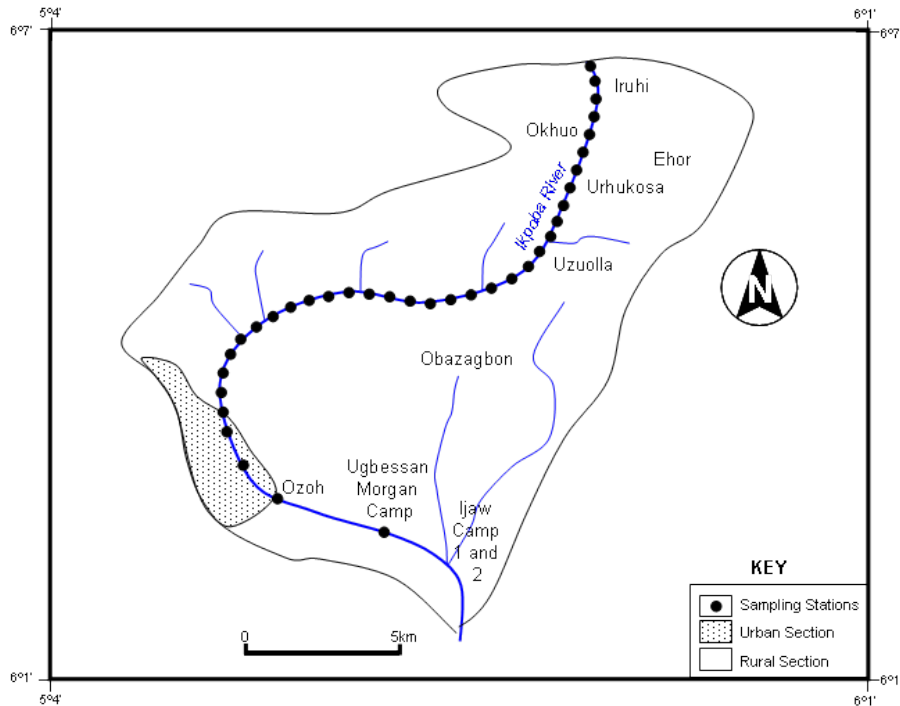


FIG. 1: Ikpoba River Basin showing sampling stations
Source: Modified from Aziegbe (2000)

2.2 Method of Data Collection

The erosion pins, 60 in numbers, were established as a transect line downslope that has been previously identified during a reconnaissance survey. The pins were installed at a distance of (96.1m) along the line as a practice with Mortlock and Foster, (2015) procedure. Recording was done directly and mean values of readings were taken into account for analysis. A reduction in erosion pins exposure is termed: 'ground advance' and an increase is ground retreat (after Haigh, 1977, Boardman and Favis-Mortlock, 2016).

Characteristics of the river basin which were thought to be related to the erosion study were also measured this include, soil shear strength, penetration resistance, aspect, slope length, and slope angle. In-situ soil shear strength was determined by Van Sher apparatus (AAS, 1965). Penetration resistance was carried out by the use of pocket penetrometer. Aspect was recorded as azimuth in degrees. Length was measured

from crest to base across the surface (Southere and Toy, 1986). Angle of slope was determined through field survey using Abney level.

Rainfall parameters which include rainfall amount, kinetic energy of rainfall storm and 15minute intensity rainfall, were measured by an autographic rain gauge. Runoff amount was generated with the aid of a horizontal-axis-Ott-type current meter which was mounted on a wooding rod and the time taken for each velocity was 60 seconds (See Appendix I) and the antecedent precipitation index was computed after the method of Gregory and Walling (1973). Thirty (30) rainfall events were monitored from a period of three (3) years (2015 to 2017) which resulted in measurable soil retreat and advance on the slope. (Table 2.1). Autograph rain gauge readings were recorded from the meteorological station and office of the Owena River Basin Development Authority, Benin City.

Table 2.1: Rainfall monitored events

Months	M	A	M	J	J	A	S	Total
Amounts (mm)	0	0	18.3	125.4	70.1	62.5	11.1	287.4
Event (No)	0	0	5	10	8	4	3	30

Source: Fieldwork, 2017

Sixty percent of these erosion generating events occurred with 15-minute rainfall intensities in excess of 20mm per hour (Table 2.2).

Table 2.2: 15-Minute Rainfall Intensity

Intensity class (mm/hr)	No	Rainfall events	% of total
20	18	60	18.3
21-40	8	30	5
40	4	10	
Total	30	100	

Source: Fieldwork, 2017

Data on rainfall parameters and erosion variables were summarized using descriptive statistics such as percentages, mean, range and median. Also, bivariate correlation analysis was used to determine the relationship between erosion rates and the individual rainfall parameters as well as the extent of inter-relationship among the rainfall parameters. In order to make more visibly the most important rainfall parameters influencing erosion, the data on erosion and rainfall were subjected to stepwise multiple regression analyses. And according to Aziegbe (2000) stepwise regression is superior to multiple regression because it is capable of bringing out fewer variables when developing stable equations which shows the individual dependent

variable relationships with the independent variables.

3.0 Results and Discussion

The statistical summary showing the mean, range, median and standard deviation from the rainfall parameters of the study is shown in Table 3.1 were rainfall amount was seen to relate to soil erosion and water availability. Similar studies carried out by Hudson (1971) and Odemerho (1982) revealed that most tropical rainfall occurs in large storms. From the Table 3.1, over 40% of the rainfall amount occur in large storms. The duration per storm for the months monitored is about 120 minutes.

Table 3.1: Summary of rainfall parameters

Rainfall parameters	Mean	Range	Median	Standard deviation
R	6.6	6.1-7.4	6.4	0.42
KE	3.1	0.9-	0.1	0.42
I15	18.7	2.3 ₁ 25.5-	19.5	4.80
RD	0.2	28.0 ₁ 0.1-	0.2	0.12
AI95	4.7	0.5 ₁ 2.0-	0.5	2.67
RO	76.6	11.0 ₁ 61.0-	76.0	7.10
		84.0		

Source: Fieldwork, 2017

- R = Rainfall amount in (mm)
 KE = Kinetic energy in (Joules M-2 MM-1)
 I15 = The maximum 15 minute intensity (mm/hr-1)
 RD = Rain fall duration (min)
 AP195 = Antecedent precipitation index based on constant of 0.95
 RO = Runoff of rain fall event (mm)

**For runoff amount/mean and rainfall amount see Appendix I and II*

Table 3.2: Erosion Variables at Test Sites

Rainfall parameters	Mean	Range	Median	Standard Deviation
Maximum erosion	13.3	8.3-20.1	12.3	4.78
Mean erosion	7.6	3.6-25.2	6.3	7.52
Proportion of pins registering erosion	15.4	9.2-22.4	8.4	4.66
Shear strength (Kpa)	2.09	7.5-15.4	6.6	2.36
Penetration resistance (Kpa)	1.07	4.3-81	1.02	0.17
Aspect (0°)	40.1	3.2-7.6	5.6	4.97
Slope length (m)	15.3	7.8-12.6	7.2	4.53
Slope angle (0°)	27.0	6.6-25.1	9.4	5.66

Source: Fieldwork, 2017

The correlation between erosion variables and rainfall parameters are presented in Table 3.2. Maximum erosion is significantly correlated with five (5) of the rainfall parameters while the number of pins registering erosion correlates with all the rainfall variables. This pattern of relationship indicates that the

erosion variables at the test sites are significantly influenced by different member and different combination of rainfall parameters. The table also reveals that the magnitude of the influence of the individual rainfall parameters on erosion variables varies from one site to the other.

Table 3.3: Correlation Between Erosion Variables and Rainfall parameters

Rainfall parameters	Y ₁	Y ₂	Y ₃	Y ₄	Y ₅	Y ₆	Y ₇	Y ₈	Y ₉
R	0.55	0.45	0.60	0.05	0.66	0.44	0.65	0.55	0.33
KE	0.4	0.33	0.54	0.38	0.36	0.26	0.05	0.38	0.25
I15	0.51	0.46	-0.70	0.06	0.25	0.44	0.04	0.41	0.36
RD	0.66	-0.56	0.40	0.09	0.57	0.53	0.55	0.55	0.28
AP195	0.51	0.38	0.55	0.48	0.55	0.66	0.08	0.38	0.44
RD	0.60	-0.53	-0.41	0.36	0.38	0.25	0.48	0.68	0.52

Source: Fieldwork, 2017

Y₁ is maximum erosion; Y₂ is mean erosion; Y₃ is proportion of pins registering erosion; Y₄ proportion of pin not registering erosion; Y₅ is shear strength; Y₆ is shear strength; Y₆ is penetration resistance; Y₇ is aspect; Y₈ is slope length; and Y₉ is slope angle.

The multiple correlation coefficients and coefficients of determination expressing the strength of the relation between each rainfall parameter and erosion variable at test sites taken together is presented in Table 3.4. From this result, test site variables most important

in slope evolution include maximum erosion (Y_1), mean erosion (Y_2), proportion of pins registering erosion (Y_3), shear strength (Y_5), penetration resistance; (Y_6), slope length (Y_8). Surely multicollinearity exist among the test site variables. This makes such a judgement

based on these erosion variables at test sites risky and old suspect validity notwithstanding the fact that the erosion variables examined were highly successful in explaining variations in slope erosion.

Table 3.4: Multiple Correlation

Rainfall parameter	R	R ²									
R	0.9324	0.9536	Y_5	Y_7	Y_3	Y_1	Y_8	Y_2	Y_4	Y_6	Y_9
RE	0.9065	0.6567	Y_3	Y_8	Y_4	Y_5	Y_1	Y_2	Y_6	Y_9	Y_7
I15	0.9246	0.7048	Y_3	Y_1	Y_2	Y_6	Y_8	Y_9	Y_5	Y_9	Y_1
AP195	0.9138	0.6752	Y_6	Y_3	Y_5	Y_1	Y_4	Y_9	Y_2	Y_8	Y_7
RD	0.9035	0.6036	Y_8	Y_1	Y_2	Y_9	Y_7	Y_3	Y_5	Y_6	Y_4

Source: Fieldwork, 2017

**In other of contribution to explain variation in significance at 5% level*

The correlation matrix for rainfall parameters matrix is shown in Table 3.5. Outstanding among them is that a large proportion of the relationships are positive. This indicates that there is a tendency for the parameters to increase or decrease together. There is also a

high correlation among the rainfall parameters. For example, rainfall duration is positively related to kinetic energy and intensity. Again antecedent precipitation index is positively related to kinetic energy and intensity.

Table 3.5: Correlation coefficient (r) between the Rainfall parameters

R	1.00					
KE	-0.98	1.00				
I15	-0.59	0.84	1.00			
RD	-0.69	0.60	0.50	1.00		
API95	0.55	0.59	0.59	0.27	1.00	
R	0.67	0.72	0.51	0.71	0.42	1.00
I		II	III	IV	V	VI

Source: Fieldwork, 2017

Before the development of a predictive equation of rainfall parameters, stepwise multiple regression was employed. Rainfall parameters are therefore taken as independent variables while erosion variables at the test sites are treated as dependent variable. The best predictive equation produced by this method are contained in table 3.7. The predictive equation is that which contains the fewer independent

variables while yielding the smallest standard error of estimate and explaining the greatest amount of variation in the dependent variable. A close examination of Table 3.7 reveals that rainfall amount, rainfall duration and intensity, judging by equations error of estimates, are good predictors of slope recession. On the whole, the most occurring variables in all the equations are; rainfall amount (R) rainfall duration (RY) and the 15 minute intensity

(115). Kinetic energy (KE) appear just twice while antecedent precipitation index (API⁹⁵) appear only once.

Y	Regression equation	S.E	S.E. as % of Y
Y	$= -2356 + 0.875R + 0.009RD + 0.0361^{15}$	1.1	15.75
Y	$= -2.046 - 0.022R + 0.014RD + 0.201^{15}$	2.3	10.97
Y	$= -100.566 + 0.258R + 1.877RD + 0.7401 + 26.150KE$	2.0	20.82
Y	$= -4.536 - 0.14R + 0.031RD + 0.0731^{15} + 0.605KE$	1.8	40.57
Y	$= -2.046 - 0.127R - 8.63RD + 0.12815 + 0.071API^{95}$	5.3	15.21

Source: Fieldwork, 2017

The influence of rainfall parameters as they affect slope recession in the studied area can be summarized as follows: rainfall amount is one of the factors that predominates in slope recession and evolution. This is followed by rainfall duration and kinetic energy. A number of researchers in Nigeria has corroborated this fact such as Lai, 1976, Odemerho, 1982. In one of the study carried out by Odemerho and Avwonudiogba (1983), an average rainfall of 1858.7 mm for 7 months in three years, with an average of 132 rainy days was reported. Rainfall in excess of 12.70mm have also been documented as threshold value for the humid tropic (Hudson, 1971). High sustained momentum and kinetic energy have been reported elsewhere for the tropics (Jimoh, 1997). These processes identified above can influence slope degeneration through detachment of soil aggregates, rapid runoff and high level of erosion. Besides, they can influence soil porosity, and hence soil hydraulic properties like saturated and unsaturated hydraulic conductivity, water retention characteristics, sorpsivity, time to ponding at a given rainfall intensity and infiltration capacity (Imerson and Kwaad, 1990).

The way and manner the parameters influence slope recession could be explained thus: rainfall amount and duration will influence moisture content of the soil, which will in turn influence aggregate stability, resulting in seasonal variations.

Penetration resistance and shear strength of soil are influenced by wetting. Wetting leads to low cohesion which leads to low shear strength values (Aziegbe, 2000). All these favour erosion and consequently slope recession in the study area.

Conclusion and Recommendations

The study reveals that the extent of slope recession and degeneration may be predicted with some degree of accuracy on the basis of relatively few rainfall parameters. The fact that kinetic energy did not feature prominently as a rainfall variable of slope recession is one of the revelations of this study. It is possible that the range of values for this variable is so limited. Rainfall amount (R), r rainfall duration (RD), and the 15-minute intensity were significantly related to slope recession. This can be corroborated by the earlier study carried out by Odemerho (1992) which states that the area understudy is an undulating plain with a relative relief of twelve (12) metres and slopes range between 1.5^0 and 3^0 . Generally, the basin is a flat and monotonous aggradational plain without marked topographical features. Therefore, topography and relief plays an insignificant role in slope recession in the basin. While the result of this study is plausible, there is need to test the performance in other environments in doing this, extreme hydrological events should be considered

particularly in simulation and model developments.

From the research findings, it is apparent that, valley side slopes occupy most of the land surface of the earth. In areas where there is occurrence of erosional topography, the entire landscape, except the valley floors, consists of hills and valley side slopes (Abraham 1986).

The study of valley side slopes are essential not only in order to understand

better the natural landscape but also for other numerous practical reasons such as controlling soil erosion, sedimentation and managing agricultural land areas along such slopes as well as mitigating the hazards posed by landslides.

Therefore, the study is seen to be relevant within the context of the aforementioned points which have not been adequately addressed.

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APPENDIX I

AMOUNT OF RUNOFF (Cum/sec) FROM THE MONTHS OF MARCH-SEPTEMBER 2015

Selected stations	Date	8am-9am	11am-12pm	2pm-3pm	5pm-6pm	Total	Mean
1	8/3/2015	0.10	0.19	0.30	0.22	0.81	0.20
2	20/4/2015	0.31	0.20	0.17	0.15	0.83	0.21
3	29/3/2015	0.40	0.44	0.27	0.17	1.33	0.33
4	5/4/2015	0.98	0.95	0.80	0.92	3.65	0.65
5	15/4/2015	0.15	0.42	0.24	0.40	1.21	0.30
6	27/4/2015	0.44	0.47	0.45	0.56	1.86	0.47
7	7/5/2015	0.38	0.35	0.70	0.35	2.58	0.65
8	20/5/2015	1.10	1.21	1.05	1.25	4.61	1.15
9	30/5/2015	0.66	1.12	0.75	0.95	3.48	0.87
10	10/6/2015	2.25	1.68	1.10	2.46	7.49	1.87
11	21/6/2015	1.36	1.24	2.00	1.98	6.58	1.65
12	21/6/2015	1.36	1.24	2.00	1.98	6.58	1.65
13	28/7/2015	1.05	1.31	1.20	1.17	4.73	1.18
14	8/8/2015	1.20	1.18	2.35	2.24	6.97	1.74
15	26/8/2015	2.75	1.46	1.66	1.58	7.45	7.86
16	10/9/2015	3.60	3.30	3.59	3.25	13.7	3.44
17	27/9/2015	3.42	3.36	3.52	3.31	13.6	3.40

AMOUNT OF RUNOFF (Cum/sec) FROM THE MONTHS OF MARCH-SEPTEMBER 2016

Selected stations	Date	8am-9am	11am-12pm	2pm-3pm	5pm-6pm	Total	Mean
1	11/3/2016	0.13	0.12	0.25	0.32	0.82	0.20
2	28/3/2016	0.15	0.17	0.19	10.12	10.63	0.16
3	7/4/2016	2.15	1.32	1.95	0.92	6.34	1.59
4	24/4/2016	1.18	1.24	1.30	1.28	8.67	1.25
5	6/5/2016	2.63	2.71	0.97	2.36	8.67	2.17
6	15/5/2016	2.36	2.11	2.36	2.04	8.87	1.97
7	26/5/2016	2.26	2.09	2.01	2.34	8.7	2.18
8	4/6/2016	1.24	2.00	1.98	1.95	7.17	1.79
9	15/6/2016	2.63	2.79	2.65	2.42	10.49	2.62
10	22/6/2016	1.05	0.95	2.30	2.10	6.4	1.6
11	3/7/2016	0.90	0.97	1.10	0.80	3.77	0.94
12	12/7/2016	1.07	1.21	1.12	1.41	4.81	1.20
13	29/7/2016	1.20	1.10	1.32	1.22	4.84	1.21
14	12/8/2016	2.36	1.46	1.67	2.05	7.54	1.89
15	25/8/2016	3.42	3.50	3.20	2.20	12.3	3.08
16	9/9/2016	2.05	2.21	2.30	2.11	8.67	2.17
17	21/9/2016	2.20	2.10	2.60	2.19	9.09	2.27

AMOUNT OF RUNOFF (Cum/sec) FROM THE MONTHS OF MARCH-SEPTEMBER 2017

Selected stations	Date	8am-9am	11am-12pm	2pm-3pm	5pm-6pm	Total	Mean
1	8/3/2017	0.11	0.13	0.27	0.36	0.82	0.20
2	23/3/2017	0.17	0.19	0.23	10.18	10.63	0.16
3	10/4/2017	2.10	1.34	1.97	0.97	6.34	1.59
4	25/4/2017	1.12	1.26	1.31	1.29	8.67	1.25
5	10/5/2017	2.59	2.79	0.99	2.39	8.67	2.17
6	17/5/2017	2.31	2.16	2.43	2.14	8.87	1.97
7	28/5/2017	2.21	2.19	2.11	2.24	8.7	2.18
8	7/6/2017	1.20	2.08	1.93	1.99	7.17	1.79
9	22/6/2017	2.69	2.83	2.61	2.47	10.49	2.62
10	30/6/2017	1.08	0.98	2.34	2.15	6.4	1.6
11	8/7/2017	0.94	0.99	1.15	0.88	3.77	0.94
12	17/7/2017	1.03	1.26	1.13	1.49	4.81	1.20
13	31/7/2017	1.23	1.16	1.35	1.28	4.84	1.21
14	16/8/2017	2.38	1.51	1.69	2.07	7.54	1.89
15	30/8/2017	3.47	3.58	3.25	2.26	12.3	3.08
16	11/9/2017	2.01	2.26	2.27	2.17	8.67	2.17
17	27/9/2017	2.23	2.17	2.57	2.23	9.09	2.27

APPENDIX II**MONTHLY AMOUNT OF RAINFALL (mm) FOR (2015)**

MARCH	APR	MAY	JUN	JUL	AUG	SEPT	TOTAL	MEAN
137.0	235.0	278.0	347.0	485.4	345.0	514.0	2338.4	334.1

MONTHLY AMOUNT OF RAINFALL (mm) FOR (2016)

MARCH	APR	MAY	JUN	JUL	AUG	SEPT	TOTAL	MEAN
135.2	229.5	274.3	379.0	391.7	300.0	425.1	2134.8	305.0

MONTHLY AMOUNT OF RAINFALL (mm) FOR (2017)

MARCH	APR	MAY	JUN	JUL	AUG	SEPT	TOTAL	MEAN
136.4	231.6	276.4	381.0	453.0	324.3	473.3	2276.0	325.1