Relationship of Anthropometric Indices with Rate Pressure Product, Pulse Pressure and Mean Arterial Pressure Among Secondary Adolescents of 12-17 Years

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Relationship of anthropometric indices with rate pressure product, pulse pressure and mean arterial pressure among secondary adolescents of 12-17 years

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Abstract

Background: Anthropometric indices are highly associated with cardiovascular events. However, there correlation with hemodynamic parameters among adolescents is still wanting.

Study purpose: To determine the correlation between anthropometric indices and the selected hemodynamic parameters among secondary adolescents aged 12-17 years.

Methods: In this study, we present data of 485 secondary school adolescents aged 12-17 years. Height, weight, waist circumference, hip circumference and neck circumference were measured using standard protocol. Conicity index, body mass index, ponderosity index and body surface area, were computed using standard formulae. Blood pressure was measured using a digital automated blood pressure machine. The rate pressure product was determined as product of heart rate and systolic blood pressure, pulse pressure as the difference between systolic blood pressure and diastolic pressure while mean arterial pressure was the sum of diastolic pressure and pulse pressure. Comparisons of hemodynamic parameters across the anthropometric index's categories were done using a one-way ANOVA and an unpaired t-test while correlation analysis was done using Pearson correlation coefficient at 95% confidence interval.

Results: Our findings showed weak positive correlation between generally body surface area, neck circumference and conicity index with the hemodynamic parameters (systolic blood pressure, diastolic blood pressure, resting pulse rate, mean arterial pressure, rate pressure product and pulse pressure). However, the ponderosity index, body mass index and waist hip ratio showed negative weak correlations with the hemodynamic parameters. There was a significant difference in pulse pressure among the BMI categories. All parameters showed significant ($p<0.05$) differences across the categories of neck circumference and waist hip ratio. Generally, in multivariate regression analysis, anthropometric indices showed significant prediction of the hemodynamic parameters.

Conclusion: Generally, a weak positive correlation between anthropometric indices and the hemodynamic parameters.

Key words: Anthropometric indices, rate pressure product, pulse pressure, mean arterial pressure.

Introduction

The role of anthropometric measurements in estimation of adiposity is widely used in both research and clinical settings. The indices, such as; bod mas index (BMI) also known as the Quetelet index, and the waist hip ratio (WHR) have been used commonly to define overweight and obesity status across various age categories. Recently, more indices such as the conicity index (CI); ponderosity index (PI); body surface are (BSA) which is a two-dimensional measurement of body size, and neck circumference (NC), a surrogate measure of upper body fat, have also attracted great attention in understanding overweight and obesity. Overweight and obesity is highly associated with a number of non-communicable diseases including cardiovascular disease, diabetes mellitus, cancers, arthritis, ovarian dysfunction and so forth. Globally, based on the world health organization (WHO) , the prevalence of obesity has tripled since 1975, as in 2016 only more than 1.9 billion adults of age 18 years and greater were overweight, of which 650 million were obese [1]. Obesity plays a very vital role in the development of cardiovascular disease (CVD) [2-4]. Several simple anthropometric parameters have been greatly associated with cardiovascular risk factors [5] and thus their relationship with

hemodynamic parameters needs to be explored. The rate pressure product (RPP) also known as the cardiovascular product, is the measure of stress put on the cardiac muscle, based on the number or times it needs to contract per minute and the arterial blood pressure that is pumping against it [6]. It is a direct indication of the energy demand of the heart and thus good measure of energy consumption by the heart. Anthropometric indices such as WHR, waist circumference (WC), and BMI were found to be significantly correlated with RPP among health young adults [7, 8], and an important predictor of cardiovascular events [9]. The mean arterial pressure (MAP) is physiologically the average pressure in the arteries during a single cardiac cycle [10] and it is useful indicator of the pressure necessary for the adequate perfusion to vital organs, while the resting pulse rate(RPR) is an indirect indicator of basal sympathoactivation . Additionally, the pulse pressure (PP) is an indirect marker of arterial stiffness and distensibility [11]. Both MAP and PP are important indicators of the pressure inside arteries and the extent of vasoconstriction or dilation. These have been found to be associated with anthropometric indices in elderly populations [12] and young adults elsewhere [13]. Further exploration of this relationship is needed for secondary school adolescents in Ugandan settings for a reliable comparison and better understanding of the cardiovascular related pathophysiology. Therefore, this study aimed at determining the correlation of anthropometric indices selected hemodynamic parameters among secondary school adolescents, in Mbarara municipality southwestern Uganda.

Methods

Study design and data

Data included in this study was part of a larger cross-sectional study which included up to 616 [14] adolescents aged 12-19 years in Mbarara municipality, southwestern Uganda. In this paper, only data of 485 participants aged 12-17 years was analyzed.

Anthropometric measurements

The methods were already described in detail by Katamba et al [15]. Briefly, height (Ht) was measured using a wall mount height board without shoes in centimetres (cm) [2]. Weight (Wt) was measured to the nearest 0.5kg using a standard weighing scale (Seca 762, GmbH & Co. KG,

Hamburg, Germany) and participants were encouraged to put on light clothing with no items in the pockets and shoeless [3]. Waist circumference (WC) was measured by an inelastic flexible measuring tape with the participant standing while hip circumference (HC) at the level of the greater trochanter to the nearest 0.1cm using an inelastic flexible measuring tape with the participant standing. Neck circumference (NC) was used as a surrogate measure for upper body adipose tissue distribution, measured at the level of the laryngeal prominence using an inelastic flexible measuring tape.

Anthropometric indices computations

$$\text{Ponderosity index (PI)} = \frac{\text{Weight in kg}}{\text{Height in cubic meters}} \text{ in kg/m}^3 \quad [16]$$

$$\text{Body surface area (BSA)} = \sqrt{\frac{\text{Height (cm)} \times \text{weight (kg)}}{3600}} \text{ in m}^2 \text{ based on the Mosteller formula} \quad [17]$$

$$\text{Body mass index (BMI)} = \frac{\text{Weight in kg}}{\text{Height in square meters}} \text{ in kg/m}^2 \quad [18]$$

$$\text{Waist hip ratio (WHR)} = \frac{\text{Waist circumference in cm}}{\text{Hip circumference in cm}} \quad [19]$$

$$\text{Conicity index (CI)} = \frac{\text{waist circumference (m)}}{0.109 \sqrt{\frac{\text{weight (kg)}}{\text{height (m)}}}} \text{ in kgm}^{-3} \quad [20]$$

Blood pressure and heart rate measurements

Blood pressure was measured using a digital blood pressure machine (Scian SP-582 Digital BP Monitor, Honsun, Jiangsu, China (Mainland) as already described by Katamba et al.,[15] . Each participant was allowed to rest quietly for 5 minutes, sitting on a chair with the back supported and feet on the floor [14]. The participant was asked to remain calm and quiet as the machine began to measure automatically after pressing the start button. When the reading was complete, the monitor displayed the BP and the resting pulse rate on the digital panel [21]. Three readings were recorded per participant at 5 minutes' interval as recommend by the WHO steps surveillance guidelines for non-communicable diseases [22]. The average of the 2nd and 3rd respective BP measurements was used as the subject's BP respectively

108 **Hemodynamic parameters computations;** The computations were made using standard
109 formulae as below stated;

110 Pulse pressure (PP) = $SBP - DBP$ in mmHg [11]

111 Mean arterial pressure (MAP) = $\frac{SBP + 2DBP}{3}$ in mmHg [10]

112 Rate pressure product (RPP) = RPR in bpm $\times$ SBP in mmHg $\times 10^{-2}$ [23]

113

114 **Statistical analysis**

115 The subjects were classified into different groups using anthropometric indices such as BMI, NC
116 and WHR. On the basis of BMI, subjects were classified into 3 groups, i.e., normal (BMI =
117 18.5–24.99 kg/m²), overweight (BMI = 25–29.99 kg/m²), and obese (BMI $\geq$ 30 kg/m²) [1]. Based
118 on WHR, the subjects were classified into two groups, i.e., WHR <0.90 and WHR $\geq$ 0.90 (WHO
119 cutoff points). The NC cut-offs for boys and girls were 30.75 cm and 29.75 cm respectively [24].
120 To compare two samples of a continuous variable, an unpaired t-test was used whereas for those
121 with three categories, one-way ANOVA test was implemented. The Pearson moment correlation
122 coefficient was used to determine the correlations between anthropometric indices and the
123 hemodynamic variables parameters followed by linear regression analysis. A *p value* < 0.05 was
124 considered to be statistically significant. The analysis of data was done by Stata software version
125 13.0 (College Station, Texas, USA).

126 **Results**

127 **Physical characteristics of study participants by sex**

128 The mean age of the participants was 14.9 $\pm$ 1.6 years, the SBP and DBP of the participants were
129 111.9 $\pm$ 8.9 mmHg which differed significantly by sex and 65.0 $\pm$ 7.4 mmHg respectively. The
130 mean RPR was 75.0 $\pm$ 8.1bpm. The mean RPP was 84.1 $\pm$ 12.8 mmHg**bp**m, while the mean PP was
131 46.9 $\pm$ 7.9mmHg as showed in table 1.

132 **Comparison of hemodynamic variables based on BMI categories**

Table 2 shows the comparison hemodynamic parameters across the BMI categories. Data analysis was done by one-way ANOVA. There was a significant difference in PP and systolic BP between the different BMI categories of the subjects. However, there was no significant difference between the RPP and MAP for the respective BMI categories.

Comparison of hemodynamic variables-based neck circumference and waist hip ratio

Table 3 depicts the effect of NC and WHR on hemodynamic parameters. Comparison analysis was done using the unpaired *t*-test. The subjects of normal NC cm showed significant difference in all hemodynamic parameters with those of high NC ($p < 0.01$). The same significant differences were found between the WHR categories.

Correlation analysis

Correlation analysis of hemodynamic parameters with anthropometric indices was done as shown in table 4. Significant positive correlation coefficients were found between body surface area and neck circumference with RPP, MAP and PP. However, some negative coefficients were found for WHR and PI.

Step wise regression analysis

The multiple and stepwise regression analysis for of anthropometric indices in relation to hemodynamic parameters is shown in table 5. BMI alone predicted only less than 3% of the hemodynamic parameters which was only significant for SBP, RPR, MAP and PP. in step 3, combining BMI, WHR and CI significantly predicted all the hemodynamic parameters. Finally, in step 4, combining all the anthropometric indices predicted up to 99.8% of all the hemodynamic parameters.

Regression equations for different stages of analysis of hemodynamic parameters;

Mean arterial pressure; ¹MAP = 23.7-0.0005BMI,

$$^2MAP = 33.3-0.025BMI - 9.6WHR,$$

$$^3MAP = 34.9 - 0.010BMI - 3.77CI-8.3 WHR,$$

$$^4MAP = 7.47BSA-6.13-0.003BMI + 1.17PI+0.5CI-0.22WHR.$$

In step 1, the regression coefficient associated with BMI was -0.0005. thus, each one unit increase in BMI is associated with a -0.0005 unit increase in mean arterial pressure. The association was statistically significant. After adjusting for WHR, there was more than 10% increase in coefficient of association between BMI and MAP, showing that WHR affects the interaction between BMI and MAP. In step 4, it was further illustrated that part of the association between MAP and BMI was significantly explained by other indices such as WHR, BSA, PI and CI.

Pulse pressure; ¹PP = 20.9 + 0.059BMI,

$$^2PP = 28.0 + 0.051BMI - 8.55WHR,$$

$$^3PP = 31.6 + 0.056BMI - 4.63CI - 7.27WHR,$$

$$^4PP = 7.5BSA - 6.3 + 1.17PI + 0.5CI - 0.165WHR - 0.0019BMI.$$

In step 1 analysis of pulse pressure with BMI, the regression coefficient associated with BMI was 0.059, implying that each unit increase in BMI was significantly associated with 0.059 times increase in pulse pressure. In steps 2 and 3, there was less than 10% change after adding WHR in predicting PP, implying that WHR doesn't affect the association between BMI, WHR CI. In steps 4, 10% change was recorded (0.059 vs -0.0019), implying that adding BSA and PI to the model, significantly affected the association between BMI and PP.

Rate pressure product; ¹RPP = 24.3 - 0.007BMI,

$$^2RPP = 33.1 - 0.020BMI - 9.8WHR,$$

$$^3RPP = 35.1 - 0.012BMI - 3.38CI - 8.6WHR,$$

$$^4RPP = 7.4BSA - 6.2 + 1.2PI + 0.5CI - 0.24WHR - 0.0015BMI.$$

In step 1 analysis of rate pressure product with BMI, the regression coefficient associated with BMI was -0.007, implying that each unit increase in BMI was significantly associated with -0.007 times change in RPP. In steps 2, 3 and 4, there was greater than 10% change after adding WHR, CI, PI and BSA in predicting RPP, implying that adding WHR, CI, BSA and PI to the

model, significantly affected the association between BMI and RPP. All these indices were very useful and the coefficient remained significant and negative.

Diastolic blood pressure; ¹DBP = 25.2 – 0.02BMI,

$$^2DBP = 34.2 - 0.04BMI - 9.8WHR,$$

$$^3DBP = 36.1 - 0.03BMI - 3.3CI - 8.8WHR,$$

$$^4DBP = 7.5BSA - 6.2 + 1.17PI + 0.47CI - 0.2WHR - 0.0014BMI.$$

In step 1 analysis of diastolic BP with BMI, the regression coefficient associated with BMI was -0.02, implying that each unit increase in BMI was significantly associated with -0.02 times change in DBP. In steps 2, 3 and 4, there was greater than 10% change after adding WHR, CI, PI and BSA in predicting DBP, implying that adding WHR, CI, BSA and PI to the model, significantly affected the relationship between BMI and DBP. All these indices were very useful and the coefficient remained significant and negative.

Systolic blood pressure; ¹SBP = 20.2 + 0.03BMI,

$$^2SBP = 29.1 + 0.01BMI - 8.7WHR,$$

$$^3SBP = 31.2 + 0.03BMI - 5.0CI - 6.9WHR,$$

$$^4SBP = 7.5BSA - 6.09 - 0.003BMI + 1.17PI + 0.51CI - 0.23WHR.$$

In step 1 analysis of systolic BP with BMI, the regression coefficient associated with BMI was 0.03, implying that each unit increase in BMI was significantly associated with 0.03 times increase in SBP. In steps 2, 3 and 4, there was greater than 10% change after adding WHR, CI, PI and BSA in predicting SBP, implying that adding WHR, CI, BSA and PI to the model, significantly affected the relationship between BMI and DBP. All these indices were very useful and the coefficient remained significant and positive.

Discussion

Our findings showed weak correlations between the anthropometric indices and the hemodynamic parameters. The correlations were all positive for NC and CI. However, the PI,

BMI and WHR showed negative weak correlations with the hemodynamic parameters. In regression analysis, combination of all anthropometric indices significantly predicted the hemodynamic parameters among our adolescents with up to 99.8% of explained variability. These observations carry physiological significance as the increase in anthropometric indices results into increased stress on the cardiovascular system, as indicated by increase in hemodynamic parameters. Rate pressure product as marker of myocardial stress through surrogate indication myocardial oxygen consumption (MVO_2) increased with increase in the anthropometric indices, as was also shown by pulse pressure, mean arterial pressure and blood pressure. Our findings are in agreement with those from a study that involved 104 male young adults aged 20-25 years. The study found a positive correlation between anthropometric indices and rate pressure product [7]. Additionally, a study among primary pupils of 6-14 years found anthropometric indices such as height, weight, waist hip ratio to be significantly correlated with both blood pressure and pulse pressure [25]. The same findings were reported among secondary adolescents of 10-18 years in Gombe Nigeria [26]. Among the 397 apparently healthy men and women from Congolese in the south port city, waist circumference was found to be associated with pulse pressure and the strength of the associations varied with age, and blood pressure status [27]. In china, the simple anthropometric indices such as BMI, WC and WHR were found to be useful predictors for cardiovascular risk [28]. The same observations were reported among Brazilian adolescents [29] and in Korean women aged 40-69 years [30]. In the elderly population, it was found that higher values of anthropometric indices such as waist to height ratio and conicity index were closely related to increased diastolic BP, body fat and lipid profiles [31]. The same closely related findings were reported among the postmenopausal women in Tehran in Iran [32]. Neck circumference in children was found to show very comparable associations as those of BMI, WHR, WHtR and was closely associated cardiovascular disease risk factors among the 324 children aged 9-13 years in Greece [33]. Despite the fact majority of studies across the different age categories agree with our study findings, the following limitations are worth noting; (1) our results included only secondary school adolescents and hence may not be generalized across all adolescents in the general public, (2) the sample size was small to draw very valid conclusions and hence this calls for a larger national wide survey, (3) being a cross sectional study, no information on causality was obtained.

Conclusion

240 A positive relationship between the anthropometric indices and hemodynamic parameters was
241 found in general. All anthropometric indices combined predict the hemodynamic parameters
242 better than a single index of adiposity.

243 **Declarations**

244 **Ethical approval and consent to participate**

245 This being part of larger cross-sectional study among secondary school adolescents of 12-19
246 years, the ethical issues were reported in detail by Katamba et al [15]. Briefly, approval was
247 obtained from the Mbarara university research ethics committee ((IRB No. 18/03-18). The
248 adolescents freely assented (12-17 years), and their class teachers provided written consent on
249 their behalf.

250 **Consent for publication**

251 Not applicable

252 **Availability of data and materials**

253 The dataset is available on request from the corresponding author

254 **Competing interests**

255 The authors declare no conflict of interest.

256 **Funding**

257 The study received no external funding.

258 **Author contributions**

259 GK: Conceptualization of work & its realization, wrote the manuscript, checked the references,
260 compiled the literature sources, data collection, statistical analysis, and interpretation of data, and
261 wrote the manuscript and is the corresponding author. AN and FM: helped in the
262 conceptualization of the work, helped in statistical and data analysis, support to data collection.
263 AM and MAK: Proof read the manuscript and searched for literature. All authors read the final
264 copy of the manuscript

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267 participated in the study.

268 **Abbreviations**

269 ANOVA: analysis of variance

270 BMI: body mass index

271 BP: blood pressure

272 BSA: body surface area

273 CI: conicity index

274 DBP: diastolic blood pressure

275 HC: hip circumference

276 Ht: height

277 MAP: mean arterial pressure

278 NC: neck circumference

279 PI: ponderosity index

280 PP: pulse pressure

281 RPP: rate pressure product

282 RPR: resting pulse rate

283 SBP: systolic blood pressure

284 SD: standard deviation

285 SE: standard error

286 WC: waist circumference

287 WHO: world health organization

288 WHR: waist hip ratio

289 Wt: weight

290 **Acknowledgements**

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367

368 Table 1 showing physical characteristics of the participants by compared by sex

Variable	Male (n=173)	Female (n=312)	p-value	Total (n=485)
	Mean±SD	Mean±SD		Mean±SD
Age (years)	14.5±1.5	15.1±1.5	<0.01	14.9±1.6
Ht (cm)	157.2±7.8	156.9±7.4	0.620	156.9±7.6
Wt (kg)	55.0±7.3	60.2±7.6	<0.01	69.1±6.8
WC (cm)	67.6±6.3	69.9±6.9	<0.01	69.1±6.8
NC (cm)	29.7±2.5	29.8±1.6	0.368	29.8±1.9
HC (cm)	79.8± 8.4	93.3±11.1	<0.01	88.5±12.1
BMI (kgm ⁻²)	22.3±2.9	24.5±2.3	<0.01	23.7±2.8
WHR	0.85±0.06	0.75±0.06	<0.01	0.79 ±0.08
PI (kgm ⁻³)	14.2 ±2.2	15.6±1.8	<0.01	15.1± 2.1
BSA (m ²)	1.55±0.12	1.6±0.13	<0.01	1.6 ±0.13
CI (kgm ⁻³)	1.05±0.09	1.04±0.08	0.072	1.04±0.08
RPR (bpm)	73.6±7.5	75.8±8.4	0.005	75.0±8.1
SBP (mmHg)	109.6±10.9	113.2±7.3	<0.01	111.9 ±8.9
DBP (mmHg)	64.3±6.9	65.4±7.6	0.123	65.0±7.4
RPP (mmHg bpm)	80.8±11.9	86.0±12.9	<0.01	84.1±12.8
MAP (mmHg)	79.4±7.5	81.3±6.6	<0.01	80.6±6.9
PP (mmHg)	45.3±8.6	47.8±7.4	<0.01	46.9±7.9

369 SD: standard deviation,

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Table 2: Comparison of hemodynamic variables between normal, overweight and obese BMI subjects

Variables	Normal (n=320)	Overweight (n=161)	Obese (n=4)	p-value
DBP (mmHg)	65.1±7.6	64.8±6.9	68±10.4	0.689
SBP (mmHg)	111.1±7.9	113.6±7.0	113±36.7	0.010
RPR (mmHg)	75.3±8.7	74.6±6.8	71.5±6.7	0.456
RPP (mmHg bpm)	83.8±13.2	84.9 ± 11.3	82.6 ±31.8	0.604
MAP (mmHg)	80.4 ±7.2	81.1 ±6.3	83 ±17.2	0.444
PP (mmHg)	46 ±7.9	48.8 ±6.4	45 ±32.1	0.001

Data expressed in mean±SD form. Statistical test was one-way ANOVA. n=Number of subjects, SD=Standard deviation

Table 3: Comparison of hemodynamic variables based on neck circumference and waist hip ratio categories

Variables	Neck circumference (cm)			Waist hip ratio		
	Normal (n=265)	High (n=220)	p	Normal (n=374)	High (n=111)	p
DBP (bpm)	63.4±0.4	66.9±0.5	<0.01	65.6±0.4	62.0±0.5	<0.01
SBP (bpm)	108.8±0.5	115.7±0.6	<0.01	112.9±0.5	108±0.7	<0.01
RPR (bpm)	74.1±0.5	76.1 ±0.5	<0.01	75.7±0.4	72.7±0.6	<0.01
RPP (mmHg bpm)	80.7 ±12.0	88.2± 12.5	<0.01	85.6±13.1	79.1± 10.0	<0.01
MAP (mmHg)	78.5 ±6.0	83.2 ±7.2	<0.01	81.4 ± 7.2	78.1 ±5.5	<0.01
PP (mmHg)	45.3 ± 7.6	48.8 ±7.9	<0.01	47.3 ±8.5	45.8 ±5.6	0.041

Data expressed in mean±SD form. Statistical test was unpaired t-test, n=Number of subjects, SD=Standard deviation

Table 4: Correlation between anthropometric indices and hemodynamic parameters

Variable	NC	BMI	WHR	PI	BSA	CI
SBP (mmHg)	0.44**	0.10*	-0.24**	-0.04	0.39**	0.25**
DBP (mmHg)	0.25**	-0.06	-0.19**	-0.14**	0.18**	0.21**
RPR bpm)	0.11**	-0.14**	-0.15**	-0.16**	-0.01	0.22**
RPP (mmHg bpm)	0.32**	-0.03	-0.23**	-0.12**	0.21**	0.28**
MAP (mmHg)	0.36**	-0.001	-0.24**	-0.12**	0.30**	0.26**
PP (mmHg)	0.27**	0.17*	-0.09*	0.09*	0.27**	0.08

*p<0.05, **p<0.01

Table 5: Stepwise analysis showing changes in multiple regression coefficient of determination (R^2) with addition of different anthropometric indices

Analysis	¹ BMI			² BMI+WHR			³ BMI+WHR+CI			⁴ BMI+WHR+CI+PI+BSA		
	R ²	SE	F	R ²	SE	F	R ²	SE	F	R ²	SE	F
DBP(mmHg)	0.004	0.017	1.88	0.076	0.017	19.7**	0.084	0.017	14.7**	0.998	0.001	59358.8**
SBP(mmHg)	0.028	0.014	4.86*	0.065	0.014	16.7**	0.085	0.047	14.8**	0.998	0.001	61411.7*
RPR(bpm)	0.020	0.015	9.88**	0.095	0.015	25.4**	0.101	0.015	18.0**	0.998	0.001	59250.8**
RPP(mmHg bpm)	0.001	0.009	0.50	0.071	0.009	18.5**	0.080	0.010	13.9**	0.998	0.000	60424.3**
MAP(mmHg)	0.000	1.455	0.00**	0.067	2.152	17.3**	0.078	2.252	13.6**	0.998	0.126	60220.4**
PP(mmHg)	0.029	0.739	14.3**	0.084	1.495	22.2**	0.103	1.868	18.4**	0.998	0.115	59950.6**

*p<0.05, **p<0.01; SE; Standard error, R; coefficient of determination, F;