

PREDICTING POST-MORTEM INTERVAL OF PORCINE REMAINS IN CHOBA, SOUTHERN NIGERIA USING ACCUMULATED DEGREE DAYS AND TOTAL BODY SCORE

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ABSTRACT

Background: Accurate post-mortem interval (PMI) estimation is fundamental to death investigations, yet forensic models from temperate regions often fail in tropical climates. This study evaluated the reliability of accumulated degree days (ADD) and total body score (TBS) for PMI estimation in the distinct seasonal environment of Choba, southern Nigeria. **Methods:** We monitored the decomposition of six porcine carcasses as human analogues across dry and rainy seasons. A regionally adapted Total Body Score system was applied daily. Ambient temperature data were collected to calculate ADD. Seasonal predictive models for PMI were generated using multiple regression analysis. **Results:** During the dry season, both ADD and TBS strongly predicted PMI, forming a robust model ($R^2 = 0.863$). In the rainy season, despite a high overall correlation, neither variable was a significant independent predictor, although the model explained substantial variance ($R^2 = 0.916$). **Conclusions:** While ADD and TBS are effective for PMI estimation in dry tropical conditions, their predictive utility is significantly confounded by wet season factors like rainfall and humidity. This underscores an urgent need for season-specific forensic models in tropical West Africa to improve investigative accuracy.

Keywords: Body scoring techniques, Environmental taphonomy, Forensic decomposition, Thermal summation models, Tropical climate forensics.

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INTRODUCTION

Owing to the decompositional changes that take place in a body, the assessment of the post-mortem interval (PMI) is used in forensic taphonomy to determine a deceased organism's time of death [1, 2]. In line with similar studies, the sequential processes of human or animal decomposition are represented by stages of slow degradation in appearance, from the fresh stage to bloated stage, followed by an active, advanced decay and to skeletonization stage [3-5]. Multiple forensic research studies have shed light on a few components that contribute to the autolytic and putrefactive alterations that occur in corpses [6-12]. Temperature has been determined to contribute more to the process of decomposition than other factors, and it is used to estimate the period since the death in the form of accumulated degree days (ADD) or the sum of temperature over time [13].

ADD is a quantitative representation of the thermal energy that accumulates during decomposition and is required for biochemical processes. It combines the elements of temperature and time. The use of ADD makes it attainable to categorize the impact of temperature, enabling studies to compare their decompositional processes between various geographical regions [11]. Environmental temperature has an impact on the body's chemical and metabolic processes after death, affecting both the decomposition and entomological colonization. Meygesi and colleagues created one of the best-known morphological techniques that have been used frequently by researchers worldwide to estimate the PMI of remains. This technique analyzed soft tissue decomposition by scoring various body regions of the deceased organism to achieve a *total body score* (TBS) over ADD [10].

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Temperature, measured in terms of ADD, was a significant determinant in Meygesi TBS system's prediction of PMI. Despite the ground-breaking research done by Meygesi and colleagues, it raised some questions, including ethical issues surrounding the use of human cadavers and the costs involved in acquiring them for research purposes, and most importantly, the neglect of some factors that are directly related to the decompositional process, such as arthropod activity, as well as potential ecological variations in different geographic regions.

Keough *et al.* [14] created an updated technique of scoring whole body decomposition based on the comprehensive investigations that were conducted using pig models to explore taphonomic events in accordance with the body scoring method of Meygesi and colleagues. According to Keough *et al.* [14], pig models were preferred as human subject equivalents for the corpse decomposition study. Pigs exhibit an omnivorous mode of feeding, which makes them share similar gastrointestinal tract morphologies with humans. Also, pigs and humans share many similarities in terms of some organ systems, including cardiovascular and respiratory systems [15-17].

The rate at which abandoned human remains are found in remote locations such as bushes, woodlands, and other terrestrial habitats in the southern regions of Nigeria is disturbing [18]. Oghenemavwe *et al.* [19] reported that this region has a history of crimes related to illegal oil theft, which has resulted in kidnapping, discontent among the local militia, and man-made disasters like oil explosions. Sometimes, security agencies ignore or fail to adequately investigate deaths that may be related to some of these catastrophes. Most local medical examiners focus less on the time of death of the deceased and instead on the cause of death of these victims [20]. This is because there is scarce information on conventional estimation model for PMI in this region of Nigeria. As a result, the study's objectives were to assess the decomposition of pigs in rainy and dry season in Choba, Nigeria and create local, seasonally appropriate regression equations. Through this investigation, more accurate PMI estimations of uncovered remains in this region will be possible.

METHODS

This study was an observational and descriptive design study that took place during the dry season (27 December 2023 to 3 February 2024) and wet season (3rd to 18th of April 2024). Six healthy pigs (*Sus scrofa domestica*) weighing between 50 – 60 kg were used as human proxies for the study. They were obtained from the Livestock Unit, Research and Teaching Farm of the Faculty of Agriculture, University of Port Harcourt, and were confirmed to be healthy by a veterinary doctor. The pigs were

euthanized with 105 ml of sodium pentobarbiturate each, which was administered intramuscularly. Death was confirmed by cessation of heartbeat and pulse. The exact date and time of death were then recorded. The pigs were taken to the study site for above-ground decomposition assessment. The study was carried out at the Anthropological / Burial Farm of the Department of Anatomy, Faculty of Basic Medical Sciences, College of Health Sciences, University of Port Harcourt. Upon arrival at the burial site, each pig was allocated a number to ensure proper observation. Three of the pigs were used for the dry season while three were used for the rainy season.

Method of total body score determination

This study used the amended method of Megyesi *et al.* [10] for pig models, which was developed by Keough *et al.* [14]. This was used to score decomposition based on the morphological appearance of three body regions: head and neck, trunk, and limbs (Figure 1). The stages of decomposition were first assessed qualitatively and then converted into quantitative scores from these three regions of the body. The allotted point value of each region was then added to determine the TBS, which represents the overall stage of decomposition of each pig from a minimum of 3 to a maximum of 35 points [14].

Method of measuring ambient temperature and calculating ADD

The daily ambient temperature was measured onsite with a digital thermo-hygrometer. The study adopted the method documented by Onyejike *et al.* [21] for measuring daily ambient temperature. The thermo-hygrometer was placed in a room, and the wire plug (containing the mercury knob) extended outside the room window while ensuring that the liquid crystal display (LCD) of the equipment was placed away from sun rays. The temperature scale was set at degrees Celsius. The time was set on the equipment to GMT+1 to ensure accuracy in documenting the readings. To calculate ADD, average daily temperatures were added from the date of placement to the time of total skeletonization or dryness of pig remains. For example, if the first day of the study recorded an average temperature of 28 degrees centigrade, the ADD for that day is 28 ADD. However, if the mean temperature of the second day of the same study period is 27 ADD, the ADD for the second day will be (28 + 27) ADD, which equals 56 ADD.

Statistical analysis

Data collected were analyzed using the Statistical Package for Social Sciences (SPSS) IBM version 25.0. Multiple regression equations were generated from the study data to develop predictive models for both seasons. The *p*-value was considered significance at less or equal to 0.05 ($p \leq 0.05$).

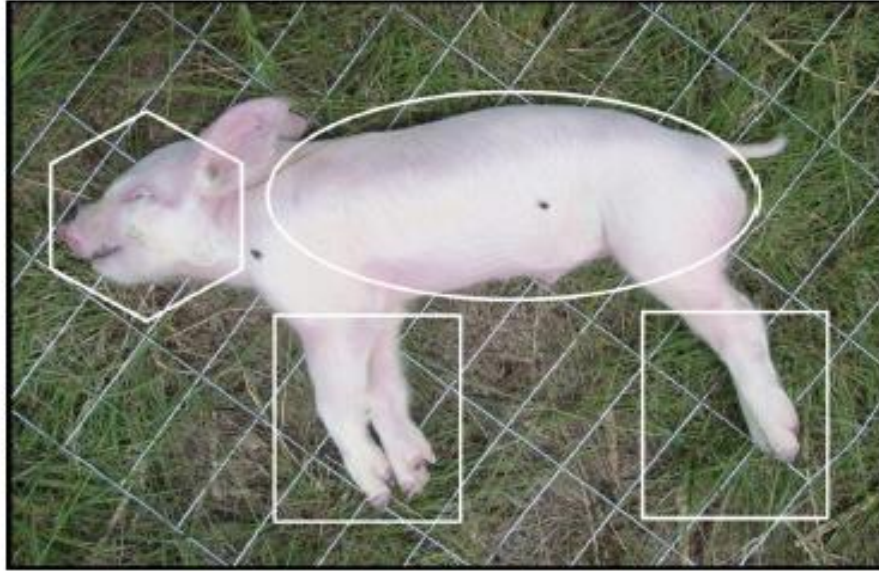


Figure 1: A pig carcass showing the body regions to be scored (represented in the form of shapes) to calculate TBS. (Adopted from Sutherland *et al.*, 2013)



Figure 2: Documented stages of decomposition for dry season (A) Fresh stage (B) Bloat (early) stage (C) Active decay stage (D) Advanced decay stage.

RESULTS

The decomposition of the pigs during the wet season progressed from fresh, to bloat, active decay, advanced decay and skeletonization stages whereas that of the dry season did not reach skeletonization (Fig. 2). In the dry season, the porcine models did

not reach full skeletonization because they were mummified by day 22 with a TBS of 29 and ADD of 668 (Tables 1 and 3). In the wet (rainy) season, the porcine models reached full skeletonization on day 13 with TBS of 35 and ADD of 421.6 (Tables 2 and 4).

Table 1: Climate readings in dry season.

DAYS	TEMP (AM)	TEMP (PM)	Mean TEMP	ADD	HUM (AM)	HUM (PM)	Mean HUM	PREP (mm)
1	27.8	33.9	30.85	30.85	30	21	25.5	0
2	26.8	32	29.4	60.25	29	29	29	0
3	27.5	32.9	30.2	90.45	48	25	36.5	0
4	28.6	32.9	30.75	121.2	52	44	48	0
5	28.9	33.9	31.4	152.6	54	42	48	0
6	32.9	35.2	34.05	186.65	48	40	44	0
7	27.7	36.4	32.05	218.7	59	20	39.5	0
8	29	35	32	250.7	60	25	42.5	0.1
9	27.7	33.9	30.8	281.5	58	28	43	0
10	25.7	35	30.35	311.85	53	21	37	0
11	25.9	35.5	30.7	342.55	51	23	37	0
12	25.9	31.8	28.85	371.4	61	46	53.5	0
13	27.7	30.5	29.1	400.5	61	58	59.5	0.13
14	27.6	35	31.3	431.8	63	29	46	0
15	25.9	32.9	29.4	461.2	63	48	55.5	0.1
16	26.6	33.9	30.25	491.45	63	45	54	0
17	27.5	32.9	30.2	521.65	62	48	55	0
18	26.6	32.9	29.75	551.4	66	53	59.5	0.15
19	26.8	31.8	29.3	580.7	68	52	60	0.14
20	28	25.9	26.95	607.65	68	62	65	0.2
21	26.4	32.9	29.65	637.3	70	54	62	0
22	28.6	32.8	30.7	668	63	53	58	0.23
23	26.8	31.8	29.3	697.3	64	60	62	0.47
24	28.6	30.7	29.65	726.95	65	61	63	0.9
25	26.8	28.6	27.7	754.65	65	53	59	0.2
26	25.9	31	28.45	783.1	69	57	63	0.88
27	25.9	31.8	28.85	811.95	71	59	65	0.45
28	24.2	30.5	27.35	839.3	72	60	66	0.58
29	26.4	32.9	29.65	868.95	58	49	53.5	0.37
30	29.5	30.5	30	898.95	59	58	58.5	0.1
31	28.3	32.9	30.6	929.55	66	51	58.5	0.1
32	26.8	30.8	28.8	958.35	65	55	60	0.1
33	29.6	31.5	30.55	988.9	63	57	60	0.5
34	25.6	30.5	28.05	1016.95	71	60	65.5	0.1
35	26.7	28.6	27.65	1044.6	66	52	59	0.44
36	26.8	31.8	29.3	1073.9	59	52	55.5	0.1
37	29.5	30.5	30	1103.9	62	60	61	0.2
38	28.6	33.3	30.95	1134.85	64	50	57	0.3
39	29.5	31.8	30.65	1165.5	61	59	60	0.3
40	28.6	30.5	29.55	1195.05	61	36	48.5	0

Temp: Atmospheric temperature, AM: Ante-meridian, PM: post-meridian, ADD: accumulated degree days, HUM: Humidity, Prep: Precipitation (rainfall)

Table 2: Climate readings in wet season.

DAY S	TEMP (AM)	TEMP (PM)	Mean TEMP	ADDS	HUM (AM)	HUM (PM)	Mean HUM	PREP (mm)
1	28.1	32.6	30.35	30.35	67	60	63.5	0.3
2	27.7	33.9	30.8	61.15	64	50	57	0.1
3	27.4	30.5	28.95	90.1	71	56	63.5	0.46
4	26.8	31.8	29.3	119.4	58	56	57	0.35
5	28.6	28.6	28.6	148	63	61	62	0.5
6	28.7	30	29.35	177.35	63	55	59	0.2
7	27.7	32.9	30.3	207.65	62	60	61	8.6
8	29.9	32.6	31.25	238.9	60	57	58.5	0.25
9	28.3	31.7	30	298.9	66	54	60	0.3
10	28.6	33.4	31	329.9	63	62	62.5	0.2
11	29.3	33.1	31.2	361.1	59	56	57.5	0.37
12	27.6	32.5	30.05	391.15	68	62	65	0.43
13	28.1	32.8	30.45	421.6	66	61	63.5	0
14	28.7	31.9	30.3	451.9	65	58	61.5	0.3
15	27.8	30.6	29.2	481.1	70	63	66.5	0

Temp: Atmospheric temperature, AM: Ante-meridian, PM: post-meridian, ADD: accumulated degree days, HUM: Humidity, Prep: Precipitation (rainfall)

For the dry season, the regression coefficient of the relationships between PMI, ADD and the mean TBS were statistically significant ($R = 0.929$, $p = 0.001$). **Tables 5 – 7** show the regression summary model, ANOVA and coefficients of regression model for the predicting PMI from the natural logarithm of ADD and TBS. As depicted in the model summary, the overall regression was statistically significant ($R^2 = 0.863$, $F(2, 37) = 116.773$, $p = 0.001$). ADD significantly predicted PMI ($\beta = 1.909$, $p = 0.001$). Also, TBS significantly predicted PMI ($\beta = -1.019$, $p = 0.003$). The fitted regression model for the dry season was expressed as:

$$PMI = -101.289 + 59.428 (\ln ADD) - 1.597 (TBS)$$

Where, $\ln ADD$ was denoted as the logarithmic form of accumulated degree days.

For the rainy season, the regression coefficient of the relationships between PMI, ADD and the mean TBS were statistically significant ($R = 0.957$, $p = 0.001$). **Tables 8 – 10** show the regression summary model, ANOVA and coefficients of the regression model for predicting the PMI from the natural logarithm of ADD and TBS. As depicted in the model summary, the overall regression was statistically significant ($R^2 = 0.916$, $F(2, 12) = 65.430$, $p = 0.001$). ADD did not significantly predict PMI ($\beta = 0.406$, $p > 0.05$). and neither did TBS ($\beta = 0.558$, $p = 0.13$). The fitted

regression model for the wet season was expressed as:

$$PMI = -8.851 + 5.154 (\ln ADD) + 0.210 (TBS)$$

Where, $\ln ADD$ was denoted as the logarithmic form of accumulated degree days.

DISCUSSION

In predicting PMI across several geographies, ambient temperature is a good predictor for decomposition rate [22-25]. In addition, variables like seasonality, elevation, geographic area, depth of burial, availability of water or moisture, moving air, vegetation, and the presence of clothing also have an impact on decomposition [26]. Studies have noted that ambient temperature, measured in ADD, determines the rate of total body decomposition and how it affects PMI estimation [27-30]. There is overwhelming evidence that thermal differences in geographical regions correlate with the rate of decomposition of remains [11]. This study examined the utility of ADD and TBS in predicting PMI of porcine remains during the rainy and dry seasons in Choba, southern Nigeria. The results support the applicability of temperature-based morphological decomposition metrics as predictive tools for PMI estimation in tropical environments (**Table 11**), albeit with notable seasonal disparities in model performance and predictor significance.

Table 3: TBS readings for pigs in dry season.

Day	TBS Pig 1	TBS Pig 2	TBS Pig 3
1	3	3	3
2	3	4	4
3	7	6	6
4	8	8	7
5	13	13	12
6	15	16	15
7	17	18	16
8	18	19	18
9	19	22	19
10	19	22	20
11	19	24	22
12	21	24	22
13	21	25	23
14	21	25	25
15	24	25	25
16	24	25	25
17	24	25	25
18	24	25	26
19	24	27	27
20	24	28	27
21	25	28	27
22	27	29	29
23	28	29	29
24	28	29	29
25	28	29	29
26	28	29	29
27	28	29	29
28	29	29	29
29	29	29	29
30	29	29	29
31	29	29	29
32	29	29	29
33	29	29	29
34	29	29	29
35	29	29	29
36	29	29	29
37	29	29	29
38	29	29	29
39	29	29	29
40	29	29	29

TBS: total body score

Table 4: TBS readings for wet season.

Day	TBS Pig 1	TBS Pig 2	TBS Pig 3
1	3	3	3
2	5	5	6
3	9	10	8
4	12	13	11
5	16	16	15
6	18	19	19
7	23	25	23
8	29	30	29
9	32	33	32
10	32	33	32
11	34	34	34
12	34	34	34
13	35	35	35
14	35	35	35
15	35	35	35

TBS: total body score

Table 5: Regression Model Summary for PMI using TBS and lnADD.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
	0.929 ^a	0.863	0.856	4.439
a. Predictors: (Constant), TBS, lnADD				

TBS: total body score, PMI: post-mortem interval, lnADD: logarithm of accumulated degree days

Table 6: ANOVA of regression model for PMI using TBS and lnADD.

Model		Sum of Squares	Df	Mean Square	F	Sig.
	Regression	4601.069	2	2300.534	116.773	0.000 ^b
	Residual	728.931	37	19.701		
	Total	5330.000	39			
b. Predictors: (Constant), TBS, lnADD						

TBS: total body score, PMI: post-mortem interval, lnADD: logarithm of accumulated degree days

Table 7: Coefficients of regression model for PMI using TBS and lnADD.

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
	(Constant)	-101.289	15.380		-6.586	0.000
	lnADD	59.428	10.008	1.909	5.938	0.000
	TBS	-1.597	0.504	-1.019	-3.168	0.003

TBS: total body score, PMI: post-mortem interval, lnADD: logarithm of accumulated degree days

Table 8. Regression Model Summary for PMI using TBS and lnADD.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
	0.957 ^a	0.916	0.902	1.39998
a. Predictors: (Constant), TBS, lnADD				

TBS: total body score, PMI: post-mortem interval, lnADD: logarithm of accumulated degree days

Table 9: ANOVA of regression model for PMI using TBS and lnADD.

Model		Sum of Squares	df	Mean Square	F	Sig.
	Regression	256.481	2	128.240	65.430	0.000 ^b
	Residual	23.519	12	1.960		
	Total	280.000	14			

b. Predictors: (Constant), TBS, lnADD

TBS: total body score, PMI: post-mortem interval, lnADD: logarithm of accumulated degree days

Table 10: Coefficients of regression model for PMI using TBS and lnADD.

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
	(Constant)	-8.851	7.118		-1.244	0.237
	lnADD	5.154	4.366	0.406	1.181	0.261
	TBS	0.210	0.129	0.558	1.624	0.130

TBS: total body score, PMI: post-mortem interval, lnADD: logarithm of accumulated degree days

Table 11: Summary of Validation results for PMI, ADD and TBS at both seasons.

PIG	Season	Actual PMI	Estimated PMI	Actual TBS	Estimated TBS	Actual ADD	Estimated ADDs
Pig 1	Dry	4	4.87	8	11.62	121.2	97.05
Pig 2	Dry	17	21.84	24	27.05	521.65	431.52
Pig 1	Rainy	6	6.52	18	15.52	177.35	140.61
Pig 3	Rainy	14	12.18	35	43.65	451.9	1018.59

TBS: total body score, PMI: post-mortem interval, ADD: accumulated degree days

The decomposition sequence -- progressing from fresh to bloat, active decay, advanced decay, and skeletonization was consistent with established taphonomic trajectories observed in similar climate zones [7, 10, 31]. This temporal pattern confirms that tropical climatic conditions (rainy season) in Choba permit rapid tissue breakdown as evidenced in the report by Onyejike et al [31] in similar climate of southern Nigeria. Consequently, the progression through distinct decomposition stages occurs over a shorter period. This acceleration can compress the effective window for PMI estimation when compared to temperate zones, as morphological changes used for scoring (TBS) evolve more rapidly and may reach a plateau earlier. In exceptionally dry conditions as evidenced in our study, the pig carcasses may undergo mummification - a process in which the skin and tissues desiccate and are preserved rather than decomposing rapidly [32, 33]. High Temperature, low humidity, low precipitation are factors that have been reported to influence mummification in southern Nigeria [34], and this was reported in our findings (Table 1). Among these, temperature plays a considerable role by affecting the rate of decomposition and desiccation of the remains.

In the dry season, both ADD and TBS were strongly correlated with PMI ($R = 0.929$, $p = 0.001$), and the combined regression model demonstrated excellent predictive power ($R^2 = 0.863$). Importantly, both lnADD ($\beta = 1.909$) and TBS ($\beta = -1.019$) were significant predictors ($p < 0.05$), indicating that increasing thermal input (as captured by ADD) and

decreasing TBS (indicative of tissue loss over time) jointly enhance temporal resolution in estimating PMI. The negative coefficient for TBS may initially appear counterintuitive, given that decomposition advances with time. However, in the logarithmic model context, this likely reflects a statistical correction for multicollinearity, given the strong covariation between TBS and ADD.

Conversely, in the rainy season, although the correlation between PMI, ADD, and TBS remained robust ($R = 0.957$), the regression model explained more variance ($R^2 = 0.916$) yet yielded no statistically significant predictors. This suggests multivariate instability in predictor contributions under high moisture conditions. Neither lnADD ($\beta = 0.406$, $p > 0.05$) nor TBS ($\beta = 0.558$, $p = 0.13$) significantly explained variance in PMI during this period. These findings point to a seasonal decoupling of thermal and morphological predictors from the actual decomposition timeline.

The discrepancy between the two seasons may be attributable to a combination of environmental and biological confounders. During the rainy season, elevated humidity and frequent precipitation likely obscure the thermal signal captured by ADD. Moisture saturates the microenvironment and may buffer surface remains from ambient temperature fluctuations, disrupting the assumed linearity between temperature and decomposition rate [35]. Moreover, rainfall may accelerate tissue liquefaction while also impeding insect activity – an essential driver of external decomposition progression measurable through TBS. This decoupling may

introduce noise into regression models, undermining the predictive stability of TBS under wet conditions. These findings echo recent calls for regionally calibrated forensic models that account for local microclimatic influences and decomposition modifiers [16, 36, 34]. In high-humidity tropical contexts like southern Nigeria, the predictive utility of thermal summation models (e.g., ADD) may be seasonally constrained. Thus, while the dry season model provides a statistically sound regression equation for PMI estimation, the rainy season model, should be interpreted with caution due to the non-significance of both predictors.

Importantly, the high R^2 values in both models indicate that TBS and ADD still track decomposition well over time, even if their individual contributions vary by season. These findings reinforce the value of a multi-factorial approach to PMI estimation, whereby climatic variables, decomposition scoring, and contextual factors such as soil type, scavenger access, and rainfall patterns are jointly considered. A recent study in the southeastern region of Nigeria by Onyejike et al. [2] noted a high degree of correlation in the prediction model for estimating PMI with a degree of accuracy of 97.2% using multiple variables such TBS, mean atmospheric temperature, precipitation, humidity, soil temperature and soil pH. This report corroborates our findings on the use of TBS and ADD to predict PMI, especially during the dry season.

CONCLUSIONS

This study evaluated the predictive efficacy of accumulated degree days (ADD) and total body score (TBS) for post-mortem interval (PMI) estimation using a porcine model in the tropical environment of Choba, southern Nigeria. The findings affirm that local decomposition progression follows the canonical stages across both dry and

rainy seasons. However, the reliability of predictive models based on ADD and TBS varies seasonally. During the dry season, both lnADD and TBS significantly predicted PMI, with the model explaining a substantial proportion of variance ($R^2 = 0.863$), confirming the value of thermal and morphological indicators in PMI estimation under relatively stable climatic conditions. In contrast, during the rainy season, although the overall model retained a high R^2 value (0.916), neither predictor reached statistical significance, suggesting that environmental factors such as high humidity, precipitation, and microbial buffering disrupt the temperature-decomposition relationship.

These results underscore the necessity for season-specific decomposition models in tropical forensic contexts and advocate for integrative frameworks that combine temperature, morphological, entomological, and biochemical markers. This study contributes novel data toward the development of regionally tailored forensic taphonomic baselines, supporting improved accuracy in medico-legal death investigations across sub-Saharan Africa.

Authors Contribution: methodology, OMA, DNO; analysis, OMA; supervision and resources, DNO, JSH; review and editing, OMA, DNO.

Ethics approval

Ethical approval was obtained from the University Research Ethics Committee of the University of Port Harcourt. The ethical approval number is UPH/CEREMAD/REC/MM83/025 dated 14th December 2021.

Consent for Publication:

All the authors consent to participate in the review process of this manuscript.

Conflict of interest statement

Authors have no conflict of interests to state.

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