

Developing a novel sodium-based calorie model with non-parametric regression: A case study with non-normally distributed data

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ABSTRACT

Background

This paper introduces a comprehensive approach to modelling calories and sodium intake using non-parametric regression, bootstrap resampling, and data splitting into training and testing sets, aiming to enhance precision in understanding their intricate relationship and inform evidence-based strategies for optimal health promotion.

Objective

This study seeks to build a non-parametric regression model that links Sodium levels with Calorie levels, to enhance prediction accuracy for Calorie levels in the analyzed patient population by employing diagnostic capabilities.

Materials and Methods

In cases where the linear regression assumption is not met, the resulting model may exhibit biased estimates. To address this limitation, a non-parametric regression model is introduced in this study, incorporating an enhanced bootstrap method to optimize the model estimation. Specifically, the study utilizes the robust estimator known as the Kendall-Theil Sen Siegel slope to assess the regression line's slope, mitigating the impact of outliers or extreme values. This method facilitates a flexible exploration of the relationship between variables, eliminating the need for specific parametric assumptions. The dataset was divided into training and testing groups using this method. The training dataset will be utilized for model development, whereas the testing dataset will be employed to validate the model.

Result

The statistical analysis conducted with R revealed that the non-parametric regression approach demonstrated enhanced predictive capabilities, particularly in cases where the data did not satisfy the normality assumption. The resulting model is as follows: $\text{Calories} = -182.2940b + 1.8361s(\text{Sodium})$. The R-squared values for the training and testing sets are 74.2% and 70.0%, respectively. This suggests that the developed methodology has exhibited an exceptional level of performance.

Conclusion

The conclusion of the study underscores the higher performance of the hybrid model approach utilized.

Keywords

Non-parametric regression model; Kendall-Theil Sen Siegel; Calories; Sodium

INTRODUCTION

Calories and sodium play vital roles in the body when taken in suitable quantities. Calories act as the essential fuel for the body, enabling crucial functions, metabolism, and physical activity¹. With vital nutrients, calories play a significant role in promoting overall health and wellness. Sodium is essential for keeping fluid balance, aiding nerve function, and helping to maintain electrolyte and acid-base balance². Calories and sodium play beneficial roles in our body, highlighting the significance of a balanced and mindful approach to eating. However, balance is essential because excessive calories or sodium can lead to health issues such as high blood pressure or weight gain. A diverse, wholesome diet and being mindful of portion sizes are the most effective approaches to attain harmony and enhance your overall health and well-being^{3,4}. Three, four. Individuals have unique dietary requirements, and consulting with healthcare professionals or certified nutritionists can provide tailored guidance that aligns with our health conditions and aspirations⁵.

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The relationship between sodium and calories in nutrition is intricate, influenced by the composition of foods, personal dietary choices, and various health considerations⁶. The two main dietary components, salt, and calories, each have specific functions in bodily functions. Foods that are processed and packaged, which are frequently linked to greater calorie counts, frequently have higher sodium content^{3,4,7}. This phenomenon is especially noticeable in ready-to-eat meals, snacks, and convenience foods where sodium is added to improve flavor and preserve food. One of the main ingredients in table salt, sodium, has a strong flavor-enhancing effect and makes food more palatable. As a result, people who have greater sodium levels may eat larger quantities, which would increase their intake of calories overall⁸. Fast food and restaurant options, which are typically known for being high in calories, also tend to add a considerable amount of sodium to one's diet. In these situations, the usage of processed and pre-prepared products frequently leads to elevated sodium and calorie content. While it's essential to recognise that not every calorie-dense food is high in salt, there is a clear connection among various food categories, particularly those that are processed or commercially made. While it's essential to recognise that not every calorie-dense food is high in salt, there is a clear connection in various food categories, particularly those that are processed or commercially made⁹.

Calories and sodium are essential components in the intricate workings of the human body. Energy, measured in calories, comes from the macronutrients found in our food: carbohydrates, proteins, and fats. The energy from these calories supports vital metabolic functions, maintaining bodily operations both at rest and during physical activity¹⁰. The balance between caloric intake and expenditure influences body weight. On the other hand, sodium, an essential electrolyte, is crucial for maintaining fluid balance, nerve function, and muscle contraction. Commonly sourced from table salt and processed foods, sodium intake is regulated by the kidneys, which excrete or retain it based on the body's needs². While sodium is vital for physiological processes, excessive intake is associated with health risks, particularly hypertension and cardiovascular diseases. Striking a balance in caloric intake and being mindful of sodium consumption is pivotal for maintaining a healthy and well-functioning human body¹¹.

Modelling calories and sodium is crucial for several reasons in the realm of nutritional science and public health¹². By employing sophisticated modelling techniques, researchers and health professionals can gain a deeper understanding of the intricate relationships between calorie and sodium intake and various health outcomes^{13, 14}. These models help identify patterns, trends, and potential correlations that might be challenging to discern through basic observation. Additionally, such models play a vital role in investigating the impact of dietary factors on conditions like obesity, cardiovascular diseases, and hypertension^{15,16,25,27}. They offer a basis for informed recommendations, supporting the creation of impactful strategies for enhancing health and preventing illness. Additionally, grasping the interplay of calorie and sodium consumption through modelling enhances personalised nutrition strategies, enabling customised dietary suggestions that align with individual health profiles. Essentially, understanding calories and sodium plays a crucial role in enhancing our grasp of nutrition, supporting public health efforts, and fostering overall wellness. Using simple non-parametric regression to model calories and sodium provides a meaningful way to grasp their effects on health¹⁷. This method allows for a flexible analysis that doesn't rely on specific assumptions about the functional form of the relationship between variables¹⁸. By employing non-parametric regression, we can capture complex patterns and variations in the data, providing a nuanced insight into how calorie and sodium intake may influence health outcomes. This approach is particularly beneficial when dealing with non-linear relationships or when the data structure is not well-defined. By embracing simplicity and flexibility, non-parametric regression enhances our understanding of the relationships between dietary factors such as calories and sodium, promoting informed choices for better health outcomes¹⁹.

MATERIALS AND METHODS

The Data

Secondary data was employed in this study (Dietetic Clinic, Hospital Pakar Universiti Sains Malaysia), with a total of forty-five individuals enrolled in the trial, and Table 1 provides a succinct overview of the data descriptions concerning the research variables.

Table 1. The data description

Variable	Description
Calories	Calories reading in kcal a day
Sodium	Sodium intake in milligrams (mg) per day

The Statistical Approach

(a) Simple Non-parametric Regression

Non-parametric regression, particularly when predicting calorie levels based on sodium, offers several advantages. In a non-parametric approach, the model doesn't assume a specific functional form for the relationship between variables, allowing for greater flexibility in capturing complex patterns²⁰. This is especially useful when the relationship between calories and sodium may not be well-described by a predefined mathematical equation. By employing non-parametric regression techniques using kernel regression methods, the model can adapt to the underlying data structure without imposing rigid assumptions²¹. This flexibility is crucial in capturing non-linearities or variations in the calorie-sodium relationship that might be overlooked by traditional parametric models. The proposed non-parametric regression model for the case is given as follows:

$$\text{Calories} = \hat{a}_0 + s(\text{Sodium}) + \hat{a}_i \quad (1)$$

where

Calories is the response variable for the i th observation

$\hat{a}_0$ is the constant / intercept

$s(\text{Sodium})$ is the non-parametric smooth function of Sodium

(b) Bootstrapping and Data Splitting

Non-parametric regression techniques, when combined with bootstrapping, can provide robust and reliable estimates of the model's performance and parameters²². Bootstrapping is a technique that involves drawing samples with replacements from the dataset multiple times to evaluate the variability and uncertainty linked to the model. By combining non-parametric regression techniques with bootstrapping and splitting data into training and testing, researchers and data scientists

can obtain more reliable estimates of the model's parameters, assess its variability, and enhance its generalizability to new data. The training set is what the model learns from, and the testing set is a separate set of data that is used to test how well it works. This helps see how well the model works with new data that it hasn't seen before.

The practice of splitting data into training and testing sets is crucial for developing robust models that generalize well to new data, helping prevent overfitting and ensuring the model's reliability in real-world applications. The practices of bootstrapping data and splitting it into training and testing sets are integral components of robust modelling methodologies. Bootstrapping, through the creation of multiple resampled datasets, plays a pivotal role in assessing the variability of model parameters and performance metrics. By drawing samples with replacements from the original data, it provides a comprehensive understanding of the model's stability and reliability. This approach facilitates the calculation of confidence intervals, aiding in the quantification of uncertainty associated with model estimates and enhancing the statistical validity of inferences. Additionally, bootstrapping serves as a valuable tool for model validation, enabling the evaluation of how well a model generalizes to different subsets of the data and identifying potential sources of bias or overfitting^{16, 22, 23}.

At the same time, separating data into training and testing sets is an important part of both testing and improving models. The separation lets you test a model's success on data it hasn't seen before, which shows how well it can work with data other than the training set²⁴. In overfitting, a model may do well on the training data but badly on new observations, this method helps find this problem. Furthermore, the testing set is instrumental in hyperparameter tuning, enabling the optimization of model configurations for enhanced performance on new, unseen data. Importantly, the separation of data into distinct training and testing sets prevents data leakage, ensuring that information from the testing set does not influence the model training and providing a more accurate assessment of the model's real-world predictive capabilities^{22, 24}. In summary, the combined practices of bootstrapping and splitting data contribute to the development of accurate, stable, and generalizable models, enhancing their utility in diverse applications.

Ethical Approval

The Human Research Ethics Committee USM (HREC) provided approval for the study under the JEPeM Code: USM/JEPeM/20090462. Rigorous protocols were adhered to in order to protect patient confidentiality and uphold their medical privacy.

Results and Discussion

In the results section, we present a detailed analysis of the findings obtained from the study conducted at the Dietetic Clinic, Hospital Universiti Sains Malaysia. The examination of data from forty-five enrolled participants offers valuable insights into the relationship between Sodium levels and Caloric intake, as investigated through the constructed non-parametric regression model. The outcomes outlined in this section contribute to a nuanced understanding of the complex interactions between dietary factors, paving the way for informed strategies aimed at optimizing health outcomes. In the beginning, an evaluation of the regression assumptions was performed to determine if a parametric or non-parametric methodology would be more appropriate for the provided situation. After conducting an assessment, it was determined that the assumptions were not fulfilled, particularly due to the identification of unstandardized residuals with a p -value below 0.05.

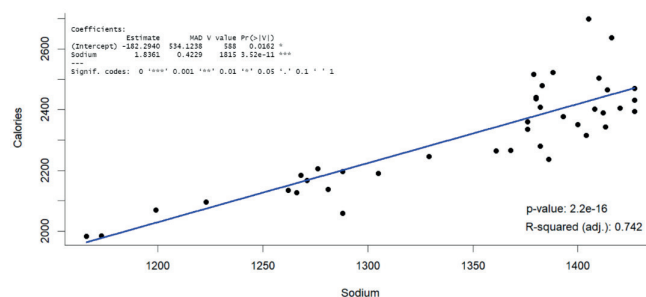


Figure 1. Non-parametric regression plot of calories and sodium

Table 2. Regression analysis of calories with sodium reading

Dependent Variable (Y)		Independent Variable (X)	Std. Coefficient Beta (β)
Calories		Constant	-182.2940
		$s(\text{Sodium Reading})$	1.8361
R ² for the Training Dataset	0.742		
R ² for the Testing Dataset	0.700		

The non-parametric regression model is given as $\text{Calories} = -182.2940 + 1.8361s(\text{Sodium})$. The intercept -182.2940 represents the estimated calorie value when the sodium level is zero, while the slope 1.8361 indicates the predicted change in Calories for a unit increase in Sodium. The positive coefficient of 1.8361 indicates that, on average, for each unit increase in sodium, the model predicts an increase of 1.8361 units in calories. In other words, as the sodium content rises, the model anticipates a corresponding increase in caloric content. This positive relationship is in line with the coefficient's sign, suggesting that higher sodium levels are associated with higher calorie counts based on the estimated model. It's important to note that the interpretation assumes the underlying data's suitability for the chosen modeling approach and the specific characteristics of the smoothing functions, $s(\text{Sodium})$.

The non-parametric aspect, denoted by $s(\text{Sodium})$, introduces flexibility by allowing for a smooth, data-driven representation of the relationship between Calories and Sodium without relying on a predetermined functional form. The specific form of the smoothing function (Sodium) is not explicitly defined in the equation, but it likely involves techniques of kernel regression approaches to capture complex patterns in the data. This model is particularly useful when the underlying relationship is non-linear or lacks a clear parametric structure. A value of R^2 is a measurement that indicates how well the model explains the variance in the variable that is being studied. On a scale that goes from 0 to 1, with 1 indicating that it is an ideal fit. In your particular situation, the fact that the model has an R^2 of 0.742 for training and 0.700 for testing indicates that it performs quite well on both datasets.

CONCLUSION

The regression equation $\text{Calories} = -182.2940 + 1.8361s(\text{Sodium})$ provides a statistical model for estimating caloric content based on sodium levels. The intercept term (-182.2940) suggests the predicted caloric value when the sodium level is zero, although the practical interpretation of this point may be limited. The positive coefficient (1.8361) associated with the smoothed sodium functions (Sodium) implies a positive association between sodium and calories. Specifically, for each unit increase in the smoothed sodium level, the model predicts a corresponding increase of 1.8361 units in calories. The inclusion of the smooth function allows

for capturing potential non-linear relationships between sodium and calories, enhancing the model's flexibility. It is crucial to note that while the model provides insights into the statistical association, establishing causal relationships would require further investigation¹⁵. Additionally, the reliability and applicability of the model depend on the appropriateness of the smoothing technique and the representativeness of the data for the underlying relationship between sodium and caloric content.

Non-parametric regression analysis serves as a viable alternative in situations where conventional regression assumptions may not hold, sample sizes are limited, or outliers significantly impact the observations, rendering the least squares method less reliable. In practical scenarios, real-world data often deviates from the idealized normal distribution, posing a challenge to traditional regression approaches. This discrepancy underscores the necessity for robust regression techniques that can accommodate non-normally distributed data and mitigate the influence of outliers. Non-parametric regression methods, by not relying on specific parametric assumptions, offer greater flexibility and resilience in handling diverse data distributions, making them particularly valuable in situations where the underlying data characteristics are less predictable or deviate from the conventional norms^{21, 24}.

Non-parametric methods make fewer assumptions about the population distribution that produces the sample than parametric methods. Parametric methods sometimes presuppose a fixed distributional form, but non-parametric methods do not²². This increases adaptation to increasingly complex datasets. This makes non-parametric techniques helpful for real-world data with unusual distributional characteristics. Thus, non-parametric methods are used when data distribution is unknown. This statistical modelling method is flexible and robust^{17, 19, 22}.

In conclusion, employing non-parametric regression models to understand the relationships between calorie and sodium intake is a powerful and flexible approach

to nutritional research. The use of non-parametric methods, such as bootstrap resampling, ensures robustness and reliability in estimating uncertainties associated with the model. By incorporating both training and testing data, this modelling approach allows for the assessment of predictive performance and generalizability, providing insights into how well the model may perform on new, unseen data. The combination of non-parametric regression, bootstrap resampling, and careful consideration of training and testing datasets enhances the precision and applicability of the models, facilitating a more comprehensive understanding of the intricate connections between dietary factors and health outcomes. This holistic approach not only contributes to refining nutritional recommendations but also strengthens the foundation for evidence-based interventions and policies aimed at promoting healthier dietary habits and mitigating health risks associated with excessive calorie and sodium consumption^{15, 17, 19, 21, 27}.

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Conflicts of Interest

The authors declare no conflict of interest.

Author's Contribution

Data gathering and idea owner of this study: WMAWA, HBS, FMMG, MNA, NAA.

Study design: WMAWA, HBS, FMMG, MNA, NAA, NFMN.

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Writing and submitting a manuscript: WMAWA, FMMG, HBS, MNA, NAA.

Editing and approval of final draft: WMAWA, HBS, FMMG, MNA, NAA, NFMN.

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