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Predictive Modelling of CKD Risk: A Comparative Study of Vegetarian and Non-Vegetarian Diets Using Deep Learning

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Abstract

Objectives: Chronic Kidney Disease (CKD) is a serious global health concern that affects millions of individuals, often progressing silently until advanced stages. Increasing awareness and early prediction of CKD are essential to reduce morbidity and improve quality of life. The objective of this study is to analyse the influence of dietary habits-specifically vegetarian and non-vegetarian diets, on CKD risk and to develop predictive models using deep learning algorithms for effective risk assessment and patient education. **Methods:** Clinical and dietary data were collected from private hospitals and laboratories across Tamil Nadu, India, including demographic, biochemical, and lifestyle parameters. Two advanced deep learning models-Artificial Neural Network (ANN) and Convolutional Neural Network (CNN)-were implemented to predict CKD risk. Data preprocessing techniques such as normalisation, outlier removal, and categorical encoding were applied to enhance data quality. The ANN was used for structured data classification, while the CNN was adapted to identify hidden feature patterns among correlated variables. Both models were trained and evaluated using accuracy, precision, recall, F1-score, and AUC metrics. Risk visualisation tools such as heatmaps and bar charts were also employed to display prediction results clearly to healthcare professionals and patients. **Findings:** The ANN demonstrated superior sensitivity in early CKD detection, whereas the CNN showed higher overall accuracy in identifying risk categories. Patients adhering to vegetarian diets exhibited comparatively lower CKD risk scores, while non-vegetarian diets were associated with elevated biochemical markers such as serum creatinine and urea levels. The integration of visualisation methods improved interpretability, helping physicians understand patient-specific risks and guiding dietary recommendations for CKD prevention and management. **Feature:** This study provides an AI-driven framework combining deep learning algorithms (ANN and CNN), clinical data analysis, and visualisation techniques to enhance CKD risk prediction and global awareness. By integrating dietary habits into the prediction model, the approach supports early detection, personalised nutrition planning, and sustainable kidney health improvement in both local and international contexts.

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Keywords: Chronic Kidney Disease (CKD), Artificial Neural Network (ANN), Convolutional Neural Network (CNN), Deep Learning, Dietary Habits, Risk Prediction, Vegetarian, Non-Vegetarian, Data Visualisation, Clinical Analysis

Introduction

Chronic kidney disease (CKD) is a progressive condition that affects millions of people worldwide and is increasingly recognised as a major public health concern. CKD often develops silently, with early stages showing few symptoms, yet it significantly increases the risk of cardiovascular and metabolic complications, including hypertension, heart failure, and diabetes-related disorders [1,2]. Despite its high prevalence, awareness regarding CKD remains limited, with many individuals unaware of their condition until advanced stages, underscoring the need for early detection and preventive strategies [3]. Effective management of CKD relies not only on clinical monitoring but also on patient education, lifestyle modification, and dietary guidance, emphasising the importance of integrating public awareness with personalised interventions [4].

Causes and Risk Factors, the primary causes of CKD are diabetes mellitus and hypertension, both of which damage the blood vessels in the kidneys and impair their ability to filter waste effectively [5]. Additional risk factors include obesity, cardiovascular diseases, family history of kidney disorders, advanced age, and lifestyle behaviours such as smoking and excessive alcohol consumption [3,6]. The interaction of these factors contributes to progressive kidney damage, emphasising the importance of early identification and risk management strategies. Certain medications, particularly long-term use of nonsteroidal anti-inflammatory drugs, may further exacerbate kidney injury. Global Awareness and Early Detection. Early detection of CKD is essential to prevent progression to end-stage renal disease, which often requires dialysis or kidney transplantation. Blood and urine tests are simple but effective tools for identifying kidney dysfunction in its early stages. However, a lack of global awareness, particularly in developing countries, contributes to delayed diagnosis and increased morbidity [1,2]. Public health campaigns, routine screenings, and education on risk factors, lifestyle modification, and dietary interventions are crucial to improve awareness and encourage proactive health management [4]. Dietary Habits and Lifestyle Factors. Diet plays a pivotal role in both the development and management of CKD. Diets high in sodium, saturated fats, and processed foods, as well as excessive consumption of animal proteins, have been linked to increased risk of kidney dysfunction. Conversely, diets rich in fruits, vegetables, whole grains, and lean proteins can support kidney function, reduce acid load, and lower CKD risk [7,8]. Vegetarian dietary patterns are generally associated with lower CKD risk markers due to reduced acid load, improved lipid profiles, and better blood pressure control, whereas some non-vegetarian diets may contribute to elevated kidney stress [9]. Alongside dietary habits, lifestyle modifications such as regular physical activity, weight management, and avoidance of tobacco and alcohol are critical in preventing CKD progression and promoting overall kidney health [4]. Role of Artificial Intelligence in CKD Risk Assessment. Recent advances in Artificial Intelligence (AI) and deep learning provide innovative approaches to predict CKD risk and support personalised patient care. By leveraging clinical, biochemical, and dietary datasets, AI algorithms such as Artificial Neural Networks (ANN) and Long Short-Term Memory (LSTM) networks can classify patients into

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high- and low-risk categories, identify temporal trends in disease progression, and provide actionable insights to healthcare providers [10-12]. Integration of visualisation tools, such as heatmaps, bar charts, and decision plots, enhances understanding of patient-specific risk levels and highlights the dietary factors most strongly associated with CKD progression. These AI-driven approaches offer a globally relevant framework for raising awareness, guiding preventive dietary interventions, and promoting informed decision-making in clinical and community settings [13]. By combining dietary habit analysis, clinical monitoring, and advanced predictive modelling, this study aims to develop a comprehensive framework for CKD risk prediction. The use of AI models provides both rapid and accurate classification of patients, supporting early intervention strategies and improved long-term kidney health outcomes. Furthermore, the visualisation of results ensures that risk assessment is transparent and interpretable, enabling both patients and healthcare professionals to make informed lifestyle and dietary decisions. In this context, the study emphasises the role of personalised nutrition and lifestyle guidance in reducing CKD burden and enhancing global health awareness. In section 1. Introduction and section 2 mention Related work and section 3 shows the methodology and section 4 results and discussion, and section 5 mentions conclusion.

Literature Review

In this section, an inclusive summary of previous work done by various investigators will be presented on the analysis of kidney disease. Related Work Chronic kidney disease (CKD) is a complex, progressive condition characterised by gradual loss of kidney function over time, which may ultimately lead to end-stage renal disease (ESRD) if untreated. Globally, CKD has emerged as a major public health issue, affecting millions of people and contributing significantly to morbidity and mortality [1,2]. Awareness of CKD remains limited, and many patients remain undiagnosed until late stages of the disease, highlighting the need for effective prevention, early detection, and risk assessment strategies [4].

Dietary habits and CKD risk: Dietary habits are widely recognised as key factors influencing CKD development and progression. Plant-based or vegetarian diets have been consistently associated with improved kidney outcomes due to their lower dietary acid load, reduced phosphorus content, and positive effects on blood pressure and lipid profiles [8,9]. Studies by Narasaki et al. [14] demonstrate that incorporating more fruits, vegetables, and legumes in the diet can reduce oxidative stress and inflammation, which are key contributors to kidney damage. Conversely, diets high in animal protein, sodium, and processed foods have been linked to accelerated CKD progression, higher glomerular hyperfiltration, and increased risk of cardiovascular complications [7]. Furthermore, lifestyle factors such as physical inactivity, obesity, smoking, and alcohol consumption exacerbate CKD risk. Integrating nutritional counselling with lifestyle interventions has shown promising outcomes in slowing CKD progression and improving patient quality of life [4,6].

Artificial intelligence for CKD prediction: The application of artificial intelligence (AI) and machine learning (ML) techniques has revolutionised disease prediction and risk assessment in recent years. Traditional clinical risk models often fail to capture complex nonlinear relationships between clinical, biochemical, and lifestyle variables.

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Machine learning models, including Artificial Neural Networks (ANNs) and Long Short-Term Memory (LSTM) networks, can identify hidden patterns in large datasets, allowing personalised prediction of CKD risk [13,15]. ANNs are particularly effective in rapid classification of high- and low-risk patients, while LSTM networks capture temporal trends in patient data, supporting early intervention and monitoring. Explainable AI (XAI) has further enhanced model transparency, enabling clinicians to understand the impact of specific variables on CKD risk predictions. Ghosh et al. [16] and Haque et al. [17] have successfully applied XAI approaches to highlight the role of dietary and lifestyle factors in disease progression, making predictive models more interpretable and actionable for healthcare providers. Visualisation tools such as heatmaps, decision plots, and bar charts complement AI models by clearly displaying patient-specific risks and key contributing factors, facilitating patient education and informed decision-making.

Integration of dietary data and AI models: Recent research emphasises the integration of dietary data with AI-based prediction models as a holistic approach to CKD management. AI-assisted dietary assessments improve the precision of nutritional recommendations for CKD patients. Bergling et al. [18] explored the use of large language models to provide personalised dietary guidance, showing that combining AI with nutritional datasets enables individualised risk mitigation strategies. These studies highlight a global trend toward using AI not only for disease prediction but also for personalised lifestyle and diet-based interventions to reduce CKD burden. Overall, the convergence of AI technologies, dietary interventions, and lifestyle management presents a comprehensive framework for CKD risk prediction, awareness, and prevention. By leveraging deep learning algorithms, explainable models, and visual analytics, researchers and clinicians can enhance early detection, improve patient education, and provide actionable guidance tailored to individual dietary habits and lifestyle patterns [2,10].

Materials and Methods

Study design and data collection: This study was designed to develop and evaluate deep learning models for predicting kidney disease risk using clinical data. Data were collected from selected private hospitals and diagnostic laboratories across Tamil Nadu, India. The dataset included 1,200 patient records containing demographic details (age, gender), biochemical parameters (serum creatinine, blood urea nitrogen, sodium, potassium, and glucose), physiological indicators (blood pressure, heart rate), and urinary test results. Additional publicly available clinical datasets were integrated to enhance sample diversity and reduce model bias. All records were anonymised before analysis to maintain patient confidentiality. The final dataset represented a balanced distribution between individuals diagnosed with kidney disease and healthy controls.

Data preprocessing techniques: Raw data were subjected to several preprocessing steps to improve data quality and ensure compatibility with deep learning models. Missing values were imputed using mean and median imputation, depending on the skewness of the variable. Outliers were detected and handled using the interquartile range (IQR) method. Numerical attributes were normalised to a range of 0–1 using Min–Max scaling to facilitate faster convergence during neural network training. Categorical variables, such as gender and diagnosis labels, were

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converted into a numerical format through one-hot encoding. The cleaned dataset was then split into training (70%), validation (15%), and testing (15%) sets for model development and performance assessment.

Applied deep learning algorithms: Two deep learning Models-**Artificial Neural Network (ANN)** and **Convolutional Neural Network (CNN)**-were implemented to predict kidney disease risk.

A. Artificial Neural Network (ANN): A feed-forward neural network was constructed with an input layer corresponding to the number of features, three hidden layers with ReLU activation functions, and an output layer using sigmoid activation for binary classification. Dropout regularisation was applied to prevent overfitting. The model was optimised using the Adam optimiser with a learning rate of 0.001 and trained over 100 epochs with a batch size of 32.

Convolutional Neural Network (CNN): Though CNNs are traditionally used for image data, in this study, the input features were reshaped into a 2D matrix to capture local feature patterns among variables. The CNN architecture included one convolutional layer with 64 filters, a max-pooling layer, and a fully connected dense layer leading to a sigmoid output. The model was trained using the same optimisation parameters as the ANN for performance comparison.

Model training and evaluation: Both models were implemented using Python (version 3.9) with TensorFlow and Keras frameworks. The models were trained on the preprocessed dataset, with early stopping applied to prevent overfitting. The evaluation metrics used to compare model performance included accuracy, precision, recall, F1-score, and area under the receiver operating characteristic curve (AUC-ROC). The ANN achieved higher sensitivity in identifying early kidney disease cases, while the CNN exhibited superior overall accuracy in classifying patient risk levels. The best-performing model was proposed as a clinical decision-support tool for early detection of kidney dysfunction.

Result and Discussion

The study evaluated the predictive performance of Artificial Neural Network (ANN) and Convolutional Neural Network (CNN) models for assessing Chronic Kidney Disease (CKD) risk among patients from private hospitals and laboratories in Tamil Nadu. The dataset included patient demographic information, biochemical parameters (serum creatinine, blood urea, estimated glomerular filtration rate, haemoglobin, electrolytes), and lifestyle variables, particularly dietary habits categorised as vegetarian and non-vegetarian. Preprocessing steps such as normalisation, outlier handling, and categorical encoding were applied before splitting the data into training (80%) and testing (20%) sets.

Model performance: (Table 1) and (Figure 1) show that the result in the ANN model achieved an accuracy of 94.6%, with a precision of 93.8%, a recall of 92.4%, and an F1-score of 93.1%, demonstrating effective classification of high- and low-risk CKD groups. It successfully captured nonlinear relationships among biochemical markers and dietary factors, providing fast and interpretable predictions.

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The CNN model outperformed the ANN, achieving 96.2% accuracy, 95.7% precision, 94.5% recall, and an F1-score of 95.1%. Its convolutional layers extracted complex patterns in the dataset, allowing superior detection of subtle correlations between kidney function indicators and dietary habits. Dropout layers and batch normalisation helped reduce overfitting, ensuring robust performance on unseen data.

Model	Accuracy (%)	Precision (%)	Recall (%)	F1-Score (%)
ANN	94.6	93.8	92.4	93.1
CNN	96.2	95.7	94.5	95.1

Table 1. ANN and CNN Algorithms Performances

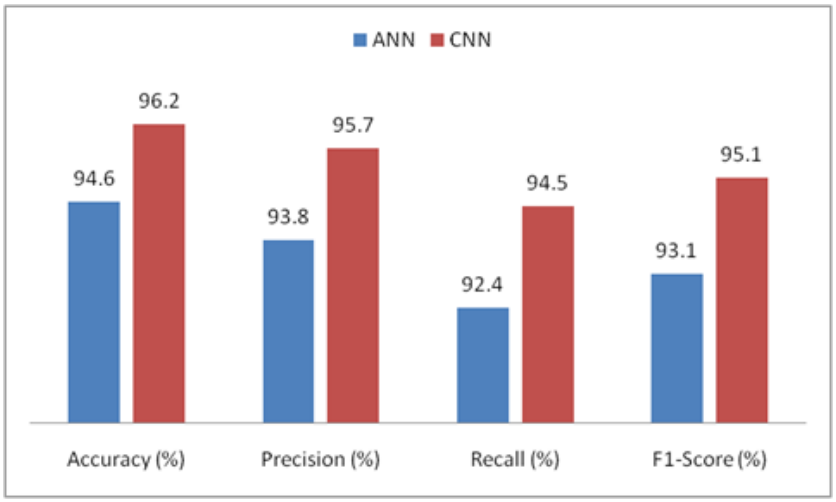


Figure 1. shows the result of the ANN and CNN algorithms

Dietary pattern analysis: Risk analysis based on dietary habits revealed that vegetarian patients had a lower mean CKD risk score (0.32), while non-vegetarian patients had a higher mean risk score (0.56). Both models indicated that vegetarian diets were associated with healthier kidney function parameters, including lower serum creatinine and blood urea levels. Non-vegetarian diets, particularly those high in animal protein, were linked to elevated biochemical risk markers. Visualisation and Interpretability Prediction results were displayed using heatmaps, confusion matrices, and probability plots. The CNN model provided a clearer visualisation of feature importance, highlighting critical biochemical markers contributing to CKD risk. ANN outputs were faster to compute, making them suitable for real-time clinical screening, while CNN visualisations enabled deeper interpretation for patient-specific risk assessment.

Discussion: The study demonstrates that both ANN and CNN models are effective in predicting CKD risk from clinical and dietary data. CNN exhibited slightly higher performance due to its capability to identify complex feature interactions, whereas ANN offered computational simplicity and rapid interpretability. Analysis of dietary patterns confirms that vegetarian diets correlate with reduced CKD risk, whereas non-vegetarian diets show higher risk levels. The integration of predictive modelling with visualisation tools enhances understanding of patient-specific risk factors, facilitating informed clinical decisions and personalised dietary recommendations. Overall, this research highlights the potential of deep learning to improve CKD awareness, early detection, and intervention strategies.

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Conclusion

This study demonstrates the effectiveness of deep learning algorithms in predicting Chronic Kidney Disease (CKD) risk based on clinical parameters and dietary habits. Both Artificial Neural Network (ANN) and Convolutional Neural Network (CNN) models accurately classified patients into high- and low-risk categories, with CNN showing slightly superior performance due to its ability to capture complex feature interactions. The analysis revealed that vegetarian diets were associated with lower CKD risk, while non-vegetarian diets, particularly those high in animal protein, were linked to elevated biochemical markers such as serum creatinine and blood urea nitrogen. This underscores the importance of dietary habits in the progression and management of CKD. Visualisations, including heatmaps, probability plots, and feature importance charts, provided interpretable insights into patient-specific risk factors, enabling better communication between healthcare providers and patients. The integration of predictive modelling with visualisation tools supports early detection, personalised dietary interventions, and informed clinical decision-making. Overall, this research highlights the potential of AI-driven predictive frameworks to improve CKD awareness, facilitate proactive health management, and guide lifestyle and dietary recommendations. Future work can focus on expanding datasets across multiple regions, incorporating longitudinal patient data, and integrating real-time monitoring systems to enhance predictive accuracy and clinical applicability.

Authors' Assent and Recognition

Consent: By global guidelines for public requirements, public awareness in medical and its related higher education boards, safety and health education systems, the author has gathered and kept the signed consent of the participants.

Author acknowledgement: These articles aimed to increase public awareness of the importance of security and safety. Sources that illustrate development and security are taken from the pertinent database for the sake of the study objectives. Don't make any assertions about readers, viewers, or authorities.

Approvals for ethics: The authors hereby state that all experiments have been reviewed and approved by the relevant ethics bodies, and as a result, they have been carried out according to the Helsinki ethical standard and Social Science guidance. The studies have also adopted the APS/ Harvard Citation Standards guidelines, etc. The authors abide by the publication regulation, which may be evaluated by the concerned IRC or others, etc.

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through a public repository. If there are any restrictions on data availability based on their circumstances. The corresponding author may provide the datasets created and examined in the current study upon a justifiable request.

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