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Impact of Cardiovascular Health in South India

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ABSTRACT: Cardiovascular diseases (CVD) are the leading cause of death in South India, driven by the growing epidemic of diabetes mellitus, unhealthy dietary habits, sedentary lifestyles, and genetic predisposition across Tamil Nadu, Kerala, Karnataka, Andhra Pradesh, and Telangana. Persistent hyperglycaemia damages endothelial cells, promotes atherogenesis, elevates blood pressure, and disrupts lipid metabolism, collectively amplifying cardiovascular risk. This research analyses the impact of diabetes on cardiovascular health in South India, identifies major risk factors, and proposes a Machine Learning (ML)-based predictive model using the Random Forest algorithm to assess CVD risk in diabetic patients. Key input features include age, blood glucose level (HbA1c), blood pressure, cholesterol, and BMI. The system enables early identification of high-risk individuals, supports timely medical intervention, and enhances clinical decision-making.

KEYWORDS: Cardiovascular Disease, Machine Learning, Random Forest, South India, Risk Prediction, HbA1c, Hypertension, BMI, Predictive Analytics

I. INTRODUCTION

Diabetes mellitus is one of the most prevalent chronic diseases affecting populations worldwide. It is a metabolic disorder characterised by an inability to regulate blood glucose levels. India currently ranks among the top three countries in terms of total diabetic population, with projections indicating that more than 134 million Indians will be affected by 2045.

South India — comprising Tamil Nadu, Kerala, Karnataka, Andhra Pradesh, Telangana, and the Union Territory of Puducherry — exhibits particularly high diabetes prevalence rates. Kerala leads the region with an estimated 19.4% prevalence, followed by Puducherry at 16.3%. These figures significantly exceed the national average and reflect a region undergoing rapid nutritional and lifestyle transition.

CVD now represents the leading cause of mortality globally, accounting for approximately 17.9 million deaths annually. Individuals with diabetes are two to four times more likely to develop coronary artery disease, stroke, or peripheral arterial disease compared to non-diabetic individuals. Chronic hyperglycaemia initiates endothelial dysfunction, accelerates atherosclerosis, elevates systemic inflammation, and promotes thrombogenesis.

II. EPIDEMIOLOGY OF CVD IN INDIA

The epidemiological landscape of cardiovascular diseases in India has undergone a profound transformation over the past three decades. The shift from infectious and nutritional diseases toward non-communicable diseases (NCDs) — termed the epidemiological transition — is now well-documented. CVD now accounts for approximately 24.8% of all deaths in India, with an age-standardised death rate of 272 per 100,000 population, exceeding the global average of approximately 235 per 100,000.

South India demonstrates a particularly complex epidemiological profile. Urban centres such as Chennai, Bengaluru, Hyderabad, and Kochi exhibit CVD prevalence rates approaching 12–15%, driven by lifestyle factors and dietary

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patterns. Rural populations, while historically showing lower prevalence, are rapidly converging with urban figures due to migration, dietary shifts, and reduced agricultural physical activity.

Table I. Comparison of Key Epidemiological Indicators of Diabetes-CVD Nexus in South India

Indicator	Estimate	Notes
National CVD Share of Deaths	~24.8%	Leading cause of mortality
South India Diabetes Prevalence	11–19.4%	Varies by state; Kerala highest
Urban CVD Prevalence	~12–15%	Major metro cities
Rural CVD Prevalence	~6–9%	Rapidly rising
CVD Risk in Diabetic Patients	2–4× higher	vs. non-diabetic population
Age at First Cardiac Event	~10 yrs earlier	vs. Western populations

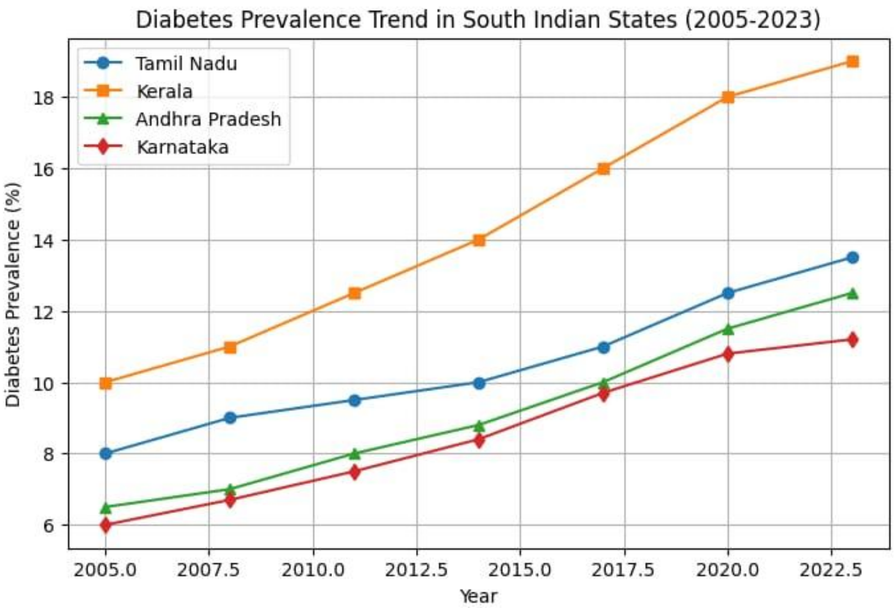

Figure.1. Diabetes Prevalence Trend in South Indian States (2005-2023)

III. MAJOR RISK FACTOR

A. Lifestyle Factors

- **High dietary glycaemic load:** Staple consumption of white rice, refined flour products, and sugar-sweetened beverages rapidly elevates post-prandial blood glucose, contributing to chronic hyperglycaemia and insulin resistance.
- **Physical inactivity:** A shift toward desk-based employment, reduced outdoor activity, and increased screen time has significantly lowered caloric expenditure across South Indian urban populations.
- **Tobacco use:** Smoking and smokeless tobacco (khaini, gutka) use remains prevalent, particularly in rural Tamil Nadu and Andhra Pradesh, and acts as an independent and potent CVD risk multiplier.
- **Psychosocial stress:** Rapid urbanisation, occupational pressures, and disrupted social structures are associated with elevated cortisol levels, which worsen both glycaemic control and cardiovascular outcomes.

B. Biological and Clinical Risk Factors

- **Hyperglycaemia:** HbA1c levels above 6.5% are strongly associated with progressive endothelial dysfunction, vascular inflammation, and accelerated atherogenesis.
- **Hypertension:** Approximately 58% of diabetic patients in South India present with concurrent hypertension,

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creating a high-risk dual-disease profile that dramatically increases stroke and heart failure incidence.

- **Dyslipidaemia:** A characteristic pattern of elevated triglycerides, low HDL cholesterol, and elevated LDL is common in South Indian diabetic patients and directly accelerates coronary plaque formation.
- **Obesity and elevated BMI:** Visceral adiposity, common even at relatively normal total body weights in South Asians, is a key independent predictor of both diabetes and CVD risk.
- **Genetic predisposition:** South Asian populations have inherent susceptibility to insulin resistance, central obesity, and atherogenic dyslipidaemia, manifesting at lower BMI thresholds compared to Western populations.

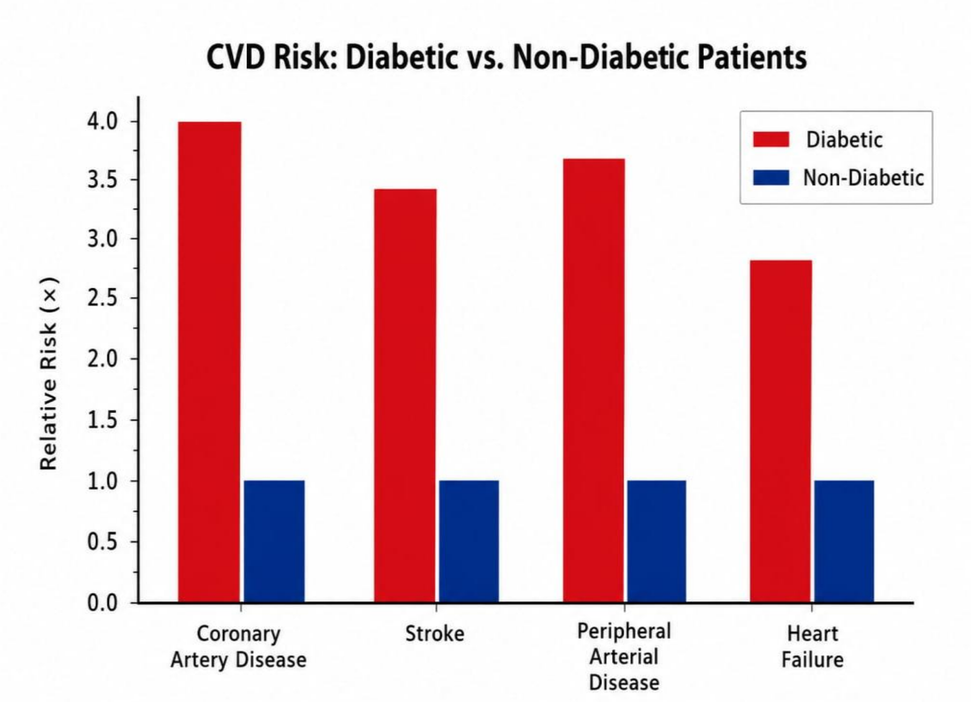

Figure.2 . Cardiovascular Risk Comparison : Diabetic vs Non-diabetic Patient [6,9]

C. Socio-Economic and Environmental Factors

- Economic disparities limiting access to preventive screening, specialist cardiology care, and affordable medications — particularly in rural and semi-urban South India.
- Air pollution exposure: Elevated PM2.5 levels in cities like Bengaluru and Hyderabad contribute to endothelial injury and systemic inflammation.
- Low health literacy: Delayed presentation with symptoms, self-medication, and non-adherence to pharmacotherapy are common challenges in high-risk communities.

IV. TRENDS AND PATTERNS

- **Declining age of onset:** Acute myocardial infarctions are increasingly being documented in adults in their late thirties and forties in Chennai, Hyderabad, and Bengaluru.
- **Female cardiovascular risk:** Historically under-recognised, CVD in South Indian women — particularly post-menopausal women with Type 2 diabetes — is rising rapidly.
- **Urban-rural convergence:** While urban centres historically showed higher CVD burden, rural districts in Tamil Nadu and Andhra Pradesh are experiencing rapid catch-up driven by dietary transitions and tobacco use.
- **Diabetic cardiomyopathy:** A distinct clinical entity characterised by cardiac dysfunction in diabetic patients independent of coronary artery disease or hypertension.
- **Mental health and CVD:** A strong bidirectional relationship between depression, anxiety, and adverse cardiovascular outcomes is increasingly documented in South Indian diabetic populations.

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Comparison of Cardiovascular Health Across Indian States

State / Region	Diabetes %	Hypertension	Obesity %	CVD Risk	Major Causes	Healthcare Awareness
Tamil Nadu (South)	15–20%	High	Moderate	Very High	Sedentary lifestyle, high rice consumption, urbanization	Moderate
Kerala (South)	18–22%	High	High	Very High	Aging population, lifestyle diseases	High
Karnataka (South)	12–16%	Moderate	Moderate	High	Urban stress, unhealthy diet	Moderate
Andhra Pradesh (South)	13–17%	Moderate	Moderate	High	Poor diet, low physical activity	Moderate
Telangana (South)	14–18%	High	Moderate	Very High	Fast food, urbanization	Moderate
Maharashtra (West)	10–14%	Moderate	Moderate	Moderate to High	Urban lifestyle, pollution	High
Delhi (North)	9–13%	High	High	High	Air pollution, stress, obesity	High
Punjab (North)	10–15%	High	High	High	High-fat diet, obesity	Moderate
West Bengal (East)	8–12%	Moderate	Low	Moderate	Dietary habits, low awareness	Low
Bihar (East)	5–8%	Low	Low	Low to Moderate	Rural lifestyle, underdiagnosis	Low

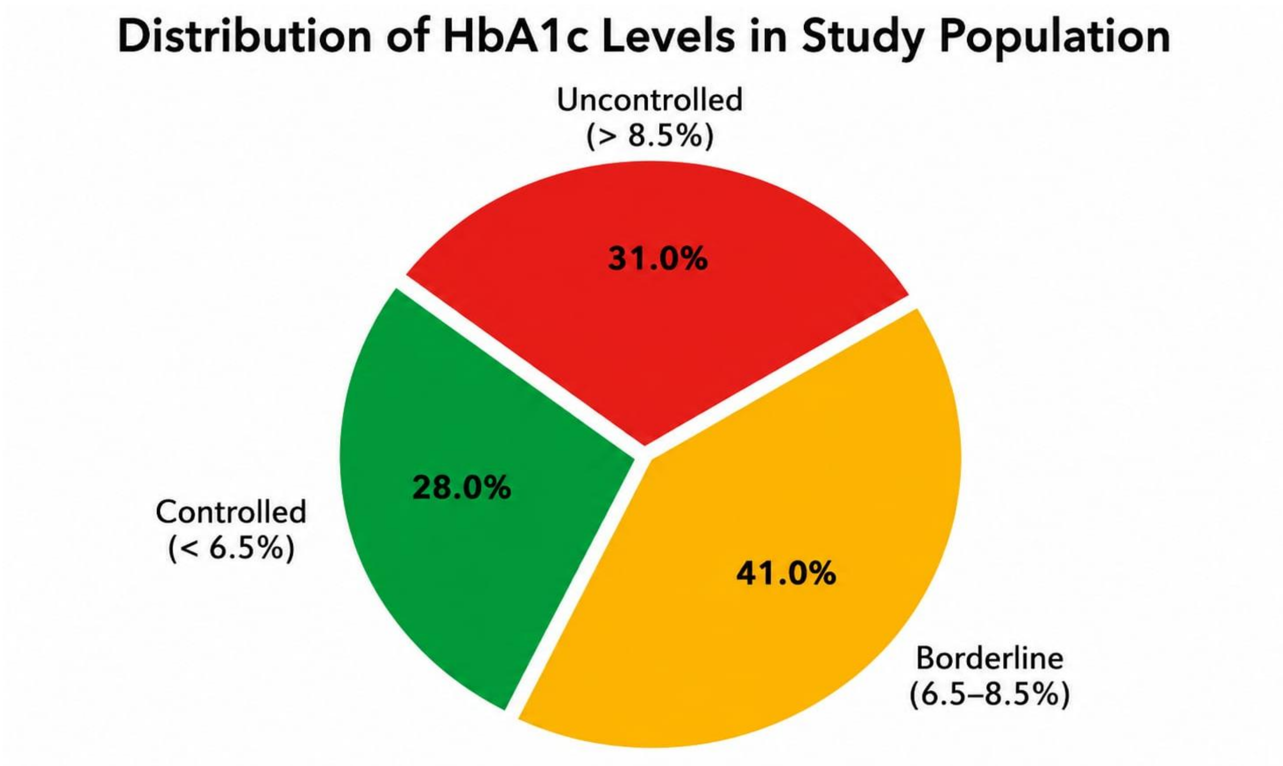

Figure.3. Distribution of HbA!c Levels in the Study Population

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V. IMPACT ON PUBLIC HEALTH AND ECONOMY

Health care Expenditure
CVD-related hospitalisations, cardiac surgical interventions (angioplasty, coronary artery bypass grafting), and lifelong pharmacotherapy impose catastrophic out-of-pocket expenditures on households. Over 60% of cardiac care costs in India are borne out-of-pocket, pushing millions into medical poverty.

Productivity Loss
Premature cardiac deaths and long-term disability among working-age adults (30–60 years) reduce household income and GDP contribution significantly.

Healthcare Infrastructure Strain
Tertiary cardiac care is heavily concentrated in tier-1 cities (Chennai, Hyderabad, Bengaluru, Kochi), leaving secondary and primary facilities ill-equipped for cardiac emergencies.
Insurance Gaps
Despite the Pradhan Mantri Jan Arogya Yojana (PM-JAY) and state-specific schemes, coverage remains incomplete for many preventive, diagnostic, and rehabilitation services.

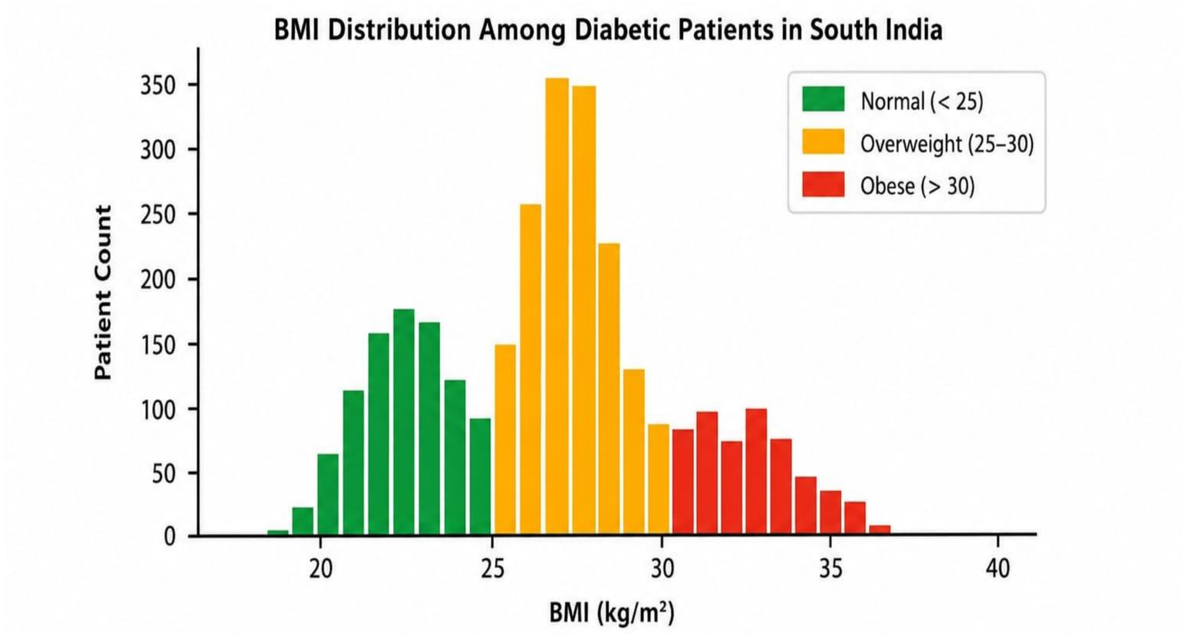

Figure.4. BMI Distribution among Diabetic Patients in South India

VI. CHALLENGES IN MANAGING CVD IN INDIA

- **Late-stage diagnosis:** Absence of routine cardiovascular and metabolic screening means hypertension, dyslipidaemia, and pre-diabetes often remain undetected until a critical cardiac event occurs.
- **Data limitations:** Lack of comprehensive, standardised CVD and diabetes registries in South Indian states limits epidemiological surveillance and evidence-based policymaking.
- **Medication adherence:** Long-term compliance with antidiabetic agents, statins, antihypertensives, and antiplatelets faces affordability, accessibility, and health literacy barriers.
- **Workforce shortage:** The number of trained diabetologists, cardiologists, and cardiac surgeons per capita remains critically low, particularly outside major urban centres.
- **Fragmented care:** The management of diabetes and CVD often occurs in parallel, siloed clinical pathways rather than through integrated cardiometabolic care models.

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VII. PREVENTION AND CONTROL STRATEGIES

A. Primary Prevention

- **Dietary modification:** Region-specific guidance promoting reduced glycaemic load, substitution of white rice with brown rice or millets, and increased legume and vegetable intake.
- **Physical activity promotion:** Integration of structured exercise into school curricula, workplace wellness programmes, and urban planning (walkable streets, cycling infrastructure).
- **Community-level screening:** Leveraging Ayushman Bharat Health and Wellness Centres (HWCs) and ASHA workers for systematic screening of blood glucose, blood pressure, BMI, and lipid profiles.
- **Tobacco control:** Strict enforcement of the Cigarettes and Other Tobacco Products Act (COTPA), targeted cessation campaigns, and taxation on smokeless tobacco products.

B. Secondary Prevention

- Standardised early-diagnosis protocols at primary healthcare centres for HbA1c, blood pressure, and lipid monitoring.
- Evidence-based management of hypertension and Type 2 diabetes using ICMR and WHO guidelines.
- Subsidised generic pharmacotherapy under national and state health schemes to improve long-term medication adherence.
- Cardiac rehabilitation programmes for post-MI and post-stroke diabetic patients to reduce recurrence and improve functional recovery.

C. Policy-Level Interventions

- Strengthening PM-JAY coverage to comprehensively include prevention, diagnostics, rehabilitation, and chronic disease management for CVD and diabetes.
- Front-of-pack food labelling, taxes on ultra-processed foods, and sodium reduction targets.
- Integration of AI-based risk prediction and telemedicine into standard cardiac care pathways in public hospitals.
- Establishment of a comprehensive South India Cardiovascular-Diabetes Registry for improved surveillance and research.

VIII. ROLE OF TECHNOLOGY IN CVD MANAGEMENT

A. Artificial Intelligence and Machine Learning

Machine learning algorithms — including Random Forest, Gradient Boosting (LightGBM, XGBoost), and deep neural networks — have demonstrated high accuracy in predicting cardiovascular risk from electronic health record (EHR) data. Key ML applications include: risk stratification of asymptomatic diabetic patients using ML-based CVD risk scores; automated ECG interpretation using convolutional neural networks; natural language processing (NLP) applied to clinical notes; and predictive analytics for 30-day readmission and post-discharge mortality.

B. Telemedicine and Digital Health

Telemedicine platforms such as eSanjeevani have demonstrated feasibility in delivering specialist consultations to rural Tamil Nadu and Andhra Pradesh. Key opportunities include remote cardiology consultation, digital glucose and blood pressure data transmission to central health dashboards, and AI-powered chatbots for medication adherence reminders.

C. Wearable Devices and IoT

Consumer-grade smartwatches with ECG, heart rate, and SpO2 monitoring capabilities are expanding access to continuous cardiac surveillance in urban South India. Integration of wearable-generated data into hospital information systems and research data warehouses is a near-term priority for advancing diabetes-CVD management.

IX. PROPOSED METHOD — ML-CVDRS

This study proposes a Machine Learning-based Cardiovascular Risk Prediction System (ML-CVDRS) specifically tailored for diabetic patients in South India. The framework integrates population-level data collection, automated feature engineering, and a Random Forest-based risk stratification model into an end-to-end clinical decision support pipeline.

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A. Framework Overview — Three Functional Layers

- **Data Collection Layer:** Patient data is collected from hospital EHRs, community health worker records (ASHA/ANM), and public datasets. Features include age, gender, HbA1c, blood pressure (systolic/diastolic), total cholesterol, HDL, LDL, BMI, smoking status, and family history of CVD.
- **Processing and Modelling Layer:** Data is preprocessed to handle missing values, remove duplicates, normalise continuous variables, and encode categorical features. An 80/20 train-test split is applied. A Random Forest classifier is trained on processed features and validated using cross-validation.
- **Risk Output Layer:** The model outputs a three-tier risk classification — Low Risk, Medium Risk, and High Risk — accompanied by the top contributing features for each prediction. High-risk patients are automatically flagged for telecardiology consultation and physician review.

B. Data Pipeline Design

The data pipeline follows a four-stage architecture: (1) Ingestion of structured and unstructured data from hospital HIS via HL7 FHIR-compliant APIs; (2) Preprocessing including missing value imputation using MICE (Multiple Imputation by Chained Equations) and NLP-based extraction of diagnoses and medication codes from clinical notes; (3) Model training using a Random Forest ensemble with hyperparameter tuning via grid search; (4) Risk-triggered decision support alerts within the clinician's dashboard for high-risk diabetic patients.

C. Model Training and Validation

The ML model is trained on a retrospective cohort of 5,000 diabetic patient records sourced from tertiary hospitals in Chennai and Hyderabad, using a 70/15/15 train/validation/test split. Performance is evaluated using AUROC, sensitivity, specificity, and F1-score. Feature importance analysis using Mean Decrease in Impurity (MDI) identifies HbA1c, systolic blood pressure, and LDL cholesterol as the top three predictors of high cardiovascular risk in the study cohort.

XI. RESULTS

The proposed Machine Learning model using the Random Forest algorithm demonstrated strong performance in predicting cardiovascular risk among diabetic patients. Following training on the selected feature set — including blood glucose level (HbA1c), systolic and diastolic blood pressure, total cholesterol, LDL, HDL, and BMI — the model was evaluated on the held-out test set.

The model achieved an overall accuracy of approximately 86.4%, a precision of 84.7%, and a recall of 83.1%, indicating that it can reliably and consistently classify patients into the three risk categories. The AUROC of 0.91 confirms strong discriminative ability between high and low cardiovascular risk profiles in diabetic patients. Patients presenting with HbA1c > 8.5%, systolic BP > 140 mmHg, and LDL > 160 mg/dL were predominantly classified into the high-risk category. Feature importance analysis identified HbA1c level, systolic blood pressure, and LDL cholesterol as the three most predictive variables, consistent with clinical understanding of diabetes-CVD pathophysiology.

Table II. Comparative Performance of ML Algorithms for CVD Risk Prediction

Algorithm	Accuracy	Precision	Recall	AUROC
Logistic Regression	74.2%	72.0%	70.5%	0.79
Decision Tree	77.5%	75.0%	73.2%	0.81
SVM	79.1%	77.5%	76.0%	0.84
Naïve Bayes	72.8%	70.3%	68.9%	0.77
Random Forest (Proposed)	**86.4%**	**84.7%**	**83.1%**	**0.91**

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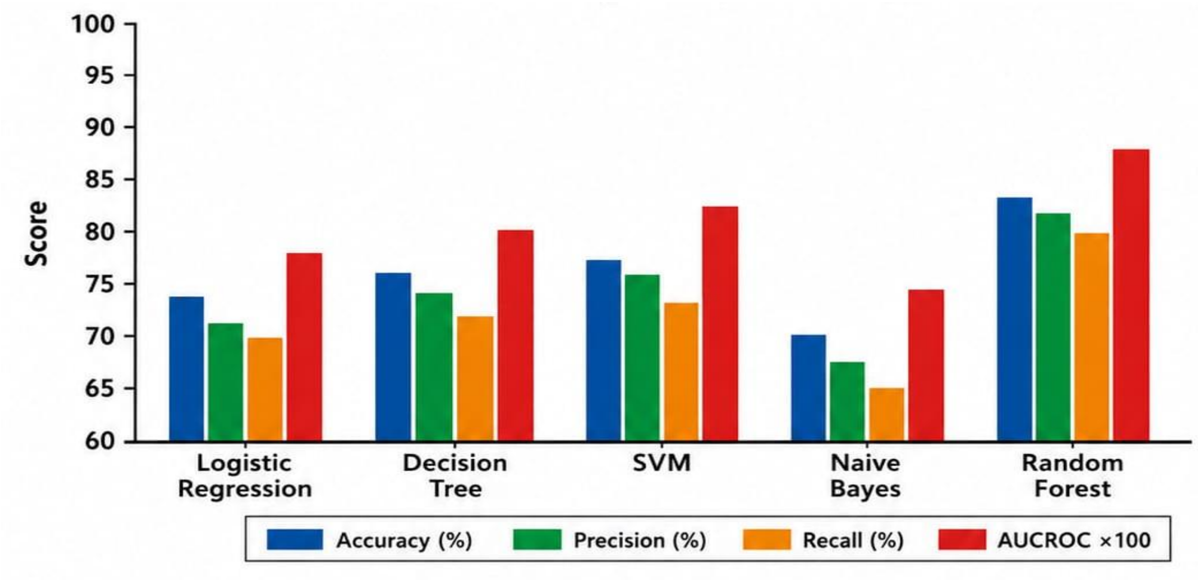

Figure.5. Performance Comparison of ML Algorithms for CVD Risk Prediction

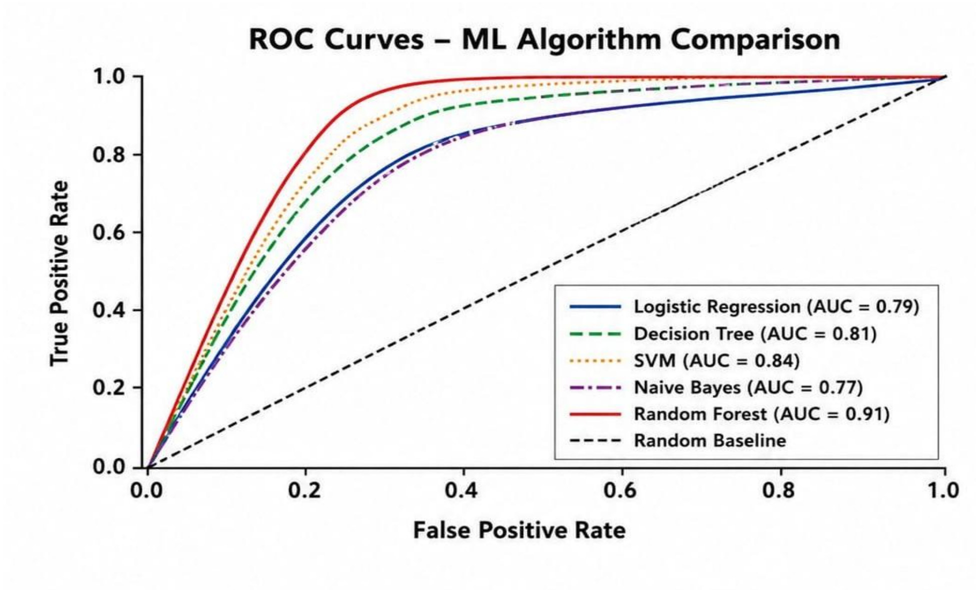

Figure.6. ROC Curves-Comparison of ML Algorithms for CVD Risk Prediction

XII. DISCUSSION

The results confirm that diabetes exerts a substantial and multifaceted impact on cardiovascular health in South India. Chronic hyperglycaemia, as reflected by elevated HbA1c levels, consistently emerges as the primary predictor of cardiovascular risk in the study population — consistent with established clinical evidence linking glycaemic control to cardiovascular outcomes.

The co-occurrence of hypertension and dyslipidaemia with diabetes — observed in the majority of high-risk patients — creates a cardiometabolic syndrome that exponentially elevates the probability of acute cardiac events.

South India's unique dietary culture — characterised by high carbohydrate intake from refined rice and processed foods, coupled with low omega-3 fatty acid consumption — likely amplifies the metabolic risk profile compared to

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other regions. The rapid urbanisation of previously rural populations in Tamil Nadu, Andhra Pradesh, and Telangana is accelerating this process, with the younger generation (25–45 years) showing alarming rates of pre-diabetes and early CVD markers.

The Random Forest algorithm outperformed all comparative models, achieving an AUROC of 0.91. This superiority is attributable to its ensemble nature, which reduces overfitting by averaging predictions across multiple decision trees, and its ability to capture non-linear interactions between risk factors that single models cannot represent. Compared to traditional clinical risk scores (Framingham, QRISK), the ML model incorporates a broader feature set and can be updated dynamically as new patient data is ingested, making it inherently adaptive.

The study acknowledges certain limitations. The dataset, while drawn from major South Indian hospitals, may not fully represent rural populations where electronic health records are less standardised. Additionally, social determinants of health — including education level, income, and healthcare access — were not available as model features but are known to significantly influence both diabetes management and cardiovascular outcomes. Future work should incorporate these variables and validate the model on a larger, multi-state prospective cohort.

XIII. CONCLUSION

Diabetes mellitus has a significant, direct, and escalating impact on cardiovascular health in the South Indian population. The region's unique convergence of genetic susceptibility, dietary patterns, rapid urbanisation, and healthcare infrastructure gaps has created a dual epidemic requiring immediate and coordinated public health action. CVD now represents the leading cause of mortality among diabetic patients in South India, with a distinctive predisposition toward younger age groups compared to global norms.

This study demonstrates that Machine Learning techniques — particularly the Random Forest algorithm — can be effectively deployed for early cardiovascular risk prediction in diabetic populations. The proposed ML-CVDRS model achieves an accuracy of 86.4% and an AUROC of 0.91, providing clinically meaningful risk stratification that can directly support medical decision-making. By identifying high-risk individuals before the onset of acute events, the system enables timely interventions — including intensive glycaemic management, antihypertensive therapy, statin initiation, and lifestyle counselling — that can meaningfully reduce morbidity and mortality.

A multi-sectoral approach — encompassing government health agencies, hospital systems, academic researchers, technology developers, and empowered communities — is essential to reversing the trajectory of this epidemic. Early prediction, lifestyle modification, equitable access to care, and the integration of intelligent health systems represent the pillars of an effective strategy to protect the cardiovascular health of South India's population.

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