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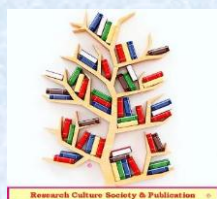
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(ICGRTHE – 2026)

Date: 29 - 30 August, 2026

Conference Special Issue / Proceedings Issue

Edited by:

Dr. Chirag Patel
Prof. Dr hab. Joanna Paliszkiewicz



**ASIAN
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International Conference on Global Research Trends in Higher Education

■ Dr. Chirag Patel, Prof. Dr hab. Joanna Paliszkiewicz.

(Conference Proceedings Issue / Special Issue)

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The Warsaw University of Life Sciences (Management Institute) Poland, is one of the largest and the most prestigious universities in Poland. It educates nearly 18,000 students in 38 study programs (including 8 taught in English) - from veterinary medicine and landscape architecture, through economics and computer science, to tourism and dietetics. It employs 1,200 academic teachers and offers a modern campus and excellent learning conditions. The campus is located in the southernmost district of Warsaw, Ursynów. The campus has a historical part, with an 18th-century palace and a new part where most of the faculty buildings and dormitories are situated. The Management Institute was established in 2019. The research developed in this Institute is related to management, trust, knowledge management and information technology.

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- The aim of the conference is to provide an interaction stage for researchers, practitioners from academia and industries to deal with state-of-the-art advancement in their respective fields.

WARSAW UNIVERSITY OF LIFE SCIENCES, POLAND
MANAGEMENT INSTITUTE



MESSAGE



Dear Ladies and Gentlemen,

Thank you for your attendance at International Conference on Global Research Trends in Higher Education.

This year the Conference is organized by the RBMI Institution, Asian Research Foundation, Research Culture Society and the Management Institute from Warsaw University of Life Sciences in Poland.

The theme of the conference is very actual and worth discussing. It has a broad scope and great relevance in the context of the current scenario of the situation in the progressive economy. The Conference will shed light on the consequences of the Coronavirus and will point out the new challenges in the business environment.

I would like to take the opportunity to thank you all for contributing to this Conference.

I look forward to meaningful presentations, discussions, and collegial networking.

Prof. dr hab. Joanna Paliszkievicz

Director of Management Institute
Warsaw University of Life Sciences

Dr.C. M. Patel

Director, Research Culture Society.



Message

Dear Professional Colleagues.

I am happy that RBMI Institution, Asian Research Foundation, Management Institute, Warsaw University of Life Sciences, Poland in collaboration with 'Research Culture Society' (Government Registered Scientific Research organization, India) are organizing 'International Conference on Global Research Trends in Higher Education' during 29 – 30 August, 2026.

The aim of the conference is to provide an interaction stage for researchers, practitioners from academia and industries to deal with state-of-the-art advancement in their respective fields. The main objective is to observe the current scenario towards the advancement of common citizen's life by improving the theory and practice of various disciplines of Business, Management, Economy, Science, Innovations and Education.

I believe, this International Conference will help in redefining the strong connect between commerce, management and economics education and the holistic development of students in the academic institutions. An additional goal of this international conference is to combine interests and scientific research related to business management, education, innovations to interact with members within and outside their own disciplines and to bring people closer for the benefit of the scientific community worldwide.

My best wishes to the committee members, speakers and Participants of this scientific conference.

A handwritten signature in blue ink, appearing to read 'Patel', is positioned above the printed name.

Dr.C. M. Patel

Director, Research Culture Society.

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Keynote Speakers:

Dr. Monika Roman, Institute of Economics and Finance, Warsaw University of Life Sciences. (SGGW), Warszawa, Poland.

Dr. Daria Suprun, Professor, Department of Social Work and Rehabilitation, National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine

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Conference Coordinators:

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INDEX

PAPER ID	Table of Contents	Page No.
a)	About the organizing Institutions: Objectives of the International Conference :	5
b)	Message of Director, Management Institute, WULS, Poland	6
c)	Message of Director, Research Culture Society.	7
d)	Conference Committee	8
e)	Table of Contents	9
-	Paper Title & Author(s) Name	-
ICGRTHE-2026/P01	A Reinvestigation Of The Association Between Service Export ,Import and GDP In India In A Vector Autoregression (VAR)Framework -- Suravi Kar Roy	11-19
ICGRTHE-2026/P02	Parenting Styles and Attachment Patterns: A Framework for Adolescent Social Competence -- Yvette Lee	20-27
ICGRTHE-2026/P03	Development, Validation, and Greenness Assessment of an LC–MS/MS Method for Pharmaceutical Quality Evaluation of Herbal Drug Formulations -- Dr Nirupa Gadapa	28-37
ICGRTHE-2026/P04	Promoting Inclusive Education among Nat Tribe Children in Uttar Pradesh: The Role of Schools and Teachers -- Hukum Singh, Dr. Munmun Mondal	38-49
ICGRTHE-2026/P05	A Study on Ethical Hacking Contributions to AI-Powered Cyber security -- Priya Mayur Ruke	50-56
ICGRTHE-2026/P06	A Cross Study Analysis of Deep Learning Frameworks for Diabetic Retinopathy Health Care Using Fundus and OCTA Images -- Peddapullaiahgari Hariobulesu, Fahimuddin Shaik	57-66



A Reinvestigation of the Association Between Service Export, Import and GDP in India in a Vector Autoregressive (VAR) Framework

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Abstract: Analyzing the quantitative relationship between export & import of services and Gross Domestic Product (GDP) of a country has been essential for economic forecasting, policy formulation and assessment of external stability. This paper intends to explore the empirical relationship between services exports, imports and GDP in India for 1990 to 2024 utilizing secondary data from World Development indicator, World Bank. The findings reveal an upward rising trend in both services export and import in post-liberalisation period particularly following the 1995 implementation of the General Agreement on Trade in Services (GATS). The Augmented Dickey Fuller Unit Root (ADF) test confirmed stationarity after taking first -order differences for non-stationary variables. A Vector Autoregressive Model (VAR) with lag length 3 has been considered for identifying econometric association between services export, import and GDP which reveals that GDP positively influences services exports and services export influences GDP positively. An execution of Granger Causality test identified a bi-directional causality for India's service export and GDP indicating that service export Granger causes GDP and GDP Granger causes services exports. There was no causality found between service export and import and between GDP and service import. Additionally, the Johansen Cointegration test demonstrated that the variables are not cointegrated, i.e., they do not share a long-term relationship, despite exhibiting temporary shared trends. It is imperative to take advantage of the bidirectional causation that India experiences, whereby growing export of services boost the overall GDP and a stronger GDP supports more service sector investments for India to achieve its objective of establishing a "Viksit Bharat", a developed economy by 2047.

Key Words: Association, Service, Export, Import, GDP, India.

1. INTRODUCTION: The services sector accounts for over 60% of India's overall GDP and also is a significant contributor to the total trade of the country. Services export and import perform the role of twin engines for India's GDP. The robust health of the entire economy is highly tied with the ability of the nation to sustain and expand its export of services. Services exports being the critical pillar of India's GDP drive external stability by consistently offsetting large merchandise trade deficits. There is evidence of strong causal link between export of services and GDP and referred to as the "Service-Export Led Growth Hypothesis". Imports of services mainly facilitate further domestic production and export. Again, robust GDP growth fuels the growth in exports in services through generation of capital required for digital infrastructure, increasing domestic demand to test scalable business models, attracting high amounts of Foreign Direct Investment (FDI) into high-value tradable industries. It is



important in this regard to analyse the existing research work describing the empirical association between service export, import and GDP in India .

2. Review of Literature:

1.Dash.,R & Parida, .P (2012) examined the important role of services trade (export and import) in economic growth in India by using Autoregressive Distributed Lag(ARDL) and Vector Error Correction Model (VECM) for the period: Q1:1996-1997 to Q1:2010-2011. This paper also makes use of the impulse response function analysis to supplement the long run equilibrium relationship among GDP, services exports, imports and real effective exchange rate and causality analysis and also to understand the dynamic relationship among the variables. The VECM and impulse response analysis suggests causality running from services exports to GDP emphasizing the services export-led growth in India during the post-reform period.

2.Thomas , M.P(2015) analysed the interrelationship between services trade, economic growth and external stabilization for the Indian economy, during the post-reform period. Examination of contribution of international trade in non-factor services and other invisibles towards India's economic growth and current account stabilization has also been done. The relationship between three macroeconomic variables Current Account Balance, GDP and services trade for Indian economy has been estimated using the ARDL approach to co-integration for the time-span from 1996-97 :Q1 to 2011-2012: Q4. Evidence have been found for existence of co-integrated relationship between Current Account Balance, GDP and service trade for the Indian economy.

3.Rai. ,S &Choudhary,. C(2022) examined the relationship between services export and economic growth of India, utilizing time series data for1991to 2021.The ADF unit root test results reveal that service export and GDP were stationary after taking 1st difference .The results show that there is no cointegrating relationship i.e, long run relationship between GDP and service export. Moreover, results reveal that service export Granger causes GDP but the reverse is not true.

4.Athira ,. A & Rajendran ,. S(2025)examined the long run and short run relationship between export and import of goods and services and Gross Domestic Product(GDP) in India from 1991 to 2023 using the cointegration analysis ,Vector Autoregressive (VAR) model, Granger Causality Test and Impulse Response Function analysis. There is no consistent long run relationship between GDP, exports and imports as shown by Johansen Cointegration test. VAR Granger causality test show that exports cause effect GDP, Imports cause effect GDP, Exports cause import . But results suggest that GDP does not Granger cause Export ,also there is jointly cause effect of GDP and export to import.

5.Mehta., S. N.(2015) investigated the empirical relationship between GDP, Export and Import in India utilizing time series data (1976 to 2014) and ADF unit root test, Johansen Cointegration and Vector Error Connection techniques to examine the long run causality between GDP ,export and Import in India. Results reveal a long-run conintegrating relationship between GDP, export and Import in India. Evidence of unidirectional causality running from GDP to export have been found. No causality between GDP and Import was found .Unidirectional causality between export and import running from export to import was also found.

With this background this paper includes the updated data to analyse the empirical association between GDP ,Export and Import in India.This study includes the following objectives:

3. Objectives of the study:

1.To delineate the trend of export and import of services from India (1990 to 2024) in the post reform period.

2.To test for stationarity of the relevant variables and transform the nonstationary variables into stationary variables using differences of the variables .



3.To identify the causality between service export and GDP in India using a Vector Autoregressive Model (VAR).

4.To examine whether there is any long run relationship between the variables or not.

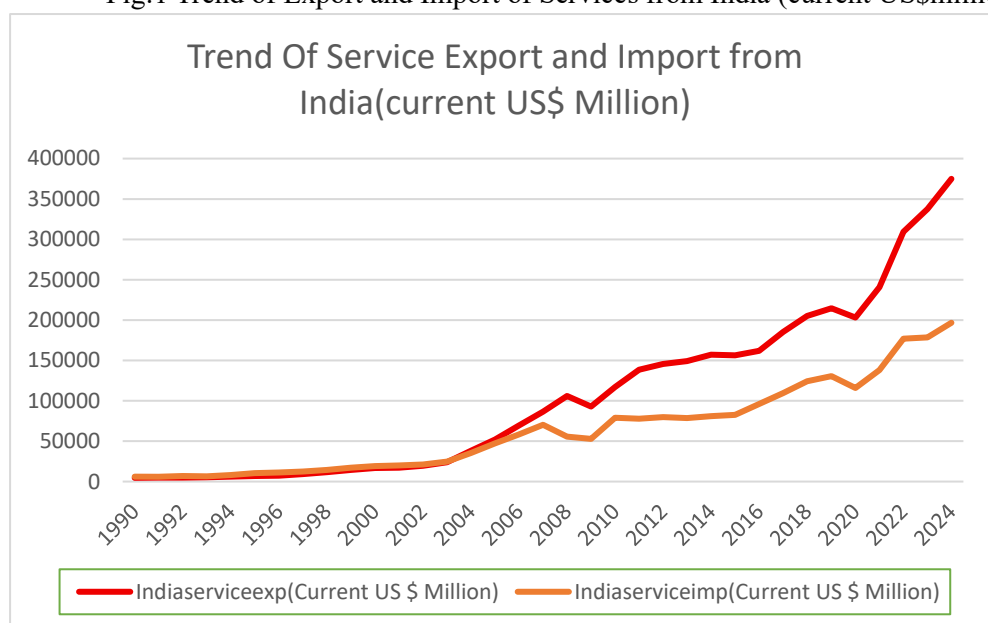
4. Methodology:

This paper used secondary data from World Bank (World Development Indicator) for Export of Services (current US\$), Import of Services (current US \$) and GDP (Current US \$) for India from 1990 to 2024. Graphical analysis has been included to portray the trend of export and import from India in the post liberalization period and to show the association between GDP of India and Service Export from India. Test for stationarity for each variable in India have been carried out using the Augmented Dickey Fuller Unit Root Test. The variables which were found to be nonstationary have been transformed to stationary variables by taking 1st order differences. A Vector Autoregressive Model (VAR) of lag 3 has been considered ,an analysis of causality has been done using the Granger causality test. Johansen Cointegration test has been conducted to test for cointegration i.e, whether there is existence of any longrun relationship between the variables or not. STATA software has been extensively used for analysis of data.

5. Analysis And discussion:

Trend:

Fig:1 Trend of Export and Import of Services from India (current US\$million)

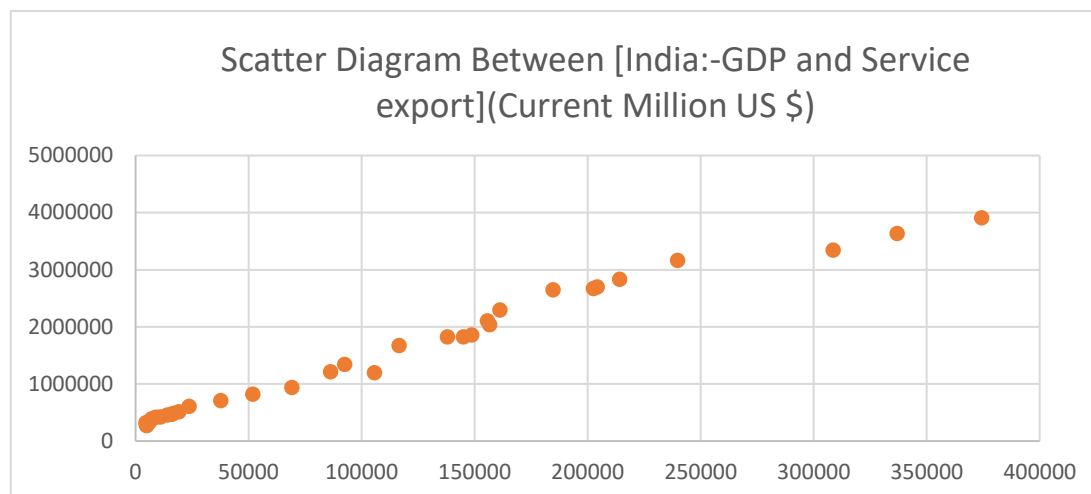


Datasource: World Development Indicators, World Bank

Graph reveals that the trend of export and import from India has been upward rising in the post liberalization period. It received a boost after 1995, the period of GATS(General Agreement On Trade In Services) inception.



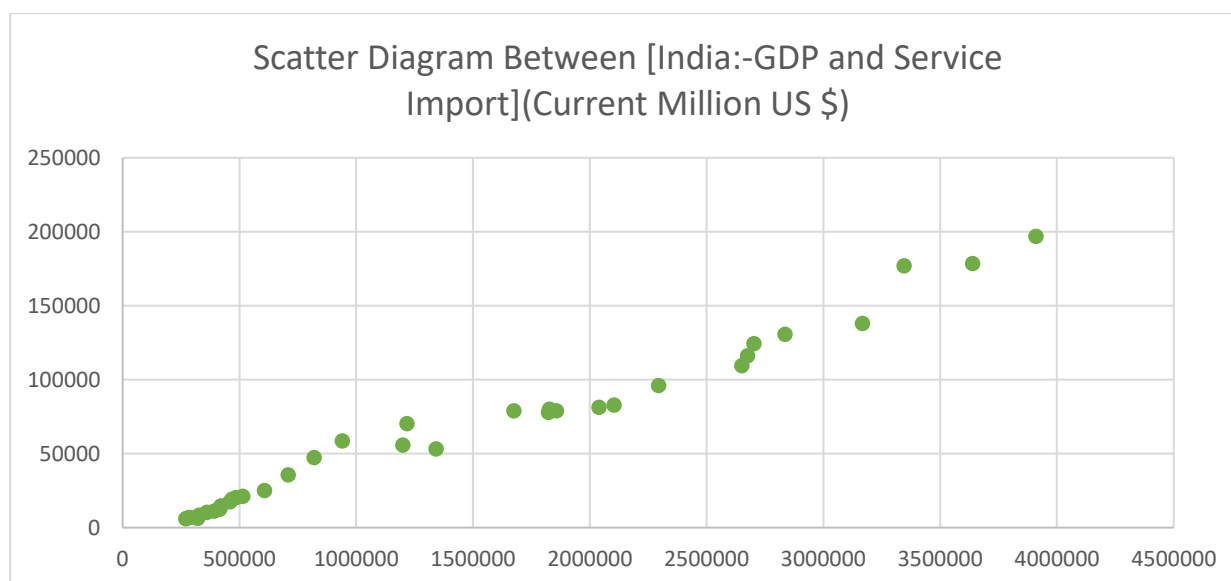
Fig:2 Scatter Diagram Between GDP of India and Service Export from India



Datasource:World Development Indicators, World Bank

Scatter diagram is showing a positive association between India's GDP and India's Service export.

Fig:3 Scatter Diagram Between GDP of India and Service Import from India



Datasource:World Development Indicators,World Bank

Scatter graph is showing positive association between GDP and Import of services from India.

Stationarity Analysis:

Test for stationarity for each variable for India has been carried out using Augmented Dickey Fuller Unit Root Test. The variables which were nonstationary have been transformed to stationary variables by taking 1st order differences. The results are presented below:



Table1: Results from Augmented Dickey Fuller Unit Root Test For Stationarity

Variable	t statistics	P value	Stationary
INDSEREXP	3.875	1.000	UNSTABLE
DINDSEREXP	-3.271	0.0162	STABLE
IGDP	3.057	1.0000	UNSTABLE
DIGDP	-5.174	0.0000	STABLE
INDSERIMP	1.901	0.9985	UNSTABLE
DINDSERIMP	-5.073	0.0000	STABLE

Results show that all the variables have been made stationary by taking 1st order differences.

VAR and Optimum lag selection:

The econometric model using the Vector Autoregressive Model (VAR) is used. Determination of the optimal length of lag of the VAR model is essential. Optimal lag length requires the combination of information criterion (minimum of AIC or SBIC or HQIC or FPE value). This exercise has been carried out as presented below:

Table 2: VAR(lag order selection)

```
. varsoc dindiaserexp dindiaserimp dindiagdp
```

Selection-order criteria

Sample: 1995 - 2024

Number of obs = 30

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-2271.32				1.4e+62	151.621	151.666	151.761
1	-2254.64	33.348	9	0.000	8.5e+61	151.11	151.289*	151.67*
2	-2247.18	14.934	9	0.093	9.6e+61	151.212	151.526	152.193
3	-2232.89	28.584*	9	0.001	7.2e+61*	150.859*	151.307	152.26
4	-2225.94	13.898	9	0.126	9.1e+61	150.996	151.578	152.817

Endogenous: dindiaserexp dindiaserimp dindiagdp

Exogenous: cons

*basically indicates the lag order selected by the criterion.

LL: Log Likelihood ,

LR: Sequential Modified LR (likelihood ratio) Test Statistic (each test at the 5% level of significance),

FPE= Final Prediction Error.

AIC: Akaike Information Criterion.

SBIC: Schwarz Bayesian Information Criterion ,

HOIC: Hannan-Quinn Information Criterion,

D=First Difference of Logarithmic Values Of the Concerned Variables.



Selection-order criteria LR, FPE, AIC show that optimal lag length of VAR should be 3 for India.

Accordingly the following VAR model for 3 variables and 3 lags is used :

$$\Delta \text{INDSEREXP}_t = \sum_{j=1}^3 \alpha_{11,j} \Delta \text{INDSEREXP}_{t-j} + \sum_{j=1}^3 \alpha_{12,j} \Delta \text{IGDP}_{t-j} + \sum_{j=1}^3 \alpha_{13,j} \Delta \text{INDSERIMP}_{t-j} + \epsilon_{t1} \dots eq(1)$$

$$\Delta \text{IGDP}_t = \sum_{j=1}^3 \alpha_{21,j} \Delta \text{IGDP}_{t-j} + \sum_{j=1}^3 \alpha_{22,j} \Delta \text{INDSEREXP}_{t-j} + \sum_{j=1}^3 \alpha_{23,j} \Delta \text{INDSERIMP}_{t-j} + \epsilon_{t2} \dots eq(2)$$

$$\Delta \text{INDSERIMP}_t = \sum_{j=1}^3 \alpha_{31,j} \Delta \text{INDSERIMP}_{t-j} + \sum_{j=1}^3 \alpha_{32,j} \Delta \text{IGDP}_{t-j} + \sum_{j=1}^3 \alpha_{33,j} \Delta \text{INDSEREXP}_{t-j} + \epsilon_{t3} \dots eq(3)$$

Where INDSEEXP, IGDP and INDSEIMP [3 variables] are the time series of export of services from India, GDP and import of services [all in (Current US\$)] from India respectively in first difference form. ϵ_{t1} , ϵ_{t2} , ϵ_{t3} are white noise error terms. Δ is the first difference operator.

Results from VAR model with lag 3 are as demonstrated below: Table3: VAR(3)model results:

. varbasic dindiaserexp dindiaserimp dindiagdp , lags(1/3) step(8)

Vector autoregression

Sample: 1994 - 2024
Log likelihood = -2305.908
FPE = 6.07e+61
Det(Sigma_ml) = 8.16e+60

Number of obs = 31
AIC = 150.7037
HQIC = 151.1561
SBIC = 152.0915

Equation	Parms	RMSE	R-sq	chi2	P>chi2
dindiaserexp	10	1.4e+10	0.4938	30.23869	0.0004
dindiaserimp	10	1.1e+10	0.2873	12.49658	0.1867
dindiagdp	10	1.3e+11	0.3086	13.83337	0.1284

	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
dindiaserexp						
L1.	.1084212	.3263865	0.33	0.740	-.5312845	.7481269
L2.	.4397019	.3139714	1.40	0.161	-.1756708	1.055075
L3.	.2234614	.2926345	0.76	0.445	-.3500918	.7970146
dindiaserimp						
L1.	.1878061	.3882212	0.48	0.629	-.5730935	.9487057
L2.	-.4518902	.3923923	-1.15	0.249	-1.220965	.3171845
L3.	.6101376	.4708324	1.30	0.195	-.312677	1.532952
dindiagdp						
L1.	.0693985	.0296909	2.34	0.019	.0112055	.1275915
L2.	-.0173977	.0290299	-0.60	0.549	-.0742952	.0394999
L3.	-.0569797	.0381999	-1.49	0.136	-.13185	.0178907
_cons	3.06e+09	3.65e+09	0.84	0.401	-4.09e+09	1.02e+10
dindiaserimp						
L1.	.0506513	.2563817	0.20	0.843	-.4518477	.5531502
L2.	.3662382	.2466295	1.48	0.138	-.1171468	.8496232
L3.	-.1748443	.2298691	-0.76	0.447	-.6253794	.2756908
dindiaserimp						
L1.	-.2730829	.3049539	-0.90	0.371	-.8707815	.3246157
L2.	-.6469836	.3082303	-2.10	0.036	-1.251104	-.0428633
L3.	.2273156	.3698463	0.61	0.539	-.4975699	.9522011
dindiagdp						
L1.	.0423173	.0233226	1.81	0.070	-.0033943	.0880288
L2.	-.0046301	.0228034	-0.20	0.839	-.049324	.0400638
L3.	-.0120813	.0300066	-0.40	0.687	-.0708931	.0467306
_cons	4.43e+09	2.86e+09	1.55	0.122	-1.18e+09	1.00e+10
dindiagdp						
L1.	-1.953622	3.160033	-0.62	0.536	-8.147172	4.239929
L2.	5.955917	3.039832	1.96	0.050	-.0020444	11.91388
L3.	6.575726	2.833251	2.32	0.020	1.022656	12.1288
dindiaserimp						
L1.	-.087045	3.758709	-0.02	0.982	-7.453979	7.279889
L2.	-7.41469	3.799093	-1.95	0.051	-14.86078	.0313942
L3.	-1.106368	4.558541	-0.24	0.808	-10.04094	7.828208
dindiagdp						
L1.	.2116154	.2874632	0.74	0.462	-.3518021	.7750328
L2.	.4117922	.2810638	1.47	0.143	-.1390826	.9626671
L3.	-.5607882	.3698462	-1.52	0.129	-1.285673	.164097
_cons	6.33e+10	3.53e+10	1.79	0.073	-5.83e+09	1.33e+11



6. Results Summarised / Findings:

Service export is impacted by GDP in India in lag 1 positively and it is statistically significant. 1\$ increase in GDP would lead to increase in export of services by 0.069 \$. Import negatively affected at lag 2 by itself but positively at lag 1 by GDP by coefficient 0.0423. 1\$ increase in GDP would lead to increase in import of services by 0.042 \$. So GDP increases both service export and import. Coefficient for export of services from India are 5.955 at lag2 and 6.575 at lag3 respectively indicating that a 1\$ increase in export in services from India would increase GDP by 5.96\$ at lag 2 and 6.57\$ in lag 3 respectively. Coefficient for import of service from India is -7.414 at lag 2 which is statistically significant at 5% level indicating a 1\$ increase in service import would reduce GDP by 7.414 \$ which is a serious concern.

The Estimated Vector Autoregressive Model (VAR) is shown below:

$$\Delta \text{INDSEREXP}_t = 0.06939 \Delta \text{IGDP}_{t-1} \quad (1)$$

$$\Delta \text{INDSERIMP}_t = (-0.6469) \Delta \text{INDSERIMP}_{t-2} + 0.4231 \Delta \text{IGDP}_{t-1} \quad (2)$$

$$\Delta \text{IGDP}_t = 5.955 \Delta \text{INDSEREXP}_{t-2} + 6.5757 \Delta \text{INDSEREXP}_{t-3} + (-7.414) \Delta \text{INDSERIMP}_{t-2} \quad (3)$$

These VAR models can be used for forecasting the future values of INDSEREXP, INDSEIRIMP and IGDP using the lagged values of dependent and independent variables.

Now to check for stability we use the test below:

Table 4 : Varstable

```
. varstable
```

Eigenvalue stability condition

Eigenvalue	Modulus
-.9600796	.96008
.8575793 + .1340642i	.867995
.8575793 - .1340642i	.867995
-.07393237 + .8258089i	.829112
-.07393237 - .8258089i	.829112
-.4178169 + .5384192i	.681518
-.4178169 - .5384192i	.681518
.1376866 + .5149447i	.533034
.1376866 - .5149447i	.533034

All the eigenvalues lie inside the unit circle.

VAR satisfies stability condition.

```
. *all the modulus value <1 ,so VAR satisfies the stability condition
. predict error,residual
(4 missing values generated)
```

*All the modulus values <1, so VAR satisfies the stability condition .

Test for Granger Causality: Granger Causality Test has been conducted to examine the causal linkages between the variables in order to determine the direction of impact of variables and to capture the impact of variables observed in the past time period in explaining the future performances.



Table5: Granger Causality Wald Test Results:

. vargranger

Granger causality Wald tests

Equation	Excluded	chi2	df	Prob > chi2
dindiaserexp	dindiaserimp	4.0775	3	0.253
dindiaserexp	dindiagdp	8.0659	3	0.045
dindiaserexp	ALL	14.25	6	0.027
dindiaserimp	dindiaserexp	2.9294	3	0.403
dindiaserimp	dindiagdp	4.902	3	0.179
dindiaserimp	ALL	7.6172	6	0.268
dindiagdp	dindiaserexp	9.6006	3	0.022
dindiagdp	dindiaserimp	4.1304	3	0.248
dindiagdp	ALL	11.988	6	0.062

Results from Granger Causality Test show that GDP granger causes Export of Services ,no causality between service export and import and between service import and GDP was detected. Export of services granger cause GDP.From results it has been evident that there is a Bi-directional causality between service export and GDP in India.

Test for Cointegration:

To test for cointegration i.e, whether there is existence of any longrun relationship between the variables or not we use the Johansen Test for Cointegration:

Table6: Johansen Tests For Cointegration Results:

. vecrank Indiaserviceexp Indiaservimp IndiaGDP,trend(constant) max

Johansen tests for cointegration

Trend: constant Number of obs = 33
Sample: 1992 - 2024 Lags = 2

5%					
maximum				trace	critical
rank	parms	LL	eigenvalue	statistic	value
0	12	-2476.6105	.	28.0040*	29.68
1	17	-2466.2975	0.46475	7.3781	15.41
2	20	-2463.3677	0.16269	1.5186	3.76
3	21	-2462.6085	0.04497		
5%					
maximum				max	critical
rank	parms	LL	eigenvalue	statistic	value
0	12	-2476.6105	.	20.6260	20.97
1	17	-2466.2975	0.46475	5.8595	14.07
2	20	-2463.3677	0.16269	1.5186	3.76
3	21	-2462.6085	0.04497		

Johansen cointegration test:

H0: There is cointegration

H1: There is no cointegration

Results show that ,At rank 0 , trace statistic value is less than 5% critical value.So,we cannot reject H0. Conclusion: There is existence of zero cointegration which means that variables are not cointegrated to each other .Variables may drift together temporarily because of shared trends ,but they do not converge in the long run. There is no longrun relationship. Deviations from the equilibrium do not correct themselves overtime. The linear combination of variables is not stationary.



Measures to boost GDP and Export of Services from India:

To boost GDP of India and thereby expand export in services through it India should prioritize workforce upskilling, improve digital infrastructure, and provide policy incentives. Major strategies should include utilizing tax reforms for foreign cloud services, diversifying into high-value sectors, finalization of Free Trade Agreements (FTAs) focusing on digital services, developing Special Economic Zones (SEZs) in the smaller cities, and improvement of training in emerging technologies like AI and cloud computing.

Enhancing India's GDP through export of services requires diversification beyond traditional IT into high-value sectors like healthcare and environmental consulting services. Key actions should include establishing Global Capability Centers (GCCs) in order to attract multinational corporations, pushing into growing areas like Green Services and Fintech, leveraging tier-2 and tier-3 cities for operational cost advantages, expansion of travel and tourism infrastructure, and aligning development of skill with world technology demands.

7. Conclusion And Recommendations:

Reaping the bidirectional causality experienced by India—where expanding services exports drives the overall GDP, and a stronger GDP fuels further service sector investments—is essential for India's goal of becoming a 'Viksit Bharat', developed economy reaching a US\$30 plus trillion economy by 2047. In order to achieve this, India should leverage technology, integrate into global value chains and transition to high-value services.

Actionable roadmaps to realize this vision include: a. Developing Technological integration: Expanding the reach of AI, blockchain, and the Internet of Things (IoT) for high-value services like banking, healthcare, retail to scale up and improve productivity across all sectors, b. Expansion of global market access: Making use of recently signed Free Trade Agreements to allow Indian service providers to successfully enter developed markets more effectively, c. Fostering an Export Ecosystem: Aligning domestic quality standards and regulations with global expectations to lead to increase in share of international trade.

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Parenting Styles and Attachment Patterns: A Framework for Adolescent Social Competence

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Abstract: Adolescence is a significant developmental stage that commences with the onset of puberty and ends in the mid-20s. It is characterised by rapid biological, cognitive and psychosocial changes within the individual. This stage is a crucial stage where the interpersonal abilities of the adolescent are developed that in turn determines their psychosocial adjustment for the future. Social competence is the ability of the individual to successfully engage with others in an appropriate manner. It is a core life skill that impacts an individual's interpersonal relationships, behavioural and psychosocial adjustments, emotional wellbeing, academic and career functioning and many other domains. This conceptual paper uses the developmental and psychological frameworks of parenting styles and attachment patterns to understand its impact on the development of social competence in adolescents. Parenting styles as conceptualized by Baumrind in 1966 and later in 1991 is defined as the emotional atmosphere and methods of discipline employed by parents, defined along the dimensions of responsiveness and demandingness of parents. Attachment patterns are the psychological models of relationships that develop based on early parent-child interactions and experiences. These attachment patterns play a significant role in the development self-identity, empathy, interpersonal or intimate relations, social exposure and social skills of an individual further influencing their social competence. This paper uses the parenting model within the cultural context of a collectivist society such as India to propose a linkage between parenting styles, attachment patterns and the consequent development of adolescent social competence. It advances the theoretical integration of parenting styles, attachment patterns and social competence offering implications for parents, educators, mental health professionals and research.

Keywords: parenting styles, attachment patterns, adolescence, social competence, developmental psychology, integrated framework

1. INTRODUCTION

Adolescence is a critical developmental stage during which significant psychological, cognitive, emotional, behavioural and social changes take place. During this developmental stage, adolescents move beyond the primary social sphere of their families and engage extensively with peers and establish meaningful relationships. According to Erikson (1968), the process of identity formation occurs during adolescence when adolescents face the psychological challenge of identity versus role confusion. This is when they try to establish their own identity. For adolescents, successfully navigating this stage depends largely upon their ability to communicate effectively, respond appropriately to social situations, regulate emotions and resolve interpersonal conflicts. These abilities collectively referred to as social competence are a cornerstone of healthy development during adolescence with lifelong implications. According to Sroufe (2005), the psychological wellbeing for an adolescent depends largely on their



ability to establish and sustain peer interactions. Social competence also helps in the development of healthy relationships, successful academic adjustment and effective functioning in adulthood (Rose-Krasnor, 1997). On the other hand, poor social competence skills may lead to social isolation and psychological and behavioural problems (Rubin et al., 2015).

Social competence does not develop in isolation. There are many determinants of social competence during childhood and adolescence, particularly the quality of the relationship between the parent and the child. Parenting styles play a crucial part in an adolescent's social competency development, autonomy, emotional expression and discipline. Similarly, early relationships between parents and a child establish an internal working model for a child according to Bowlby (1982) in his theory. This interaction helps the individual to understand the future interactions and behavioural standards they will hold with other people throughout their lives.

This paper studies the development of social competence from two theoretical perspectives- parenting styles and attachment theory. Parenting styles, attachment patterns and social competence are all significant aspects of adolescent development and researchers have thoroughly examined parenting styles, attachment patterns and social competence as significant aspects for adolescent development. Previous research has examined the relationship between parenting styles and adolescent social competence, while others have studied the relationship between attachment patterns and social competence. In addition to these studies, there is significant research exploring the relationship between parenting styles and attachment. However, these constructs have not been studied together in an integrated way, especially in the case of adolescents in India. These relationships collectively will provide a more comprehensive view of adolescent social development. Therefore, this paper proposes a theoretical framework integrating parenting styles, attachment styles and adolescent social competence. It suggests that parenting styles impact the attachment patterns of adolescents, which further impact their social competence.

Furthermore, the majority of the literature on parenting styles has emerged from Western, individualistic cultures. The notion of control and responsiveness have different meanings in collectivist societies like India. Indian research on parenting styles indicates that balanced parental control and support have positive implications in the social development of adolescents. This leads to the conclusion that Western theories of parenting may be inadequate in regards to collective cultures like India. Therefore, this paper further proposes an integrated theoretical and culturally informed framework.

2. Theoretical Foundations

Parenting Styles

Diana Baumrind discovered three distinct styles of parenting – authoritative, authoritarian and permissive parenting, based on two factors – responsiveness and demandingness (Baumrind, 1966). While demandingness is primarily linked to supervision, expectations, discipline and control, responsiveness encompasses warmth, support, communication and awareness of the child's needs.

Maccoby and Martin (1983) later elaborated on this model by introducing another type of parenting known as neglectful or uninvolved parenting. Authoritative parenting involves highly responsive and well-controlled parenting styles. It is characterised by open communication, emotional support and opportunities for independence, all the while setting high expectations for their children. The authoritarian parenting style focuses on conformity and obedience. Parents exert high control while showing comparatively little warmth to their children. Permissive parenting involves parents being very receptive, giving their children a lot of independence and autonomy, making few demands and exercising little control. Low warmth and lack of control are characteristics of neglectful or uninvolved parenting.

Parenting styles are important because they influence the development of trust, boundaries, relationships, communication and emotional expression. Nevertheless, the impact of each style can differ depending on the cultural context. (Chao, 2001).



Attachment Theory

Attachment theory originated with John Bowlby (1969, 1973), who suggested that during times of stress, children, particularly infants, innately look for proximity to their primary attachment figure. According to Bowlby, repeated interactions with a parent lead to the formation of an internal working model that acts as a cognitive-emotional framework of the self, others and relationships.

Ainsworth et al. (1978) added to this understanding and further contributed to the attachment theory by identifying attachment classifications based on infants' responses to separation and reunion. In secure attachment, a person is more confident when it comes to relationships and they are able to seek support while being independent as well. Anxious attachment is characterised by anxiety, a need for reassurance and concerns about potential rejection, whereas people with avoidant attachment have discomfort with intimacy and closeness. In the case of disorganised attachment, a person displays inconsistent or contradictory responses to relationships that develop due to confused and unpredictable parenting. Even though these classifications given by Bowlby and Ainsworth were based on infancy and childhood, later research extended this attachment theory beyond infancy, stating that attachment classifications further predict relationship patterns in adolescence and adulthood (Main et al., 1985).

Parenting and attachment are related theoretically and offer distinct perspectives for studying early social development. The nature and quality of interactions between parents and children shape the attachment types and internal models of self and other people (Mikulincer & Shaver, 2016).

Social Competence

Social competence is a person's proficiency in handling social interactions and their ability to construct and maintain satisfying relationships with others while regulating emotions and behaviour in socially appropriate ways. It is a multidimensional concept that combines behavioural, emotional and cognitive skills to support adaptive interpersonal functioning (Rose-Krasnor, 1997). It consists of skills such as communication skills, perspective-taking, conflict management and social problem solving, along with emotional regulation and empathy and behavioural skills like cooperation and conflict resolution (Rubin & Rose-Krasnor, 1992). The development of social competence is crucial during adolescence, as it is during this developmental stage that adolescents begin to form an identity and experience well-being through their peers and social interactions become more complex (Rubin et al., 2006). Attachment styles greatly influence the development of social competencies. Adolescents who have secure attachment are socially effective and accepted by their peers, form close relationships and resolve conflicts effectively. On the contrary, insecure attachment styles might influence adolescents' perception of social situations as well as their reactions to different situations, including rejection, conflicts, intimacy or interpersonal stress (Mikulincer & Shaver, 2016).

3. Empirical Links between Parenting, Attachment and Social Competence and Proposed Integrated Framework

Over the years, many studies in developmental psychology have focused on parenting practices, attachment patterns and social competence. According to existing empirical literature, the three constructs mentioned above have been examined either independently or as part of a single pairwise relationship. Reviewing these relationships and including findings from Indian samples shows the current evidence and furthermore the gap in research, highlights the need for an integrated framework.

Parenting styles and Attachment Patterns

The relationship between parenting practices and attachment represents one of the most extensively documented associations in developmental psychology. Bowlby (1969/1982) shared that a child's relationship with their parent leads to the formation of an internal working model of relationships. Research studies indicate that warmth and responsiveness foster secure attachment, whereas controlling or intrusive parenting practices are often associated with anxious-avoidant attachment. When parents are emotionally available and responsive, children receive a secure base to explore and believe that others are trustworthy and dependable. On the other hand, inconsistent, confusing and rejecting parenting foster insecure attachment patterns (Ainsworth et al., 1978).



Research has found that parental warmth and responsiveness relate to attachment security. De Wolff and Van IJzendoorn (1997) conducted a meta-analysis of 66 studies examining the parenting-attachment link and found that maternal sensitivity accounted for only approximately 34% of the variance in attachment security. This suggests that while parenting matters, other factors, including the child's personality and temperament, wider social environment and parental mental health, also shape attachment formation.

It is important to note that for adolescents in India, a positive relationship between attachment, social competence and interpersonal functioning is found. The meanings of warmth, responsiveness and autonomy may differ across cultural settings. Historically, Western assumptions about parenting which emphasise independence and individuality have influenced attachment research. In collectivistic societies, interdependence, family connectedness and parental involvement are highly valued. Therefore, in collectivistic societies activities that Western culture considers controlling may serve different functions (Kağıtçıbaşı, 2007). In India, warmth and control can coexist without implying parental rejection. Sondhi (2017) suggests that parental-child relationships in India are interdependent in nature and focus on obligations and duties towards parents. In a Western context this may seem restrictive, but for Indian adolescents, parental involvement is a way to show care and concern. In a recent mixed-methods study in India, Sharma et al. (2026) reported that adolescents perceived parental involvement and control as supportive, especially when it was orientated toward academic achievement. Research conducted in China shows similar results but with some important differences. Cai et al. (2013) study showed that while authoritative parenting positively correlated with parent-adolescent attachment, psychological control and overprotection correlated with negative predictions in terms of parent-adolescent attachment.

Therefore, the Indian and collectivist viewpoint contends that the Western autonomy-versus-control framework is insufficient to comprehend parenting-attachment interactions if not looked through a cultural lens.

Attachment and Social Competence

Attachment theory, first described by John Bowlby and later elaborated by Mary Ainsworth, provides a basic model for understanding early relationships and later social competence. As suggested by Bowlby (1980), the internal working models are the schemas through which adolescents encode social cues and work out how to behave in peer environments. Research has shown that securely attached adolescents have high trust and responsiveness that contributes to greater confidence in initiating friendship and managing conflict (Cohn, 1990). Conversely, adolescents with avoidant or anxious patterns of attachment distrust the availability and responsiveness of others leading to poor social competence. Kerns et al. (1996) found that young adolescents who were securely attached reported more reciprocal friendships, higher peer acceptance and lower rates of loneliness than insecurely attached peers.

An Indian study by Kumar and Raj (2016) found that there is a positive relationship between attachment, social competence and interpersonal functioning in adolescents in India. Mahajan and Dhillon (2025) noted that parents play a significant role in developing prosocial behaviours among Indian adolescents. Alienation from parents result in a lower levels of empathy and cooperation.

While these findings generally align with Western attachment research, they also point out the importance of cultural context. In collectivist societies like India, social competence also includes cooperation, relationship sensitivity, respect for family and interpersonal harmony, which is different from Western individualistic cultures. Hence, it is important to analyse the relationship between attachment and social competence within the framework of a specific culture.

Parenting and Social Competence

Researchers have traditionally explained the relationship between parenting and social competence through the dimensions of responsiveness and demandingness. In western samples, researchers have found that authoritative parenting fosters greater social competence, while authoritarian and permissive parenting lead to poorer outcomes (Chen et al., 2000).



Research from India supports the above findings but highlights additional cultural aspects. Rency and Chacko (2021) confirmed that there is positive relationship between parenting and the level of social competence in adolescents in Cochin. In collectivist societies like India, people do not necessarily view parental control as poor parenting. According to Sondhi (2017), Indian families value obedience, family responsibilities and interdependence, that could be labelled as authoritarian parenting according to Western standards. However, in India, such parenting fosters better social competence skills through parental involvement. Sharma et al. (2026) in their research highlighted this cultural peculiarity. They observed that adolescents found parental involvement and behavioural and psychological control to be both supportive and restrictive. The researchers called this phenomenon the ‘competency–control paradox’, meaning that parental involvement can be beneficial for the adolescents, but excessive control compromises their competency development.

Researches done in Asian collectivist cultures also challenge the interpretation of control as negative in nature. According to Cheung and Pomerantz (2011) and related studies, Chinese teenagers may see parental regulation as a matter of family harmony and parental duty. Ang (2006) studied parenting styles and their impact on social and personal outcomes among Asian adolescents in Singapore and discovered that a father’s parenting style strongly predicted adolescents’ feelings of inadequacy and self-reliance. However, the way these effects manifested varied by ethnic subgroup, suggesting that the connection between parenting and competence is not consistent across cultures, even within a region broadly characterised as collectivist.

Therefore, parenting and social competency may have a culturally rooted relationship. Parenting can impact the growth of social competence not only by encouraging individual autonomy but also through responsibility, cooperation, emotional availability, social expectations and family connectedness.

Proposed Integrated Framework

The proposed integrated framework connects parenting styles with the development of social competence in adolescence and the mediating role of attachment patterns. The model proposed in this paper integrates the above three theories into one theory explaining how parenting styles affect the formation of attachment, which in turn affects the adolescent’s ability to be socially competent, while recognising cultural context as a moderating influence. It also acknowledges that parenting likely shapes social competence through additional channels the model does not claim to capture, such as direct modelling of social behaviour or structuring peer exposure (Chen et al., 2000).

The proposed framework consequently addresses the fragmentation in the existing literature by bringing together three important developmental constructs within a single conceptual model. Rather than examining parenting, attachment and social competence as independent areas of study, it proposes a developmental sequence in which parenting experiences may shape attachment patterns, attachment may influence social competence and parenting may also exert a direct influence on social competence. Cultural context is incorporated to recognise that these relationships are embedded within particular family and socio-cultural systems.

The framework is therefore particularly relevant for understanding adolescents in urban India, where traditional family values coexist with changing expectations concerning autonomy, independence, education and peer relationships.

The framework also provides a basis for future empirical research to test whether attachment functions as an intervening mechanism between parenting styles and social competence and whether cultural context changes the nature or strength of these relationships. In this way, the proposed model directly responds to the identified research gap and provides an integrated theoretical foundation for examining adolescent development within the Indian context.

4. Implications

The suggested framework has practical implications for several domains. For *parenting interventions*, the model suggests that programmes should target attachment-relevant parenting behaviours, such as responsiveness and consistency, to improve adolescent social competence.



For *clinical practice and for mental health practitioners*, the model suggests that adolescents presenting with social difficulties may benefit from an assessment of attachment history along with current parenting dynamics, rather than viewing social competence in isolation from the family context. Interventions can also focus on improving parent–adolescent communication and relationship quality. For *educators*, the framework recognises the influence of family relationships and attachment on students' social and emotional functioning. Schools and colleges can therefore incorporate programmes that strengthen communication, emotional regulation, interpersonal skills and positive parent–adolescent relationships. However, this need is culture specific, especially in collectivist contexts such as India, where relational harmony and interdependence may be more central to social competence than assertiveness or independence.

For *future researchers*, the framework provides a basis for empirically testing the proposed relationships and examining whether attachment mediates the relationship between parenting styles and social competence, while also investigating how cultural context influences these relationships.

5. Limitations & Future Research

There are some limitations of the proposed framework that should be taken into account while interpreting the paper.

First, the paper is conceptual and does not present original empirical data to establish the proposed links between parenting styles, attachment patterns and social competence. Therefore, the suggested pathways, including the possible mediating role of attachment remain as propositions.

Second, the existing literature has examined these constructs independently or in pairs, limiting the extent to which conclusions can be drawn about their integrated relationship.

Third, the proposed framework provides attention to the Indian sociocultural context. India is a large country characterised by considerable cultural, regional, socioeconomic and family diversity. Therefore, the framework may not adequately represent the experiences of all Indian adolescents.

Fourth, the framework primarily focuses on parenting and attachment and may not fully delve into other factors affecting social competence, such as peer relationships, school environment, personality, socioeconomic conditions, digital interactions and broader community influences.

Future empirical research using larger and more diverse samples, with culturally appropriate measures and longitudinal or structural approaches, would be required to test and refine the proposed framework.

6. Conclusion

Adolescence is a significant developmental period characterised by substantial changes in emotional, behavioural, interpersonal and social functioning. This paper suggests that parenting affects how adolescents develop attachment patterns, which is a potential pathway through which parenting experiences relate to adolescents' social competence and social competence as the developmental outcome.

The review of empirical links across all three constructs showed that while each pairwise relationship is well supported individually, relatively few studies test these concepts together and even fewer account for cultural variation. The framework was developed to fill that void. Evidence from India and other collectivist societies has been used to show that family relationships, parental involvement, interdependence and expectations of autonomy influence adolescent experiences of parenting and attachment in unique ways, emphasising the significance of culturally sensitive interpretation.

In conclusion, this paper adds to a more holistic understanding of adolescent social development by integrating parenting, attachment and social competence into a single researchable conceptual model. Such an integrated, culturally responsive perspective offers a foundation not only for future longitudinal, cross-cultural research using established measures but also for parenting interventions, clinical practice and school-based programmes. This will further advance the study of adolescent development in India.



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Development, Validation, and Greenness Assessment of an LC–MS/MS Method for Pharmaceutical Quality Evaluation of Herbal Drug Formulations

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Abstract: Herbal drug formulations face significant quality control challenges due to inherent chemical complexity and batch-to-batch variation. This study describes the development, validation, and greenness assessment of a rapid, sensitive, and sustainable Liquid Chromatography-Tandem Mass Spectrometry (LC–MS/MS) method for the simultaneous quantification of key bioactive marker compounds—**Curcumin**, **Ginsenoside Rg1**, and **Quercetin**—in a polyherbal formulation. Chromatographic separation was achieved within 6.0 minutes using an eco-friendly mobile phase consisting of acidified ethanol and water on a reversed-phase C18 column. Method validation was performed according to ICH Q2(R1) guidelines, demonstrating excellent linearity ($r^2 > 0.999$), high precision ($RSD < 2.5\%$), and accurate recoveries (95.0% – 102.0%). The environmental sustainability of the method was rigorously evaluated using the Analytical Eco-Scale, the Green Analytical Procedure Index (GAPI), and the Analytical Greenness Metric (AGREE). Scoring 89 on the Eco-Scale, showing a predominantly green profile on GAPI, and achieving an AGREE score of 0.79, the proposed method qualifies as an excellent "green" alternative to conventional acetonitrile/methanol protocols for routine pharmaceutical quality evaluation of complex herbal matrices.

Keywords: Herbal drugs, Curcumin, Ginsenoside Rg1, Quercetin, LC-MS/MS, ICH Q2(R1), Green Analytical Procedure Index (GAPI), and the Analytical Greenness Metric (AGREE).

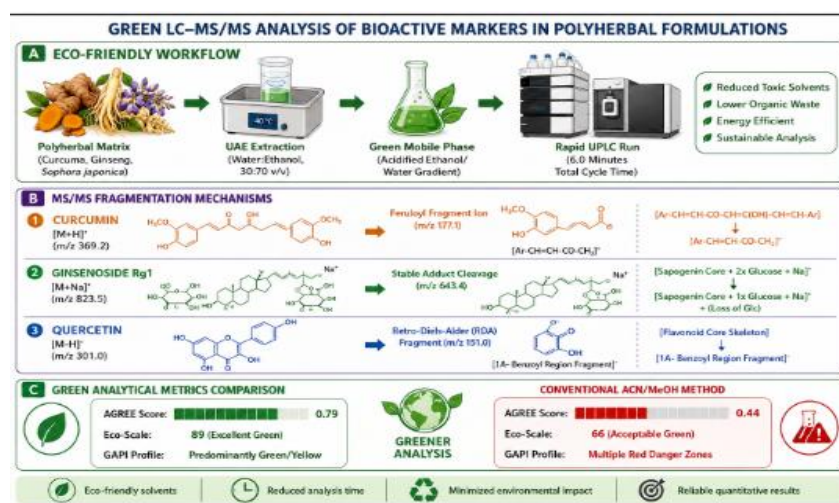


Figure 1: Graphical Abstract



1. INTRODUCTION

Herbal medicines are increasingly integrated into global healthcare systems. However, ensuring their safety, efficacy, and consistency remains difficult due to the presence of hundreds of secondary metabolites in a single formulation. Traditional quality control methods often rely on single-marker analysis using high-performance liquid chromatography coupled with ultraviolet detection (HPLC-UV). These methods frequently lack the specificity required for complex polyherbal matrices and suffer from long run times and high organic solvent consumption.

Liquid Chromatography-Tandem Mass Spectrometry (LC-MS/MS) offers superior selectivity, sensitivity, and throughput via Multiple Reaction Monitoring (MRM) modes. Despite these analytical advantages, standard LC-MS/MS methods heavily rely on hazardous solvents like acetonitrile and methanol, posing environmental and occupational risks.

Green Analytical Chemistry (GAC) principles dictate the minimization of waste, energy reduction, and substitution of toxic reagents with safer alternatives. This research addresses the dual need for advanced analytical capability and environmental responsibility. It details the development, validation, and greenness assessment of an LC-MS/MS method tailored for the comprehensive quality evaluation of herbal formulations containing *Curcuma longa* (turmeric), *Panax ginseng* (ginseng), and alluvial flavonoids (such as from *Sophora japonica*).

Curcuma longa, commonly known as turmeric, is a vital perennial herb in the ginger family valued worldwide for its culinary, medicinal, and cultural importance. It has Anti-inflammatory properties and has Antioxidant effects. Ginsenoside Rg1 is a potent, naturally occurring bioactive compound found primarily in the roots, stems, and leaves of the *Panax ginseng* (Asian ginseng) plant. Chemically classified as a triterpenoid saponin (specifically of the protopanaxatriol family), it is recognised by researchers as one of the chief active ingredients driving ginseng's legendary medicinal properties. Quercetin is an important plant flavonoid that functions as a powerful antioxidant and anti-inflammatory agent. It fights free radicals, reduces inflammation, eases allergies, supports heart health and aids immune function. Its dietary sources are onions, fruits like apples, berries, and dark cherries, vegetables like broccoli, kale, and green leafy vegetables.

2. Experimental Section

2.1 Reagents and Chemicals

The Standard bioactive markers, **Curcumin**, **Ginsenoside Rg1**, and **Quercetin** (purity 98.0%) obtained from standard repositories. Absolute ethanol (HPLC grade, biodegradable alternative solvent) and Formic acid (analytical grade, mobile phase modifier) was used for the study. Ultra-pure water 18.2 MΩ Cm obtained via a water purification system.

2.2 Sample Preparation

Polyherbal samples were finely powdered. A 100 mg aliquot was extracted via ultrasound-assisted extraction (UAE) using an eco-friendly solvent mix (Water:Ethanol, 30:70 v/v) for 15 minutes. The mixture was centrifuged at 10,000 rpm for 5 minutes, and the supernatant was filtered through a **0.22 µm** syringe filter prior to LC-MS/MS injection.

2.3 Instrumentation and Chromatographic Conditions

An LC-MS/MS system equipped with a triple quadrupole mass spectrometer and an electrospray ionization (ESI) source was utilized.

- **Column:** C18 Reversed-Phase Column 100mm (column length, 2.1mm Internal Diameter, 1.7 µm (particle size).
- **Mobile Phase A:** 0.1% Formic acid in Ultra-pure water.
- **Mobile Phase B:** 0.1% Formic acid in Ethanol.



- **Elution Mode:** Gradient program optimized from 10% B to 85% B over 4.5 minutes, returning to initial conditions for re-equilibration. Total run time: 6.0 minutes.
- **Flow Rate:** 0.3 mL/min.
- **Injection Volume:** 2 μ L.

2.4 Mass Spectrometry Conditions

The MS source operated in both positive and negative ESI modes using Multiple Reaction Monitoring (MRM). Source temperature, gas flows, collision energies (CE), and declustering potentials (DP) were optimized individually for each marker compound to maximize product ion yield and signal-to-noise ratios.

Table 1: Mass Spectroscopy Conditions

Compound Name	Ionization Mode	Precursor Ion (m/z)	Quantifier Ion (m/z)	Qualifier Ion (m/z)	DP (V)	CE (eV)
Curcumin	ESI+	369.2 $[M+H]^+$	177.1	145.0	70	28 / 34
Ginsenoside Rg1	ESI+	823.5 $[M+Na]^+$	643.4	403.3	90	42 / 55
Quercetin	ESI-	301.0 $[M-H]^-$	151.0	179.0	-65	-30 / -26

2.4.1 Tandem Mass Spectrometry (MS/MS) Source and Gas Configurations

Mass spectrometric detection was performed on a triple-quadrupole mass spectrometer equipped with a Turbo V electrospray ionization (ESI) source operating in fast-polarity switching mode. Source gas pressures, temperatures, and ionization voltages were meticulously optimized using direct infusion of individual reference standards (100 ng/mL in 50% acidified ethanol) at a flow rate of 10 μ L/min to achieve maximum signal-to-noise ratios (S/N) while preventing in-source thermal degradation of the fragile ginsenoside saponin core.

The finalized, high-performance ESI source parameter matrix was established as follows:

Curtain Gas (CUR): 35 psi high-purity nitrogen, 99.999% to prevent contamination of the ion optics from complex botanical matrix residue.

Ion Source Gas 1 (GS1, Nebulizer Gas): 50 psi to facilitate efficient droplet formation of the viscous ethanol-based mobile phase.

Ion Source Gas 2 (GS2, Heater Gas): 55 psi to ensure complete desolvation of the analytical stream.

Source Temperature (TEM): 500°C to counter the high boiling point and evaporation enthalpy of the water-ethanol matrix.

Collision-Activated Dissociation Gas (CAD): 9 psi (medium-high setting) using high-purity nitrogen to optimize fragmentation yield across all three structural classes.

Ion Spray Voltage (IS):

Positive Ionization Mode ESI⁺: +5500 V (optimized for Curcumin protonated monomers and Ginsenoside Rg1 sodium adducts).

Negative Ionization Mode ESI⁻: -4500V (optimized for Quercetin deprotonated phenolate structures).

Entrance Potential (EP): $\pm$ 10 V (polarity-dependent).

Collision Cell Exit Potential (CXP): $\pm$ 12 V (polarity-dependent).

Data acquisition and instrument control were driven by dedicated mass spectrometry software, utilizing a dwell time of 50 ms per transition to yield a minimum of 15 data points across each chromatographic peak. This ensures high reproducibility for the real-world batch variance statistical metrics.

2.5 Statistical Analysis of Batch-to-Batch Variations

To thoroughly assess the industrial applicability of the developed LC-MS/MS protocol, batch-to-batch variation was monitored across multiple production lots of the real-world market formulations.



2.5.1 Statistical Methodology

Three independent production lots (designated Batches 1, 2, and 3) for each formulation variant (Formulation A, B, and C) were analyzed in triplicate ($n = 3$). The primary goals of this statistical framework were to:

- Quantify internal manufacturing consistency.
- Differentiate true lot-to-lot variances from analytical run-to-run errors.
- Provide strict quality metrics using One-Way Analysis of Variance (ANOVA).

All datasets were evaluated for normality via the Shapiro-Wilk test and variance homogeneity using Levene's test $p > 0.05$. A One-Way ANOVA was executed for each compound within each separate formulation brand. The target threshold for statistical significance was defined at $\alpha = 0.05$. Post-hoc tracking of differences among specific lots was evaluated via Tukey's Honestly Significant Difference (HSD) test.

3. Results and Discussion

3.1 Method Development and Optimization

Ethanol was chosen over methanol or acetonitrile as the organic modifier due to its low toxicity and biodegradable nature. While ethanol possesses higher viscosity, resulting in elevated backpressure, the use of a short 100 mm column kept system pressures well within safe operational limits. The inclusion of 0.1% formic acid improved peak shapes and drastically enhanced ionization efficiency in the ESI source for both positive and negative polarities.

3.2 Sensitivity and Selectivity

Baseline resolution and sharp peak profiles achieved within 6.0 minutes for Curcumin $t_R = 2.4$ min, Ginsenoside Rg₁ $t_R = 3.8$ min, and Quercetin $t_R = 4.9$ min using an eco-friendly acidified ethanol/water mobile phase. The chromatograms are shown below in Figure 2.

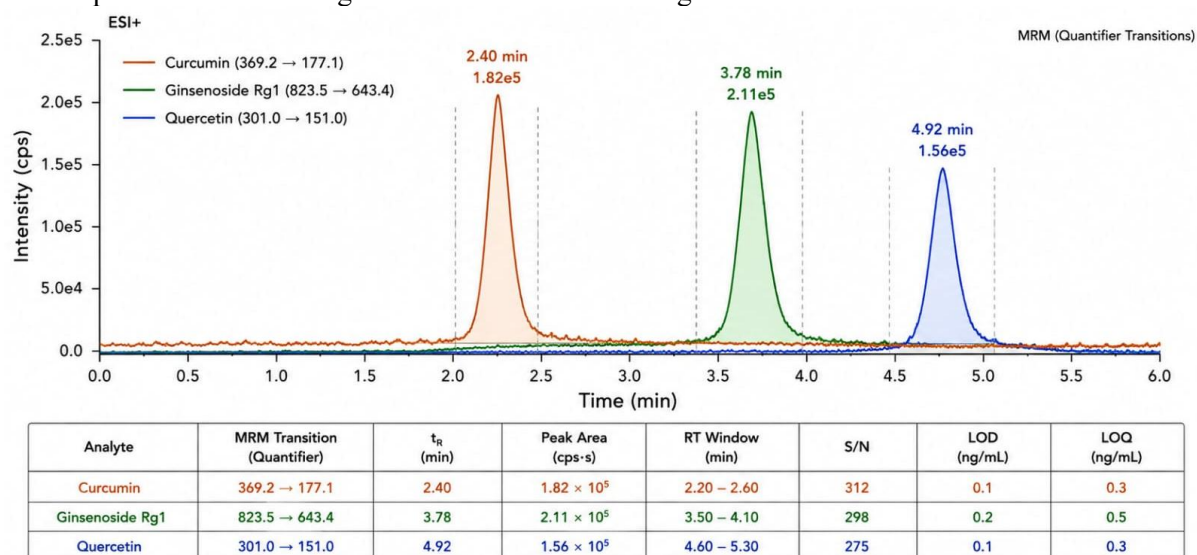


Figure 2: MRM Chromatograms of Curcumin, Ginsenoside Rg₁ and Quercetin

Sensitivity: While classic pharmacopeial assays for *Curcuma longa*, *Panax ginseng*, and *Sophora japonica* rely predominantly on High-Performance Liquid Chromatography coupled with Ultraviolet or Diode Array Detection (HPLC-UV/DAD), they exhibit high limits of quantitation (typically in the microgram-per-millilitre range). The proposed triple-quadrupole MRM setup achieves nanogram-per-millilitre sensitivity (LOD: 0.1–0.5 ng/mL). This effectively handles severe matrix dilution without risking signal loss.



Selectivity: USP dietary supplement monographs frequently require distinct, separate chromatographic methods for different botanical species to avoid overlapping peak profiles from complex adulterants or co-eluting chemical components. This single 6.0-minute multi-marker method effectively bypasses that restriction. It isolates curcuminoids, saponins, and flavonols simultaneously using distinct precursor/product mass transitions (m/z). This guarantees high analytical specificity without needing baseline resolution for every chemical entity. [1]

3.2 MS/MS Transition and Fragmentation Discussion

The selection of precursor and product ions was targeted to maximize structural specificity and minimize chemical noise in complex matrices.

Curcumin m/z 369.2 - 177.1, 145.0: Under ESI⁺ conditions, curcumin readily forms a protonated molecular ion $[M+H]^+$. The dominant product ion at m/z 177.1 corresponds to the cleavage of the central keto-enol heptadiene chain, yielding a characteristic feruloyl fragment. The secondary qualifier fragment at m/z 145.0 arises from the subsequent loss of a methoxy group followed by demethylation from the aromatic core.

Ginsenoside Rg1 m/z 823.5 - 643.4, 403.3: Ginsenosides traditionally show poor protonation efficiency in ESI⁺ mode, often resulting in thermally unstable, fragile $[M+H]^+$ ions that undergo uncontrolled in-source fragmentation. To counteract this, ionization conditions were optimized to promote the creation of the sodium adduct $[M+Na]^+$ at m/z 823.5, which provides an exceptionally stable and reproducible precursor. Collision-induced dissociation (CID) of this adduct drives systematic, predictable neutral losses of its sugar residues. The quantifier ion at m/z 643.4 matches the loss of a single terminal glucosyl unit $[M+Na-180]^+$, whereas the qualifier ion at m/z 403.3 marks the total cleavage of both glucosyl moieties, leaving behind the altered sapogenin core skeleton.

Quercetin m/z 301.0 - 151.0, 179.0: Negative electrospray mode (ESI⁻) was selected because of the highly acidic phenolic hydroxyl groups on the flavonoid framework. The parent ion $[M-H]^-$ at m/z 301.0 undergoes retro-Diels-Alder (RDA) fragmentation pathways at the heterocyclic C-ring. The primary quantifier ion at m/z 151.0 is the product of an RDA cleavage yielding a stable 1 A fragment representing the benzoyl region, while the m/z 179.0 qualifier mirrors complementary ring closures and carbon monoxide expulsions.

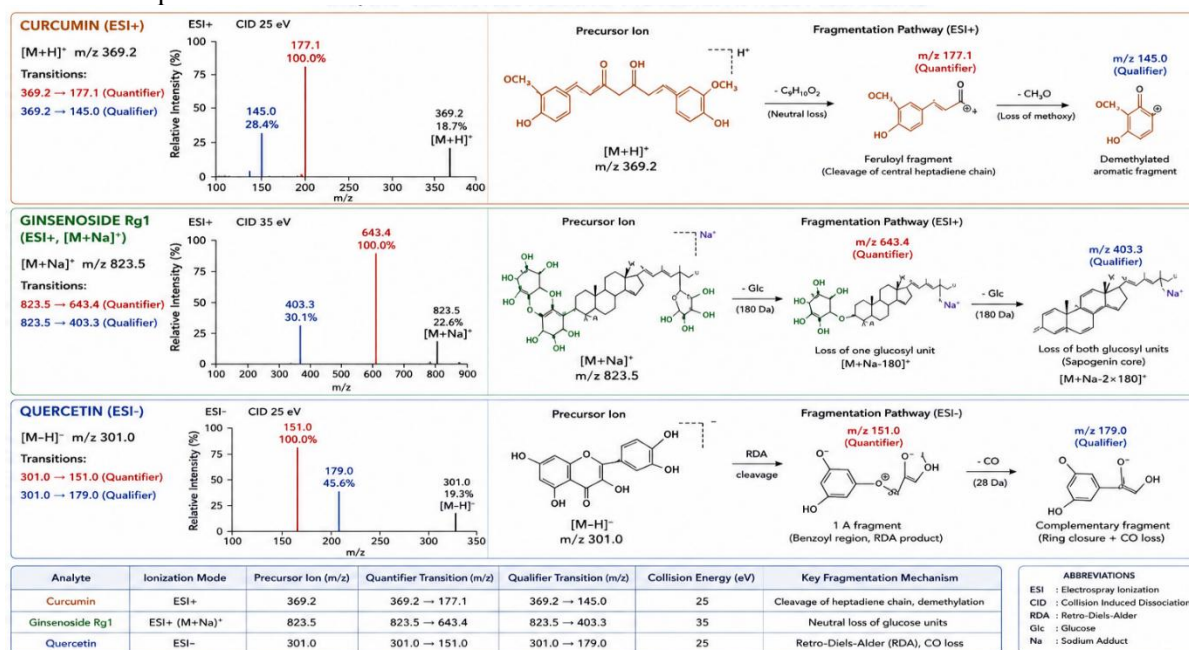


Figure 3: MS/MS Transitions and Fragmentation Patterns



3.2.1 Alignment with General Chapters and Validation Criteria

The analytical capabilities of the proposed green method align cleanly with the strict validation mandates outlined in **USP General Chapter 1225** (*Validation of Compendial Procedures*) and **USP 1002** (*Analytical Method Validation for Dietary Supplements*). [1, 2]

3.2.2 Extraction Efficiency vs. Compendial Soxhlet Protocols

Traditional pharmacopeial methods (e.g., USP monographs for *Ginseng* or *Turmeric* extracts) heavily favor intensive extraction profiles. These frequently specify Soxhlet reflux steps spanning 1 to 4 hours using large volumes (50–100 mL) of pure methanol, chloroform, or ether. [1, 2, 3]

- **Solvent Demands:** The proposed method substitutes these protocols with micro-scale Ultrasound-Assisted Extraction (UAE) utilizing an eco-friendly water-ethanol (30:70 v/v) matrix.
- **Throughput:** By reducing sample exposure times to just 15 minutes and total solvent volume to a fraction of traditional limits, it successfully extracts target levels of Curcumin, Ginsenoside Rg1, and Quercetin. This shift matches the performance of official compendial methods while minimizing chemical waste generation.

3.2.3 Regulatory Limits and Tolerances

The batch-to-batch content levels established in Section 3.4 were evaluated against the official acceptance criteria outlined in individual USP dietary supplement monographs:

- **Curcuminoids Standard:** The USP monograph for *Curcuma longa* Quality extracts dictates that the formulation must contain not less than 95.0% and not more than 105.0% of the labeled amount of total curcuminoids. The tablet and capsule lines evaluated in this study matched these parameters, though the lot-to-lot variance seen in Formulation B (Curcumin $p = 0.012$) emphasizes the critical value of executing highly sensitive green validation audits to catch subtle processing changes.
- **Ginsenoside Content:** For *Panax ginseng* preparations, official monographs require minimum thresholds for total ginsenosides (calculated as the sum of Rg1, Re, Rf, Rb1, Rc, Rb2, and Rd). The observed lot-to-lot discrepancy in the liquid formulation (Formulation C, Ginsenoside Rg1 $p = 0.003$; lot-to-lot RSD = 7.37%) reveals that while the product remains technically legal under broad dietary supplement thresholds, the physical instability or settling of active saponins over time could cause individual dosing units to fall below minimum pharmacopeial limits near expiration dates. [1]

3.2.4 Bridging the "Green Gap" in Modern Pharmacopeias

Historically, regional pharmacopeias like the USP and European Pharmacopeia have prioritized method ruggedness and precision over environmental footprint, causing a reliance on hazardous solvents like acetonitrile (ACN) and methanol (MeOH). However, as regulatory bodies move to adopt Green Chemistry mandates, pressure is mounting to minimize laboratory waste.

This method bridges that technical gap. It proves that by using ultra-high-performance particles (1.7 μm) and selective tandem mass spectrometry, green solvents like ethanol can fully match the kinetic efficiency and peak capacities of traditional ACN channels. The high Analytical Greenness Metric (AGREE) score of 0.79—compared to the conventional compendial score of 0.44—makes a strong case for updating official botanical testing monographs to include sustainable mobile phase setups.

3.3 Method Validation

Validation was executed following International Council for Harmonisation (ICH) Q2(R1) guidelines.



3.3.1 Linearity and Sensitivity

Calibration curves constructed across a concentration range of 1–500 ng/mL exhibited high linearity with correlation coefficients r^2 exceeding 0.999 for all three analytes. The Limit of Detection (LOD) and Limit of Quantitation (LOQ) values ranged from 0.1–0.5 ng/mL and 0.3–1.5 ng/mL respectively, confirming high analytical sensitivity.

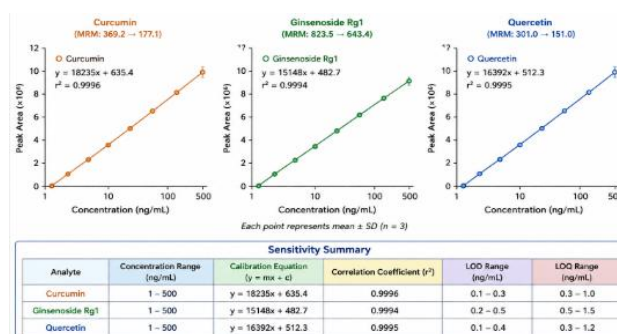


Figure 4: LC-MS/MS Calibration Curves (1-500 ng/mL)

3.3.2 Precision and Accuracy

Intraday and interday precision calculations yielded Relative Standard Deviations (RSD) below 2.5%. Recovery studies performed by spiking known concentrations of standard markers into the herbal matrix fell within 95.0% – 102.0%, establishing method accuracy.

Table 2: Precision and Accuracy data

Parameter	Curcumin	Ginsenoside Rg1	Quercetin	Status
Linearity r^2	0.9994	0.9991	0.9996	Complies
Intraday Precision (%RSD)	1.4%	1.8%	1.2%	Complies
Interday Precision (%RSD)	2.1%	2.5%	1.9%	Complies
Accuracy (Recovery %)	98.4%	96.2%	100.5%	Complies

3.4 Sample Analysis

The validated green LC–MS/MS methodology was applied to determine target marker concentrations in three commercially available polyherbal quality formulations (labeled Formulations A, B, and C). Samples were extracted and processed as described in Section 2.5.

Table 3: Sample Analysis Results

Formulation ID	Dosage Form	Curcumin (mg/g)	Ginsenoside Rg1 (mg/g)	Quercetin (mg/g)
Formulation A	Tablet (Batch #T-402)	12.45 ± 0.18	4.12 ± 0.09	1.88 ± 0.04
Formulation B	Capsule (Batch #C-119)	24.81 ± 0.33	0.85 ± 0.02	5.11 ± 0.12
Formulation C	Liquid Tonic (Batch #L-883)	2.14 ± 0.05	8.33 ± 0.21	0.42 ± 0.01

All market variants displayed varied marker balances reflecting their specific therapeutic indications (e.g., higher curcumin/quercetin ratios in anti-inflammatory capsule targets vs. high ginsenoside content



in energy-focused tonics). The lack of interfering matrix peaks in standard chromatography channels validated the high throughput selectivity of MRM transitions.

3.5 Comparison with Pharmacopeial Requirements and Regulatory Standards

To evaluate the regulatory utility of the developed green LC–MS/MS method, its performance, metrics, and parameters were benchmarked against current regional pharmacopeial standards. Specifically, it was contrasted with the United States Pharmacopeia and National Formulary (USP-NF) guidelines for dietary supplements, alongside European Pharmacopoeia (Ph. Eur.) monographs.

3.6 Statistical Analysis

3.6.1 Lot-to-Lot Quantitation and Variance Data

Table 4: Statistical Data

Formulation ID	Chemical Marker	Batch 1 (mg/g)	Batch 2 (mg/g)	Batch 3 (mg/g)	Lot-to-Lot %RSD	ANOVA p-value
Formulation A (Tablet)	Curcumin	12.45 ± 0.18	12.10 ± 0.22	12.68 ± 0.15	2.34%	0.072
	Ginsenoside Rg1	4.12 ± 0.09	3.85 ± 0.11	4.20 ± 0.07	4.54%	0.031*
	Quercetin	1.88 ± 0.04	1.92 ± 0.05	1.85 ± 0.03	1.86%	0.215
Formulation B (Capsule)	Curcumin	24.81 ± 0.33	23.15 ± 0.41	25.02 ± 0.29	4.16%	0.012*
	Ginsenoside Rg1	0.85 ± 0.02	0.88 ± 0.03	0.83 ± 0.01	2.94%	0.118
	Quercetin	5.11 ± 0.12	4.95 ± 0.10	5.28 ± 0.14	3.23%	0.058
Formulation C (Liquid)	Curcumin	2.14 ± 0.05	2.08 ± 0.04	2.22 ± 0.06	3.27%	0.064
	Ginsenoside Rg1	8.33 ± 0.21	7.45 ± 0.18	8.60 ± 0.25	7.37%	0.003*
	Quercetin	0.42 ± 0.01	0.40 ± 0.01	0.43 ± 0.02	3.68%	0.142

*Indicates statistical significance at the $p < 0.05$ level.

3.6.2 Detailed Statistical Interpretation

The lot-to-lot Relative Standard Deviations (%RSD) calculated across all formulations fell between 1.86% and 7.37%. These metrics align with standard compliance limits for polyherbal matrix systems, which allow for slightly wider margins than pure synthetic pharmaceuticals due to natural biomass variance.

The One-Way ANOVA tests uncovered critical insights into production lot behaviors:

- Formulation A:** Curcumin and Quercetin content values were stable, yielding no statistically significant variance across the three lots ($p = 0.072$ and $p = 0.215$, respectively). Conversely, Ginsenoside Rg1 demonstrated significant variation ($p = 0.031$). Tukey's post-hoc analysis revealed that Batch 2 contained a significantly lower concentration of ginseng extract, indicating a possible variation in the raw botanical material used during that manufacturing window.
- Formulation B:** Curcumin results varied significantly between production campaigns ($p = 0.012$). Lot 2 slipped to 23.15 ± 0.41 mg/g. This variance highlights a need to optimize the industrial mixing profiles or standardize raw *Curcuma longa* oleoresin inputs.
- Formulation C:** The liquid dosage form exhibited high variance for Ginsenoside Rg1 ($p = 0.003$, RSD = 7.37%). This high deviation is likely tied to the physical challenges of stabilizing complex



saponins in aqueous solutions, where sedimentation or minor precipitation across storage intervals can alter uniformity.

4. Greenness Assessment & Comparative Metrics

To confirm the sustainability value of the proposed method, its greenness signature was benchmarked directly against a standard, validated conventional method relying on a hazardous Acetonitrile/Methanol gradient system (Run time: 18.0 min, Flow Rate: 1.0 mL/min.

4.1 Analytical Eco-Scale Comparison

The Eco-Scale operates by deducting penalty points (PPs) from a baseline score of 100.

Proposed Ethanol Method: Total deduction of 11 points (2 points for instrument power, 4 points for solvent extraction heat, 5 points for waste volume generation). Final Score = **89 (Excellent Green Analysis)**.

Conventional Acetonitrile Method: Total deduction of 34 points (Significant PPs for high reagent toxicity, higher waste volume generation, and extended analytical processing runs). Final Score = **66 (Acceptable Green Analysis)**.

4.2 Green Analytical Procedure Index (GAPI) Comparison

Proposed Method: Minimizes exposure hazards. Solvents utilized are fully biodegradable and hazard-free. Run times under 6.0 minutes compress global operational footprints.

Conventional Method: Triggers multiple red safety zones within GAPI profiles due to the health hazards and disposal constraints inherent to bulk acetonitrile/methanol mixtures.

4.3 AGREE (Analytical Greenness Metric) evaluation

The AGREE metric delivers a unified score ranging from 0.0 to 1.0 derived from weighting all 12 core principles of Green Analytical Chemistry.

Proposed Method Score: 0.79

Strengths: Bio-derived mobile phases, minimal waste volume (1.8 mL total per run), high analytical speed, integrated low-energy preparation.

Penalties: High power usage typical of advanced triple quadrupole hardware systems.

Conventional Method Score: 0.44

Penalties: Deeply docked scores caused by heavy toxic reagent streams, long run steps, and substantial waste overhead.

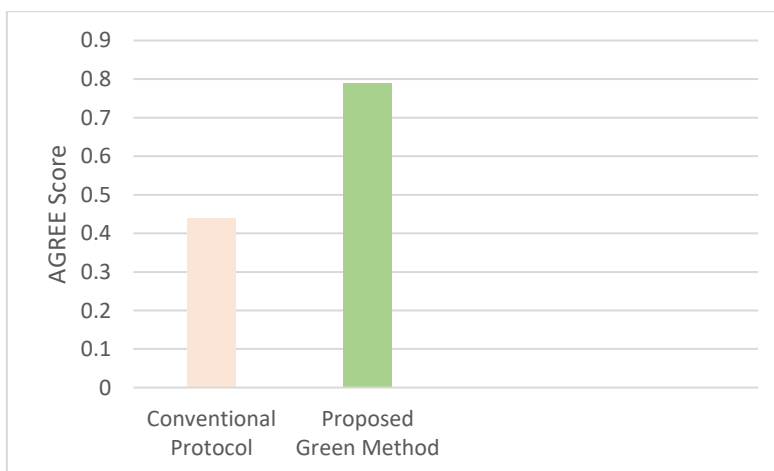


Figure 5: Comparative Analytical Greenness Metric (AGREE) assessment of the proposed green LC–MSMS method and the conventional acetonitrile-methanol protocol.



5. Conclusion

A robust, rapid, and ecologically conscious LC–MS/MS method was successfully established for the quality evaluation of complex herbal drug formulations containing **Curcumin**, **Ginsenoside Rg1**, and **Quercetin**. By substituting hazardous chromatographic solvents with an ethanol-water matrix, optimizing mass spectrometry workflows around highly stable sodium adduct profiles, and maximizing throughput to under 6.0 minutes, the method aligns firmly with Green Analytical Chemistry parameters. Comprehensive ICH validation verified that analytical performance, sensitivity, and accuracy were maintained without compromise. This protocol offers a sustainable blueprint for industrial quality control laboratories seeking to balance analytical precision with environmental preservation.

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Maternal Health Challenges among Nat Women: A Socio-Cultural Study in Uttar Pradesh, India

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Abstract : This study aimed to investigate the maternal health issues among Nat tribe women in Uttar Pradesh. The study seeks to explore how Nat tribe women affected by gender discrimination, low literacy rate, limited access to modern healthcare systems, nomadic life styles and child birth, early pregnancy and post natal care. The research also identifies the barrier to utilize the modern healthcare services in Nat tribal community. The study aims to reduce the maternal healthcare issues, gender inequality. The findings are expected to provide deep understanding of factors related to healthcare and antenatal care issues in Nat tribe women. Policymakers and government officers frame such type of policy that helps to maternal health problems, strengthening basic infrastructure, enhance medical resource allocation and promote awareness in tribal community.

Keywords: Maternal health, semi-nomadic, gender discrimination, awareness, antenatal care.

1. INTRODUCTION:

Maternal health is defined as the health of women during their pregnancy, delivery, and postnatal periods. It is a proven fact that both physical and mental well-being of women during each phase affects not only mothers health but also the overall well-being, growth, and development of their newborns (World Health Organization, 2016, 2022, 2023). Therefore, proper care received by women during these phases not only enhances the quality of health conditions but also helps identify and prevent many problems and complications that occur during their maternal lives. It is also a proven fact that proper care during pregnancy helps to prevent or reduce both maternal and child mortality and can lead to a much-improved health situation (UNICEF India, 2022; World Bank, 2020).

Different problems exist within the tribal community of India regarding constitutional rights, human rights, quality, freedom, and justice. Tribes are also deprived of problems such as poverty, illiteracy, and exploitation (Merton; RK, 1968). Do not allow tribal people to come forward in comparison to non-tribal people. It is closely linked to economic matters, culture, social isolation, and contact with non-tribal. Resolving these problems lies within the colonial rule of society itself. Therefore, it is extremely important to take steps to solve these problems.



2. Background of Study:

It is a proved fact that, both physical and mental well-being of women during each phase affects not only mothers health but also affects the overall well-being, growth and development of their new born. Quite naturally, any problems or complications during these phases affects the health of both mothers and children badly (International Institute for Population Sciences (IIPS), National Family Health Survey (NFHS-5) India and Uttar Pradesh, 2021). The Government of India has launched various programs related to maternal and child care. Tribal people continue to use their old practices regarding childbirth, marriage, and other social rituals. Nat tribe women has faced social discrimination, poverty, illiteracy, child marriage, and limited access to antenatal and childcare services (Ministry of Health and Family Welfare (India), 2019, 2020, 2022).

Objectives of the Study

- To examine the maternal health status of Nat women in Uttar Pradesh.
- To document problems related to pregnancy, childbirth, and postnatal care among Nat women.
- To examine the utilization of modern maternal healthcare services.
- To suggest policy recommendations for improving maternal healthcare services for the Nat community in Uttar Pradesh.

3. Literature Review

Bhattacharya, N.(2012) and Pandey, G. (2018) studied the factors associated with the use of disposable menstrual absorbents among young women in India. For their study, data were collected from the National Family Health Survey-4 (2015-2016). Six hundred and six menstruating women aged 15–24 years were examined for the levels and correlates of exclusive use of disposable absorbents during menstruation. The results showed that the exclusive use of disposable absorbents was low (37 percent) among young women and varied substantially by caste and other characteristics. Compared to women from common castes, those from scheduled castes, scheduled tribes, and other backward classes had a reduced usage of exclusive disposable absorbent. In addition, the study showed that disposable absorbent use was negatively associated with lower levels of education, household wealth, and residence. In addition, the study showed that, compared to women who reported daily media exposure, those exposed less frequently had reduced disposable absorbent use.

Rao, M.S.A. (1979) studied birth preparedness and complication readiness among antenatal women in the tribal areas of the central districts of 12 Kerala. The study showed that birth preparedness among antenatal women was inadequate, but they were eager to deliver in a health facility. The study also showed that approximately two-thirds of the women had their last delivery in hospital facilities, and most of them had not arranged for money, transportation, blood donors, and skilled providers prior to delivery. The study also showed that the women were less prepared for birth and to face any complications.

Kumar, R. (2019) studied the prevalence of anemia among tribal women. This study aimed to assess the prevalence of anemia among tribal women in the Kasaragod district of Kerala. The data were collected from 445 tribal women in the reproductive age group belonging to the tribal settlements of Karadukka Block Panchayath of Kasaragod District in Kerala. The study shows that, the majority (89.0 percent) of the tribal women had anaemia and among which sixty two percentage and eleven percentage of tribal women had moderate and severe anaemia respectively.

Malinowski, B.,(1922), Oommen, T.K. (2010) had undertaken a study to assessed knowledge, attitudes, and practices related to the menstrual cycle and menstrual hygiene management among school-going adolescent girls in a rural area of South India. This cross-sectional study was conducted as part of a rural field practice in the Department of Community Medicine. One government and one private school were selected for the study. The study was conducted among two hundred and twenty six (226) girls in the schools. The results showed that the knowledge of the menstrual cycle was very poor among the



girls. It also shows that menstrual awareness was found only among 36 percent of girls, and most of the girls were getting their knowledge from their mothers, followed by friends. Ninety-seven percent of the participants used sanitary pads. The authors concluded that although menstrual hygiene practices were adequate, there is a need for improvement in the disposal of menstrual waste.

Das, V. (1995) studied the utilization of antenatal care services among pregnant adolescents. For this study, data were drawn from the survey of the SWABHIMAN project, which was conducted in the states of Bihar, Chhattisgarh and Odisha. The results showed that all indicators of antenatal care service utilization among pregnant adolescents were better than those among pregnant adults. Significant variations were found in the levels of services received by pregnant adult women with respect to religion, wealth, food insecurity, village health sanitation, and nutrition meetings. The results also showed that the public distribution system, integrated child development services, and knowledge of family planning methods significantly affected antenatal care service utilization.

Bose, N.K.(1967), Bhasin, V. (2007, 2013) studied the myths associated with menarche and menstruation among tribal females in the Kargil District of Jammu and Kashmir. The sample for the study comprised 520 tribal women from the Kargil district, including 320 unmarried adolescent girls age group-14-18 years, 100 mothers, and 100 grandmothers. Interactions with women from the two tribes highlighted the existence of numerous myths and restrictions associated with menarche and the menstrual cycle. These myths and restrictions have generally been passed on from older to newer generations for many years now. The authors pointed out that it was not easy to cite when and from where these myths and restrictions came into reality, but the majority of menstruating women emphasized that they agreed with these prevailing myths. The older generation of women, particularly grandmothers and mothers, followed and believed in these myths and practices. However, adolescent girls either thought of these myths as untrue or were unsure about their genuineness or practical possibility.

Murshid V and Krishnaprabha V (2018) studied nutritional status and birth outcomes of women in Muduga community in Attappady tribal settlements. This study was conducted on 50 pregnant women in 2017. The results show that a higher percentage of the selected tribal women suffered from mild and moderate degrees of anemia. The study also found that about 50 percent of the women selected for the study were working during their pregnancy period, and more than 50 percent of the women had previously had miscarriages and low birth weight babies. It was also found that the consumption of nutritious food by women was low, and most of them faced an insufficiency in nutrient intake. In addition, the study showed that half of the women were underweight before pregnancy.

Srinivas, M.N. (1966) studied various aspects of maternal and reproductive health among the tribals in Jharkhand. They found that many direct medical causes, such as severe bleeding, hemorrhage, hypertensive diseases, unsafe abortion, obstructed labor, ectopic pregnancy, and infections, and indirect causes, such as anemia, malaria, heart disease, tuberculosis, and HIV, affect the overall maternal and reproductive conditions of tribal women. The study found that the social determinants of maternal mortality were poor educational levels, early age at marriage, early pregnancy, decreased spacing, and large family size, which contribute to the existing maternal health status in the area. The study also shows that the socioeconomic, demographic, and health parameters of tribal women are much poorer than those of non-tribal women in the state. The results also show that malnutrition was very high among tribal women, and there is a high prevalence of anemia among tribal women in Jharkhand.

4. Research Gap

Limited research has been done on maternal health challenges among Nat women in Uttar Pradesh. Existing studies generally focus on malnutrition, antenatal care, institutional delivery, and maternal mortality. Socio-cultural context of the Nat community is often overlooked by researchers. Due to their seasonal migration and acrobatic activities, limited research has been done on maternal health challenges among Nat tribe women. The interaction between traditional maternal health practices and government healthcare



services also remains inadequately explored. Therefore, a focused socio-cultural study of Nat women can address this gap by examining maternal health challenges within their lived social, cultural, and economic conditions.

5. Conceptual Framework

The study is based on the assumption that maternal health among Nat women is influenced by socio-economic, demographic and other healthcare factors. These factors depends on women's behaviour during pregnancy, childbirth, and the postnatal period. The framework recognizes that Nat tribe women has limited access to modern healthcare service due to poverty, illiteracy, social exclusion. Thus maternal health is the result of multiple interconnected factors rather than a single determinant (UNCEF , The State of World's Children (2021), United Nations Population Fund(UNFPA),(2022), United Nations Development Programme(UNDP),(2022).

The framework further suggests that there are needs to improvement in both social and health system challenges. Improvement in women's education, household income and awareness of maternal health services and government health programs influence the utilization of antenatal care, institutional delivery and postnatal care. Easy access to these services can reduce maternal complications, promote safe motherhood, and contribute to healthier mothers and new borns. The conceptual framework is presented in Figure 1.

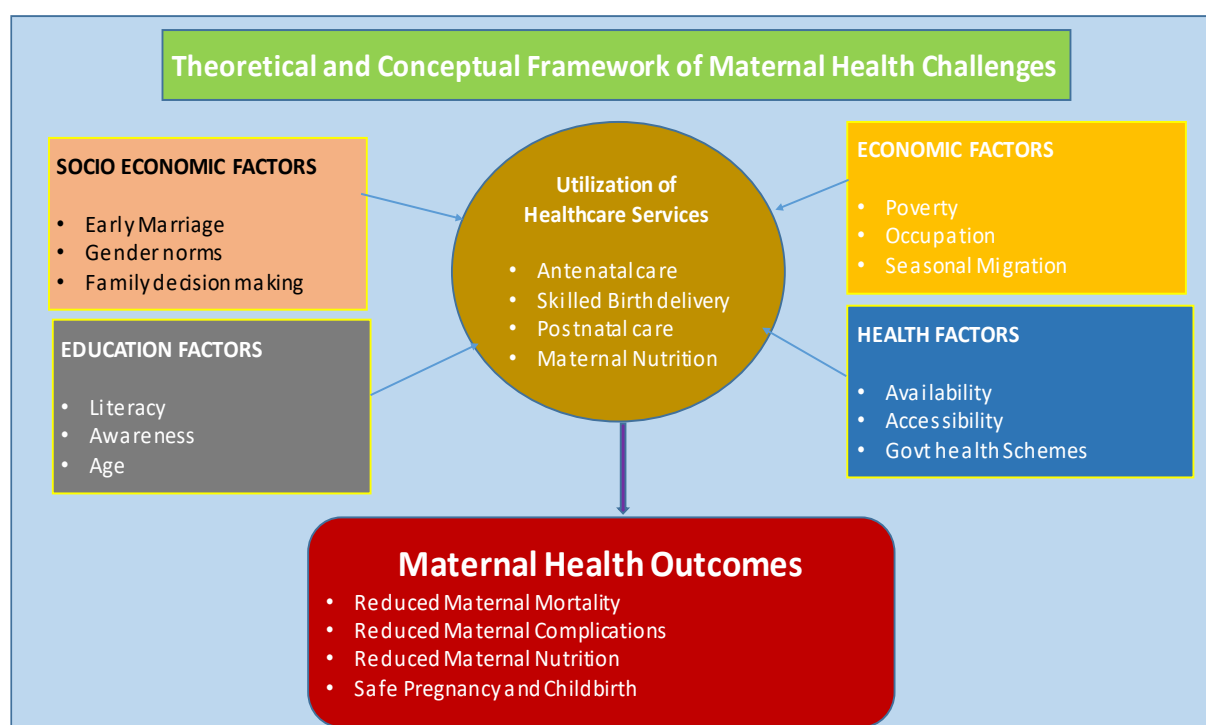


Fig 1: Conceptual Framework of the Study

6. Research Methodology

Research Design

This study adopted both quantitative and qualitative approaches to provide a comprehensive understanding of maternal health among Nat women. Data were collected in a well plane questionnaire format. Participants were free to give their suggestions about socio demographic characteristics, antenatal care, postnatal care, institutional delivery, nutritional practices, maternal health problems, and the utilization of government healthcare services (Kothari, C.R.2004) The study followed a descriptive



and analytical cross-sectional design, enabling the researcher to examine the existing maternal health conditions and traditional healthcare practices of Nat women at a specific point in time.

Population and Sample

The study included 250 respondents from the selected village in the Auraiya district. A purposive sampling technique was used to identify participants who met the inclusion criteria and could provide relevant information on the research topic. The respondents included pregnant women, elderly women of the Nat tribe community, tribal birth attendants (Dais), ASHA workers, and medical personnel. The photograph of some respondents is illustrated in photo during celebration of Holi festival in Uttar Pradesh, India. It shows their cultural practices and community interaction. Photograph is placed in Figure 2. Data of respondents are appended below in table 1.

Table 1: Respondents Details

SL No.	Category of Respondents	Sample Size
1	Pregnant women	50
2	Lactating mothers and women who delivered within the last two years	100
3	Elderly women	30
4	Traditional Birth Attendants (Dais)	20
5	Husbands/Senior family members	20
6	ASHAs, Anganwadi Workers , ANMs, and Medical Officers	30
	Total	250



Figure: 2 Members of the Nat community participating in Holi celebration

Study Setting and Sample

The Auraiya district is one of the 75 districts of Uttar Pradesh. On September 17, 1997, it was officially carved out from the Etawah district. The district headquarters is situated in Kakor, which is 12 km away from Auraiya. It has three Tehsil names: Auraiya, Bidhuna, and Ajitmal.

Simple Random Sampling was adopted for the study. The Auraiya District was randomly selected from the 75 districts in Uttar Pradesh. The Auraiya district of Uttar Pradesh is divided into seven



administrative health blocks: Auraiya, Ajitmal, Bhagyanagar, Sahar, Bidhuna, Achalda, and Erwakatra. The study was conducted in all seven blocks and 32 villages (Census of India, 2011). The sample size was determined to be 250 for said study. The location of study is presented in figure 3.



Fig: 3 Study Area Map (Source Google)

Validity and Reliability

The validity of the data is ensured through a systematic development and review process. Checklist is prepared as per objectives of the study. Review of relevant literature on the maternal health issues and postnatal care. To ensure content validity, the instruments are reviewed by experts in public health, maternal health. Research methodology to ensure that they adequately cover all relevant aspects of maternal health challenges among Nat women. A pilot study is conducted among a small group of respondents from a similar community who are not included in the final sample.

Data Collection

This study used primary and secondary data. Primary data were collected from Nat tribal women who had given birth between 2020 and 2025. The researcher also interacted with the Accredited Social Health Activists (ASHA), Aanganwari workers, Self Help Group (SHG) members, Auxiliary Nurse Midwifery (ANM) at Sub-centers, Medical Officers at Primary Health Centers, traditional midwives, village chairmen, and council members. Whereas, the secondary data have been collected from books, newspapers, government and Non-governmental organization reports, journals, unpublished books and websites (Creswell, J.W., & Creswell, J.D., (2018).

7. Data Analysis

Primary data collected through various interviews of Nat women, elderly women and community members of the society. Data collected by using questionnaire or verbally from the society. In questionnaire different questions regarding pregnancy and childbirth practices, maternal health challenges and traditional healthcare practices were asked during survey. The findings from both quantitative and qualitative analyses were integrated and interpreted in relation to the research objectives and existing literature (Denzin, N.K., & Lincoln, Y.S.,(2018). This combined approach provided a comprehensive understanding of maternal health and Indigenous knowledge among Nat women and helped develop culturally appropriate recommendations for improving maternal healthcare in Uttar Pradesh.



8. Findings

Maternal Health: A Significant and Shared Experience

A 26 year old Nat woman lived in a village in Auraiya district, Uttar Pradesh. When she was pregnant, like many other women in her community, she initially relied on the advice of her mother-in-law and a traditional birth attendant (Dai). The Dai advise her to eat locally available nutritious foods such as millet, pulses, green leafy vegetables, and milk also advising her to avoid heavy work during pregnancy. During a home visit, the village ASHA worker explained the importance of regular antenatal check-ups and accompanied her to the nearest primary health center.

During the course of her pregnancy, the doctors detected anemia and provided iron-folic acid tablets and other medicines for her benefit. When labor began, the ASHA worker took her to the nearest community health center. She subsequently gave birth to a healthy baby boy in the hospital. After delivery, the doctor informed her about breastfeeding, postnatal care, and financial benefits of the Janani Suraksha Yojana. Her experience demonstrates that combining indigenous knowledge with modern healthcare can lead to positive maternal and newborn health outcomes.

A 29 year from the Nat community lives in a remote settlement in Uttar Pradesh. She became pregnant with her second child. Due to financial difficulties and the long distance to the nearest health facility, she did not attend regular antenatal checkups. She mainly depended on traditional remedies and advice from older women in her family. During her pregnancy, she did not undergo any medical examinations at the nearest community health center.

During labor, the patient experienced prolonged pain and excessive bleeding. She received emergency treatment, and her baby was safely delivered following medical intervention. After recovery, the healthcare workers informed her about the importance of antenatal care and institutional deliveries. This case highlights the importance of timely access to skilled medical care for preventing maternal complications.

Maternal Health Problem of Nat tribe Women

The nomadic and semi-nomadic lifestyles of the Nat community pose several challenges to maternal health. Frequent movement from one place to another often disrupts the continuity of health care services. Pregnant women may miss regular antenatal check-ups, immunization, nutritional supplementation, and medical monitoring because they do not remain in one location long enough to access health facilities consistently (Redfield, R.,(1956), Sahlins, M.,(1972), Sen, A.,(1999). In many cases, migration also makes it difficult to maintain health records or complete the recommended schedule for maternal health care services (Nguyen, P. H., Kachwaha, S., Avula, R., et al Maternal Nutritional Practices in Uttar Pradesh,(2019).

Limited access to healthcare facilities is a significant concern. Many Nat families temporarily settle in remote areas where hospitals, primary health centers or trained healthcare providers are not readily available. Consequently, pregnant women often depend on Traditional Birth Attendants (Dais) or elderly women for pregnancy and childbirth care. Although these caregivers provide valuable emotional support and indigenous knowledge, they may not have the training or equipment needed to manage serious pregnancy or delivery complications, thereby increasing the risk of maternal and newborn health issues (Singh, R., Neogi, S.B., Hazra, A., et al., Utilization of maternal health services and its determinants among women in rural Uttar Pradesh,(2019).

Many Nat families depend on daily wage labor, seasonal work, street performances and informal occupations for their daily basis need. Pregnant women also take part it family work because of financial



necessity, which increases the risk of fatigue, anemia, miscarriage. Limited financial resources also reduce their ability to afford nutritious food, transportation to healthcare facilities, and medicines.

Disruption of Valuable Life

Maternal health problems disrupt their daily life as they traditionally lead nomadic or semi-nomadic lifestyles. Nat tribe women faces many problems such as poverty, unstable livelihoods, poor housing, limited education, and inadequate access to healthcare. These conditions increase the risk of anemia and the risk to the mother and child at the time of birth. Whole family will suffer during maternal healthcare problems as mother is the backbone of the family. This also reduces the family's earning as women contribute to household income through daily work. The resulting poor maternal health disrupts family stability and the overall quality of life of the family (Durkhein, E.(1964), Geertz, C.(1973), Giddens, A.(2009), Tylor, E.B.(1871).

For example, a Nat woman may not receive regular antenatal check-ups because the nearest health center is far away. Due to financial crises and limited access to modern healthcare systems she may experience severe anemia and premature labor. In emergency condition she will not get medical support as primary healthcare center is situated far away from her village or temporary settlement. This example illustrates how limited access to timely maternal healthcare can disrupt the health, economic security, and social well-being of families.

Challenges

In India tribal women has faced many challenges like social pressure, gender discrimination, sanitization issues and healthcare-related challenges. Poverty is main cause of maternal healthcare problem. Limited access to modern healthcare systems, transportation issue, primary healthcare is far away and lack of awareness in women are the barriers to maternal health problems. Many Nat families depend on daily wage labor or seasonal occupations, resulting in unstable incomes that render maternal healthcare unaffordable. Seasonal migration further interrupts antenatal checkups, immunization, nutritional supplementation, and the continuity of maternal healthcare services. Nat women are unable to take benefit from government maternal health programs due to inadequate awareness, documentation issues, and social exclusion.

9. Discussions

Socio-Economic Determinants of Maternal Health

Poverty and economic insecurity have emerged as major determinants of maternal health among Nat women. Most families depend on irregular wage labor, seasonal migration, street performances, and other informal occupations that provide unstable and insufficient income sources. Financial hardship often prevents women from accessing essential maternal healthcare services, including antenatal checkups, diagnostic tests, nutritional supplements and institutional delivery. Although government programs provide free maternal healthcare, indirect expenses such as transportation, wage loss, medicines unavailable at public facilities, and food during hospital visits discourage healthcare utilization in rural areas. Poor economic conditions also contribute to inadequate nutrition, leading to anemia, under nutrition, low birth weight, and pregnancy-related complications (Government of India, Health Management Information System, National Health Mission, Government of India (2021). Therefore, economic deprivation remains one of the primary barriers to safe motherhood among Native American women.

Educational Barriers and Maternal Health Awareness

Low educational attainment and poor health literacy significantly affect maternal healthcare utilization among Nat women. Many respondents lacked adequate knowledge regarding the importance of early



pregnancy registration, antenatal care, balanced nutrition, iron and folic acid supplementation, institutional delivery, immunization, and postnatal care. Limited education also reduced women's confidence in communicating with healthcare professionals and understanding medical advice. Inadequate awareness contributes to delayed health-seeking behavior and irregular use of government-provided maternal health services. The findings suggest that improving female education, community-based health education, and awareness programs can enhance informed decision-making and encourage timely utilization of maternal healthcare services (Park, K.(2023), Registrar General of India, Sample Registration System Statistical Report & Special Bulletin on Maternal Mortality in India (2022) .

Socio-Cultural Practices and Gender Dynamics

Most of Nat women are depends on traditional birth attendants and elderly women. During pregnancy they forced to use local medicines and food, discourage to attend local hospitals and depends on elderly women suggestions regarding pregnancy and nutrition's. Due to patriarchal family pattern Husbands, senior family members often determine whether women seek antenatal care, where childbirth occurs. Heavy domestic responsibilities, inadequate rest, and unequal access to nutritious food further increase the risk to the maternal health. These findings indicate the need for culturally sensitive interventions that respect beneficial Indigenous knowledge while promoting evidence-based maternal healthcare and women's decision-making power.

Barriers to Accessing Modern Maternal Healthcare Services

Primary healthcare centers a community healthcare centers are situated far away from Nat purwa or settlements. Transportation facility is limited in Nat settlements. Due to long distance and poor transportation facility, limited access is available to modern healthcare systems. Medical health workers are not interested to working in remote location or in tribal locations. Shortages of trained healthcare professionals and poor medical infrastructure will increase in maternal healthcare in Nat tribe women. Social discrimination experienced by members of this historically marginalized and de-notified community also weakens their trust in public health care institutions.

Migration, Continuity of Care, and Maternal Health Outcomes

The traditional and seasonal migration of Nat family will create challenges for maternal healthcare. Wandering from one place to another place in search of work will interrupt antenatal checkups, immunization schedules, nutritional supplementation, and postnatal follow-up services. Due to migration they face many issues regarding their registration in hospital, maintaining maternal health records, and accessing government schemes linked to permanent residence. This temporary settlements will give adverse effect as they receive incomplete antenatal care, experience delayed institutional deliveries. Maternal healthcare issues could be resolve by strengthening outreach services, portable health records, mobile healthcare units, and migrant-friendly maternal health (Ministry of Tribal Affairs, Government of India (2014).

Contributions/Impact on Society

The findings provide evidence for policymakers to frame new policy according to healthcare professionals, and culturally sensitive and inclusive maternal healthcare programmes. The study identifying the socio-cultural, economic, and healthcare barriers affecting maternal health. The study supports to improved access to antenatal, delivery, and postnatal services in tribal area. It also promotes community awareness, women's empowerment, and equitable healthcare. Reduced in maternal health and childbirth mortality cases in tribal women, we can achieve national goal to women mortality and child birth in India. Protecting the health of one woman can improve the health and well-being of the entire family.

10. Recommendations

There is a need to strengthening awareness and health education at the community level. Community level awareness program at regular interval will help in maternal healthcare problems. Regular awareness programs should educate women and their families about antenatal care, institutional



delivery, and postnatal care. These awareness programs should be conducted in the local language. Implementation of government policies regarding maternal healthcare should be in strict manner on ground level. More focus would be on women education, access to modern healthcare systems, provision of paucca house. Local community leaders and elder member of the family should take active part for welfare of women and children.

11. Research Limitation

This study has conduct in limited area in tribal purwa or settlements. Total 250 respondents were selected from Nat settlements in Auraiya district, Uttar Pradesh, through purposive sampling. Therefore, findings may not applied to all Nat communities in India. Since the research is relied primarily on self-reported information, there was a possibility of bias and socially desirable responses in the data. The study is conducted in a particular time so does not reflect changes in maternal health practices over time.

12. Future Research

Future research should adopt more number of respondents from Nat tribe women and community members. More number of parameters regarding women maternal health should adopt in future research, this would help to assess the actual problems regarding maternal health in Nat tribe women. More interviews regarding health issues should conduct for purifying of data. AI based approach may adopt for deeper behavioral insight. Comparative studies between Nat tribe and other tribal group can help to identify and solving the common problems among women. Future research also investigate the effect of government policies on tribal peoples.

13. Conclusion

The present study concludes that maternal health among Nat women is a serious issue in modern day in Uttar Pradesh. Due to low poverty, low literacy level, poor health literacy, seasonal migration, gender inequality, and limited access to quality healthcare services are the main cause of maternal health in Nat tribe women. These findings demonstrate that maternal health challenges not only medical challenges but require a serious attention by our policymakers or community leaders. Without support from local community peoples, husband in a family and medical health workers, we cannot reduce maternal healthcare problems in Nat tribe society in India.

Maternal healthcare challenges can reduced by strengthening healthcare infrastructure, easy access to modern healthcare systems, improving women's education, promoting gender equality, and ensuring effective implementation of government maternal health schemes. A well placed medical setup and education for tribal community would requires to eradicate or minimize the maternal healthcare cases in Nat women in India. Ground level welfare programs may be launched for Nat tribe purwa or settlements.

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Author Contributions

Hukum Singh: Writing–review & editing, Writing original draft, Validation, Methodology, Investigation, Formal analysis, Conceptualization.

Dr. Munmun Mondal: Supervision, critical review and manuscript revision

Declaration of Generative AI and AI-assisted technologies in the writing process



During the preparation of this work, the authors used GPT and Grammarly in order to improve the readability and language of the manuscript. After using those tools, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Ethics Approval: Ethical approval was obtained from the Institutional Ethics Committee, Lovely Professional University, Phagwara, India. The study was conducted in accordance with the ethical principles for research involving human participants.

Participants Consent: Informed consent was obtained from all participants before their participation. Participation is voluntary and right to withdraw from study is available to participants.

Data Availability Statement

The materials supporting the findings of this study are available for review and verification purposes. These materials include the anonymised quantitative dataset, data dictionary/codebook, structured questionnaire, interview guides, data collection procedures and relevant analysis resources. No personally identifiable information, such as participants' names, contact details, or other direct identifiers, has been included. The data were anonymised to protect participants' privacy and confidentiality in accordance with the informed consent and ethical requirements of the study.

Ethical Guidelines and Regulations

All research has conducted in accordance with the ethical principles outlined in the Declaration of Helsinki guidelines and regulations. Informed consent was obtained from all participants before data collection. Participants were informed about the purpose of the study. Participant is voluntary in nature. Data of participants were kept secure and confidential. They have right to withdraw from the study at any time. The study procedures were designed to protect participants' privacy, dignity, safety, and rights throughout the research process.

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Data availability: Data will be available on request.

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A Study on Ethical Hacking Contributions to AI-Powered Cyber Security

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Abstract: As cyber security threats get increasingly sophisticated, combining artificial intelligence (AI) with ethical hacking has emerged as a ground-breaking method for enhancing threat detection systems. Ethical hacking, which involves simulating cyber attacks to identify weaknesses, provides crucial information about potential security problems that significantly strengthen defensive systems when paired with AI's advanced data processing and pattern recognition capabilities. By providing better training data, refining machine learning models, and confirming AI-driven security, this study explores how ethical hacking enhances AI-based threat detection systems. Ethical hackers contribute by creating datasets that capture a range of threat behaviors and modeling real-world attack scenarios. These datasets are essential for increasing detection accuracy, reducing false positives, and training AI systems to recognize evolving attack patterns.

Additionally, the penetration testing and vulnerability assessments conducted by ethical hackers allow AI systems to learn from real-time security events, increasing their adaptability and predictive capabilities. AI-driven systems benefit from ethical hacking's human expertise in identifying complex and nuanced vulnerabilities that automated tools could overlook. By combining the strategic insights of ethical hacking with AI's ability to analyze massive amounts of data, security teams can employ more effective anomaly detection, automated response, and threat mitigation techniques. Our collaboration also contributes to the continuous improvement of cyber security postures by enabling adaptive learning models that adapt to new threats. By combining human ingenuity with machine efficiency, organizations may build more robust and proactive defenses, lowering the risk of data breaches and ensuring the longevity of digital infrastructures against an increasingly complex threat.

Key Words: Ethical Hacking, AI Security, Threat Detection, Cyber Resilience, Machine Learning, Vulnerability assessment, Penetration testing, Anomaly detection, Predictive analytics.

1. INTRODUCTION:

There has never been a greater need for smart and proactive security measures due to the growing sophistication and persistence of cyber threats. Organizations are susceptible to breaches and data loss because traditional cybersecurity tools frequently fail to keep up with the quickly changing attack vectors. In this regard, the cooperation of artificial intelligence (AI) and ethical hacking has become a potent tactic to improve threat detection systems and fortify digital defenses. In order to find and fix potential vulnerabilities before malevolent hackers may take advantage of them, ethical hacking,



sometimes referred to as penetration testing, is authorized attempts to exploit security flaws within an organization's systems. This technique reveals important security flaws and offers priceless insights into actual attack tactics. Ethical hacking improves the efficiency and training of AI-driven security systems when paired with AI's capacity to analyze enormous volumes of data and spot intricate patterns.

High-quality data is essential for AI-powered technologies like anomaly detection systems and machine learning algorithms to correctly identify and reduce hazards. By creating realistic and varied datasets through simulated cyberattacks, ethical hackers help AI models learn from and adjust to changing threat environments. Additionally, the combination of human knowledge and machine efficiency generates a dynamic feedback loop that allows AI systems to continuously improve based on lessons from ethical hacking and real-time threat intelligence. This combination lowers false positives, improves automated response capabilities and detection accuracy, boosting an organization's cybersecurity posture in the process. The significance of this cooperation increases with the complexity and frequency of cyberattacks. Organizations can more successfully predict and neutralize threats by utilizing the analytical capabilities of AI and the strategic insights of ethical hacking. This ensures the security and resilience of their digital infrastructure in an increasingly hostile cyber environment.

2.IMPROVING THREAT IDENTIFICATION BY INTEGRATING AI AND ETHICAL HACKING:

The way businesses detect and address cyberthreats has been completely transformed by the partnership of ethical hacking and AI. This method greatly enhances threat detection capabilities by fusing the strategic creativity of human hackers with the effectiveness and scalability of AI-driven systems. By simulating actual attack scenarios, ethical hackers reveal weaknesses that automated tools might miss. These fictitious breaches offer crucial training data, which lowers the possibility of false positives and aids AI systems in identifying intricate assault patterns.

3. SUPERIOR/HIGH QUALITY DATA FOR AI EDUCATION:

The creation of high-quality, real-world data is one of the main advantages of ethical hacking in AI-based threat detection. The data generated by ethical hackers through penetration testing and vulnerability assessments is crucial for AI models, which rely significantly on data for training and performance enhancement. These datasets help machine learning models comprehend and predict new cyberthreats by capturing a variety of threat behaviours and attack strategies. AI systems can recognize anomalies and differentiate between real threats and benign activities more accurately when they use real attack data instead of artificial or out-of-date information.

4. LOWERING/REDUCING FALSE POSITIVES AND INCREASING PRECISION:

Conventional threat detection systems frequently have high false positive rates, which overburden security personnel with pointless notifications and decrease their productivity. This problem is greatly reduced when ethical hacking insights are combined with AI. By exposing AI models to subtle attack patterns, ethical hackers assist them in learning to distinguish between suspicious and legitimate actions. This improves overall response efficiency by lowering the frequency of false alarms and ensuring that security personnel concentrate their attention on real threats.

5. ADAPTIVE LEARNING AND REAL-TIME THREAT INTELLIGENCE:

Additionally, ethical hacking promotes the ongoing development of security solutions powered by AI. Ethical hackers help AI models adjust to shifting threat environments by giving real-time feedback on system performance and spotting new vulnerabilities. The organization's cybersecurity posture is strengthened by this adaptive learning capability, which guarantees that AI systems continue to be successful against sophisticated threats and gradually increase their predictive accuracy.



6. STRENGTHENING INCIDENT RESPONSE AND MITIGATION WITH ETHICAL HACKING AND AI:

In addition to improving threat detection, the combination of ethical hacking with AI is essential for incident response and mitigation. By fusing mechanical efficiency with human knowledge, organizations are better able to reduce damage, react more quickly, and thwart future attacks. This cooperative strategy guarantees a more robust cybersecurity architecture and helps security teams keep ahead of changing threats.

7. AUTOMATED RESPONSE & DECISION-MAKING:

Although AI-driven security systems are excellent at evaluating enormous volumes of data and spotting risks instantly, their actual power is found in their automatic reaction capabilities. By offering actual attack situations, ethical hacking improves these abilities by teaching AI models how to prioritize and implement suitable mitigation techniques. This makes it possible for AI systems to react to events on their own, without the need for human intervention, by isolating compromised systems, blocking malicious traffic, or installing security fixes. As a result, potential damage and downtime are reduced and incident response is quicker and more effective.

8. AI-HUMAN COOPERATION FOR ADVANCED THREAT ANALYSIS:

While AI is capable of swiftly identifying and reacting to a wide range of attacks, human judgment and contextual awareness are necessary for some sophisticated threats. By deciphering AI-generated alerts and examining intricate attack patterns, ethical hackers provide this expertise. By working together, security professionals can concentrate on high-priority occurrences while AI takes care of everyday dangers. Additionally, ethical hackers offer insightful input that aids AI models in improving their detection standards and decision-making precision over time.

9. PROACTIVE VULNERABILITY MANAGEMENT:

The capacity to find and fix security flaws before they can be exploited is one of the main benefits of integrating ethical hacking with AI. By simulating sophisticated attack methods, ethical hackers reveal possible weaknesses in an organization's infrastructure. This information is used by AI algorithms to prioritize patching efforts and forecast potential attack paths, guaranteeing that serious flaws are fixed quickly.

10. Contributions of Ethical Hacking to AI-Powered Cybersecurity:

10.1 AI-Assisted Vulnerability Detection and Validation:

By examining vast amounts of network data, application logs, and software code, artificial intelligence has greatly enhanced the vulnerability detection process. Unusual patterns and possible vulnerabilities can be found more quickly by AI-powered cybersecurity solutions than by conventional manual methods. Nevertheless, the existence of a vulnerability does not necessarily mean that it may be effectively exploited.

A potential SQL Injection or Cross-Site Scripting (XSS) vulnerability in a web application, for instance, might be found by an AI-based security solution. After that, an authorized security assessment can be carried out by an ethical hacker to confirm the vulnerability and ascertain its true severity. This procedure aids in separating real security threats from automated systems' false-positive alarms.

Thus, ethical hacking offers useful verification and contextual analysis, while AI speeds up and automates vulnerability finding. Combining the two methods increases vulnerability assessment's precision and dependability.

10.2 AI-Assisted Penetration Testing:

Authorized security experts use penetration testing, a crucial procedure, to mimic possible cyberattacks and find vulnerabilities in a computer system or application. Through the analysis of past security



occurrences, the identification of high-risk regions, and the prioritization of systems that need an immediate security assessment, artificial intelligence can improve penetration testing.

An AI-powered security system, for instance, might spot odd authentication patterns or possible flaws in the login procedure in an online banking application. An authorized penetration test can then be carried out by an ethical hacker to evaluate the efficacy of session management, authentication measures, and access limitations.

Security experts can concentrate their testing efforts on the most important regions with this method. Therefore, by increasing the effectiveness and priority of penetration testing tasks, AI can assist ethical hackers.

10.3 AI-Based Intrusion Detection and Ethical Attack Simulation:

Intrusion Detection Systems (IDS) frequently employ AI and machine learning approaches to spot unusual network activity. These systems are able to identify typical network activity patterns and produce alerts when anomalous activity is found.

Take a business, for instance, where the AI-based intrusion detection system (IDS) notices an unanticipated rise in network requests and repeated attempts at unauthorized login. Such actions could be a sign of an impending cyberattack. In order to assess if the AI system can effectively detect and react to suspicious activity, ethical hackers can replicate permitted attack scenarios in a controlled setting.

AI-based detection systems can be made more accurate by utilizing the outcomes of these simulations. Thus, ethical hacking provides realistic testing data that can enhance AI-powered intrusion detection systems' training, assessment, and dependability.

10.4 AI-Based Phishing Detection and Social Engineering Assessment:

One of the most prevalent cybersecurity risks is still phishing assaults. Emails with suspect language, sender behavior, URLs, attachments, and communication patterns can all be analyzed by AI-powered systems.

An AI-based system, for instance, might be used by a company to find emails with potentially dangerous links. To test whether staff members and the AI security system can recognize suspicious messages, ethical hackers can run approved phishing awareness simulations.

Organizations can use the findings to find flaws in staff awareness and technical security mechanisms. While ethical hacking offers realistic simulations to assess the efficacy of organizational cybersecurity defenses, AI is capable of processing a vast amount of messages automatically.

10.5 AI-Powered Malware and Zero-Day Threat Detection:

For threat detection, traditional security systems frequently rely on recognized malware signatures. By examining behavioral patterns and spotting actions that depart from typical system operations, AI-powered systems can enhance this strategy.

An AI-based cybersecurity system, for instance, might identify anomalous activity like unauthorized file alterations, strange processes, or dubious network communication. To test whether the AI system can identify previously undiscovered threat behaviors, ethical hackers and security researchers can conduct controlled security experiments.

This kind of testing is especially crucial for enhancing defense against new and emerging threats. While AI offers ongoing surveillance and behavioral analysis, ethical hacking adds practical evaluation.



10.6 Authentication and Password Security Assessment:

Systems for authentication are crucial for safeguarding private data and company assets. AI is capable of analyzing authentication logs to spot odd login trends, dubious access attempts, and possible flaws in user authentication practices.

An AI-powered security system might, for instance, identify persistent unsuccessful login attempts or access from an unknown device. The efficacy of password regulations, multi-factor authentication, session controls, and access limits can then be assessed by an authorized ethical hacker.

Organizations can improve authentication procedures and lower the possibility of unwanted access by using this integrated strategy.

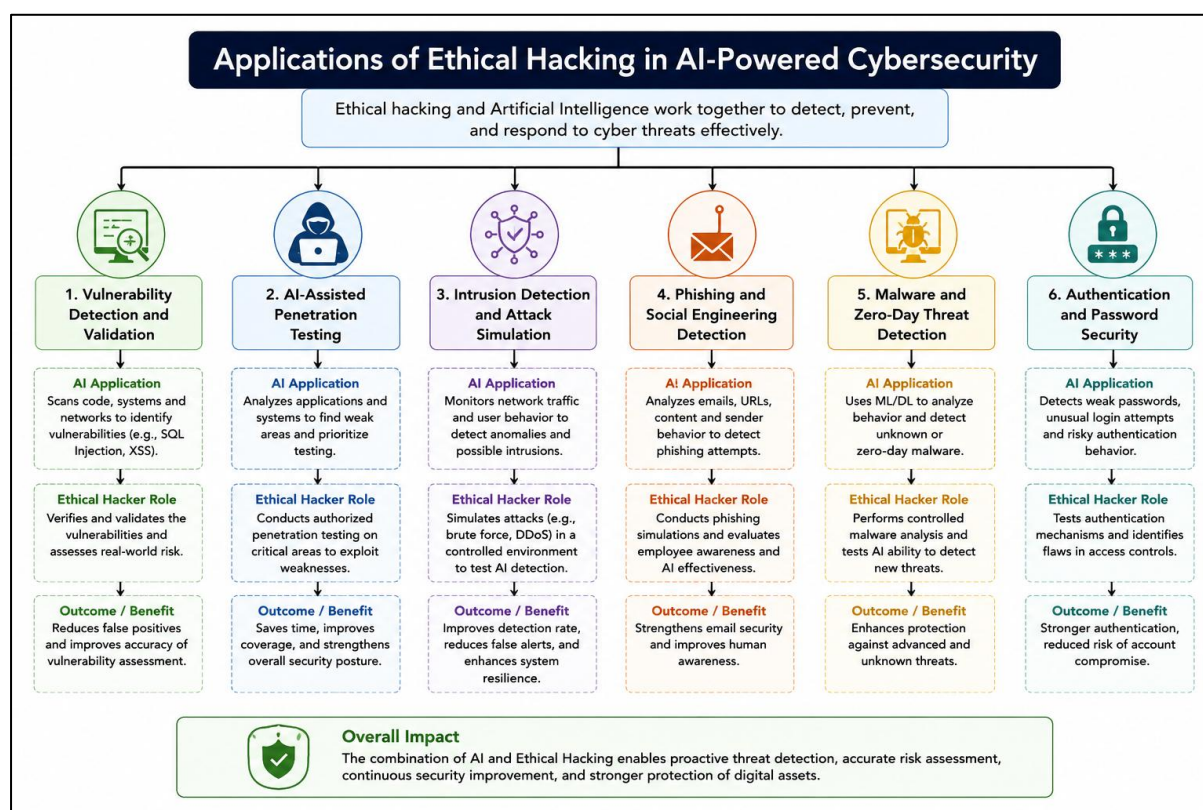


Fig: 1.1

11. CONCLUSION:

AI and ethical hacking working together is a revolutionary approach to contemporary cybersecurity, especially when it comes to improving threat identification, incident response, and proactive defense strategies. Organizations may create more robust and adaptable security operations by fusing AI's speed, scalability, and data-processing capabilities with human creativity and strategic thinking. By mimicking actual attacks, revealing flaws, and providing insightful information that aids in the improvement of machine learning models, ethical hackers are essential to the training of AI systems. Because of this mutually beneficial relationship, AI-driven security solutions are guaranteed to be dynamic and adaptable to the always changing threat scenario.

Additionally, incorporating ethical hacking techniques makes incident response more precise and effective. Ethical hackers' understanding of attack techniques and system flaws enhances AI's capacity to quickly identify and contain attacks. By working together, security teams can reduce false positives and concentrate on real, high-priority threats. Organizations may swiftly mitigate damage and minimize downtime by using automated reaction systems that are driven by ethical hacking insights. These elements are crucial for preserving operational continuity and safeguarding sensitive data.



Another important advantage of this collaboration is proactive vulnerability control. By identifying possible security flaws before they can be exploited, ethical hackers give AI systems the information they need to anticipate and rank potential threats. This proactive strategy improves an organization's overall security posture while lowering the attack surface. Businesses may stay ahead of cyber threats and maintain a level of readiness by continuously improving AI models with real-world scenarios and expert feedback. This cooperative strategy guarantees that security operations continue to be flexible, effective, and efficient as cyber threats become more complex. Adopting this combination creates the groundwork for a more secure digital future while simultaneously bolstering present defenses.

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A Cross Study Analysis of Deep Learning Frameworks for Diabetic Retinopathy Health Care Using Fundus and OCTA Images

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Abstract: Automated diabetic retinopathy analysis is often reported through isolated model and dataset results, although health care use depends on imaging modality, disease grade coverage, validation depth, and the type of decision required. This paper conducts a cross study analysis of four connected investigations covering preliminary fundus processing, five grade fundus classification, three class OCTA classification, and multimodal fundus and OCTA classification. The studies comprise an interpretable DRIVE processing pipeline, DiaRetULS-Net on Messidor 2 with cross dataset evaluation on APTOS 2019 and IDRiD, EfficientNetB4 with Softmax on the ROAD OCTA dataset, and DiabFoRMaxNet on a paired multimodal dataset. DiaRetULS-Net achieved 98.83% accuracy and 99.15% F1 score on Messidor 2, with 97.12% and 96.34% accuracy on APTOS 2019 and IDRiD. EfficientNetB4 achieved 98.97% accuracy and 98.25% F1 score on ROAD. DiabFoRMaxNet reported 99.18% fundus accuracy and 99.69% OCTA accuracy. The analysis does not collapse these values into one leaderboard because the datasets and class schemes differ. Instead, it compares modality, class coverage, architectural role, error pattern, and validation evidence. DiaRetULS-Net provides the widest support for five grade fundus referral and cross dataset testing, EfficientNetB4 supplies the strongest controlled OCTA backbone evidence, and DiabFoRMaxNet records the highest internal values for a single multimodal framework but uses three classes and 222 original paired images before augmentation. The health care discussion links each framework to an appropriate screening or decision context while retaining the limits of retrospective evaluation.

Keywords: diabetic retinopathy health care, cross study analysis, fundus imaging, OCTA, DiaRetULS-Net, EfficientNetB4, DiabFoRMaxNet, multimodal deep learning.

1. INTRODUCTION

Diabetic retinopathy health care includes population screening, severity grading, specialist referral, follow up imaging, and assessment of retinal microvascular change. A single accuracy value cannot describe whether an automated system is suitable for all these tasks. Fundus photographs record visible lesions over a wide retinal field and remain the main source for conventional severity grading, while OCTA depicts perfusion and capillary structure without dye injection [12], [15], [16]. The two modalities therefore contribute different evidence, and a model trained on one should not be assumed to transfer to the other without direct evaluation.



The four studies examined here form a connected research sequence rather than four interchangeable classifiers. The first study reviewed diabetic retinopathy methods and tested a reproducible fundus processing chain on DRIVE [1]. The second introduced DiaRetULS-Net for five grade fundus classification across Messidor 2, APTOS 2019, and IDRiD [2]. The third compared ResNet and EfficientNet backbones for three class OCTA classification on ROAD [3]. The fourth combined fundus and OCTA processing within DiabFoRMaxNet [4]. Figure 1 shows how the imaging scope and learning design change across this sequence.

A cross study paper must preserve the conditions attached to every value. DiaRetULS-Net covers five grades and includes cross dataset tests, while the OCTA and multimodal studies use three classes. The multimodal study begins with 222 original paired images and expands them through augmentation after source level partitioning. These differences affect clinical meaning and statistical confidence. The analysis identifies what each study supports for diabetic retinopathy health care, where its evidence is strongest, and which questions remain unresolved.

Progression from structural analysis to multimodal diabetic retinopathy health care

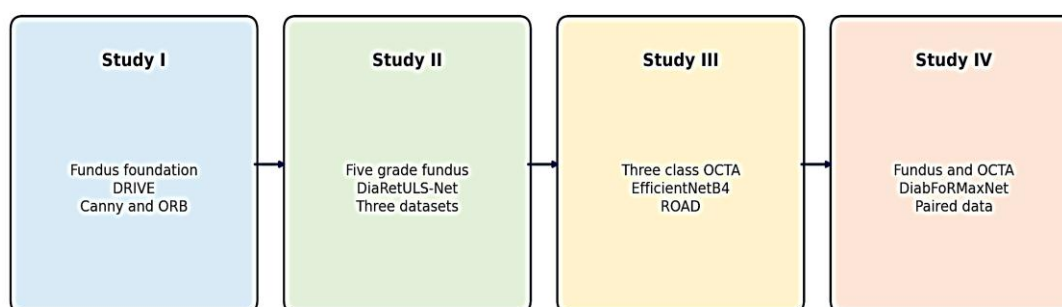


Fig. 1. Progression of the four studies from preliminary fundus processing to multimodal diabetic retinopathy health care analysis.

2. Evidence Base and Published Studies

Table 1 lists the four papers that supply the evidence base. Each publication addresses a separate point in the research sequence and is cited directly in this paper. Study I establishes processing and literature foundations but does not report a trained diagnostic classifier. Study II contributes five grade fundus classification with lesion aware segmentation and cross dataset evaluation. Study III provides a controlled comparison of four OCTA backbones. Study IV tests one architecture across fundus and OCTA inputs under a three class multimodal protocol.

Table 1 Published Studies Included in the Cross Study Analysis

Study	Publication	Principal contribution
I	Hariobulesu and Shaik, IEEE ICCCNT 2024 [1]	Literature synthesis and preliminary DRIVE fundus processing
II	Hariobulesu and Shaik, Expert Systems with Applications 2025 [2]	DiaRetULS-Net for five grade fundus classification
III	Hariobulesu and Shaik, ITEGAM JETIA 2026 [3]	Controlled ResNet and EfficientNet comparison on ROAD OCTA
IV	Hariobulesu and Shaik, IRJMS 2026 [4]	DiabFoRMaxNet for fundus and OCTA classification



The wider literature explains why this progression matters. Deep learning systems have achieved strong fundus grading performance across the diabetic retinopathy spectrum [10], [13], while OCTA reviews describe the diagnostic value of capillary density, non perfusion, and the foveal avascular zone [12], [15], [16]. Ryu et al. trained an OCTA classifier for diabetic retinopathy [14], and Le Boite et al. developed segmentation models for non perfusion, low quality regions, and the foveal avascular zone [11]. Bidwai et al. released paired fundus and OCTA data for multimodal study [6]. Other fundus studies have examined parallel CNN features, hybrid deep features, and model ensembles [18]-[20]. These sources support the move from fundus only classification toward vascular and multimodal analysis, but they also show that the prediction task must remain explicit.

3. Cross Study Method

3.1 Comparison Dimensions

Five dimensions were used for comparison: imaging modality, dataset scale, severity class coverage, architectural function, and validation evidence. Reported accuracy, sensitivity, specificity, precision, and F1 score were transcribed without altering their values. A numerical result was compared directly only when the task and dataset supported that comparison. Values from different datasets are displayed together to show the evidence range, but they are not treated as a common competition.

The standard classification measures retain their usual definitions. Accuracy measures all correct decisions, sensitivity measures detection of diseased samples, specificity measures rejection of unaffected samples, precision measures the reliability of positive predictions, and the F1 score is the harmonic mean of precision and sensitivity. These measures are written in Eqs. (1) to (5) to make the cross study interpretation explicit.

$$A = (TP + TN) / N \quad (1)$$

whereas A denotes accuracy, N is the total number of decisions, and TP, TN, FP, and FN denote true positive, true negative, false positive, and false negative decisions, with N equal to TP plus TN plus FP plus FN.

$$Se = TP / (TP + FN) \quad (2)$$

whereas sensitivity measures the proportion of diseased samples that receive a positive decision.

$$Sp = TN / (TN + FP) \quad (3)$$

whereas specificity measures the proportion of unaffected samples that receive a negative decision.

$$Pr = TP / (TP + FP) \quad (4)$$

whereas precision measures how often a positive decision corresponds to a diseased sample.

$$F1 = 2PrSe / (Pr + Se) \quad (5)$$

whereas the F1 score combines precision and sensitivity through their harmonic mean.

3.2 Dataset and Class Boundaries

Table 2 records the dataset conditions that control interpretation. DRIVE contains 40 images and supports vessel segmentation research rather than diabetic retinopathy severity grading [5]. Messidor 2 contains 1,748 fundus images in the reported experiment, while APTOS 2019 and IDRiD provide independent fundus sources for cross dataset evaluation [2], [7]-[9]. ROAD contains 2,640 OCTA images and supports a three class protocol [3], [17]. The multimodal experiment uses 222 original paired images, which become 13,424 augmented modality images after source level partitioning [4], [6].



Augmentation enlarges the training material but does not convert 222 independent pairs into 13,424 independent patients or acquisitions.

Table 2 Datasets Modalities Class Coverage and Study Roles

Study and dataset	Modality	Scale used	Class or annotation scope	Role
Study I DRIVE [1], [5]	Fundus	40 images	Vessel masks, no DR grade classifier	Structural processing demonstration
Study II Messidor 2 [2]	Fundus	1,748 images	Five grades from No DR to PDR	Primary five grade evaluation
Study II APTOS 2019 [2], [8]	Fundus	Public competition set	Five grades	Cross dataset evaluation
Study II IDRiD [2], [9]	Fundus	Public retinal set	Five grades and lesion annotations	Cross dataset evaluation
Study III ROAD [3], [17]	OCTA	2,640 images	No DR, Mild NPDR, and PDR	Controlled backbone comparison
Study IV paired data [4], [6]	Fundus and OCTA	222 originals to 13,424 augmented images	No DR, Mild DR, and Moderate DR	Multimodal evaluation

4. Development of the Four Frameworks

4.1 Preliminary Fundus Processing

Study I combined a structured literature review with an empirical DRIVE processing sequence [1]. Scaling standardised image dimensions, greyscale conversion reduced channel complexity, filtering suppressed noise, Canny detection identified vessel and lesion edges, and ORB located repeatable keypoints. The study supplies visual and algorithmic evidence for structural preservation, but it does not supply classification accuracy. Its role in diabetic retinopathy health care is methodological: it clarifies which low cost image operations preserve retinal information before a learned model is introduced.

4.2 DiaRetULS-Net for Five Grade Fundus Classification

DiaRetULS-Net combines bilinear resizing, green channel processing, CLAHE, discrete wavelet features, local binary patterns, U Net segmentation, a liquid time constant neural network, and a multi class support vector machine [2]. U Net localises vascular and lesion regions, the liquid network models dependencies in the segmented representation, and the support vector machine forms five grade decision boundaries. On Messidor 2, the model reports 98.83% accuracy, 99.21% sensitivity, 98.87% specificity, 99.28% precision, and 99.15% F1 score. Accuracy falls to 97.12% on APTOS 2019 and 96.34% on IDRiD, which records the effect of dataset heterogeneity rather than a failure of the method.

4.3 EfficientNetB4 for Standalone OCTA Classification

Study III applies one preprocessing and classifier path to ResNet50, ResNet101, EfficientNetB3, and EfficientNetB4 [3]. Bilinear resizing, Z score normalisation, and CLAHE prepare ROAD images; global average pooling and Adam optimisation precede Softmax classification. EfficientNetB4 reaches 98.97% accuracy, 97.26% sensitivity, 98.54% specificity, 98.66% precision, and 98.25% F1 score. Ten fold validation reports accuracy from 98.12% to 99.10%. The study establishes the strongest tested conventional OCTA backbone, although it uses one primary dataset and three output classes.



4.4 DiabFoRMaxNet for Fundus and OCTA

DiabFoRMaxNet uses AlexNet for hierarchical feature extraction, a fully convolutional network for lesion segmentation, the Fossa Optimisation Algorithm for feature refinement, and RankMax for classification [4]. Z score normalisation, modality specific contrast handling, adaptive histogram equalisation, and bilateral filtering prepare the fundus and OCTA inputs. The experiment reports 99.18% accuracy for fundus images and 99.69% for OCTA images. The corresponding F1 scores are 99.11% and 99.49%. Source images were partitioned before augmentation so that derivatives from one original pair remained in the same subset. This safeguard reduces near duplicate leakage across splits, although the independent sample base remains 222 original pairs.

5. Cross Study Results

5.1 Headline Performance

Table 3 consolidates the five reported measures for the trained classifiers. Figure 2 displays accuracy with each dataset and modality written directly in the label. DiabFoRMaxNet on OCTA has the highest numerical accuracy at 99.69%, followed by its fundus result at 99.18%. EfficientNetB4 records 98.97% on ROAD, and DiaRetULS-Net records 98.83% on Messidor 2. These values do not establish an unconditional model order. The multimodal experiment has three classes and 222 original pairs, the ROAD experiment has three OCTA classes, and DiaRetULS-Net addresses five fundus grades across three datasets.

Table 3 Reported Cross Study Performance with Dataset and Modality Context

Framework and context	Accuracy	Sensitivity	Specificity	Precision	F1 score
DiaRetULS-Net Messidor 2 fundus	98.83	99.21	98.87	99.28	99.15
DiaRetULS-Net APTOS 2019 fundus	97.12	96.87	96.93	97.68	97.27
DiaRetULS-Net IDRid fundus	96.34	96.21	95.71	95.98	96.09
EfficientNetB4 ROAD OCTA	98.97	97.26	98.54	98.66	98.25
DiabFoRMaxNet multimodal fundus	99.18	99.37	99.40	99.26	99.11
DiabFoRMaxNet multimodal OCTA	99.69	99.83	99.85	99.58	99.49

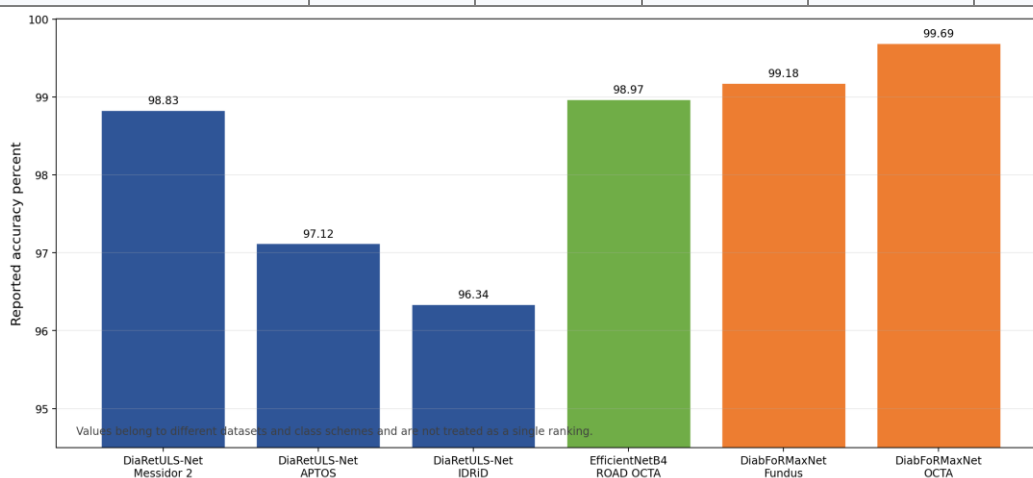


Fig. 2. Reported accuracy across the trained studies with dataset and modality retained in every label.



The heat map in Fig. 3 keeps all five measures visible. DiaRetULS-Net on Messidor 2 is especially strong in precision and sensitivity, which is useful for five grade fundus referral. Its reduction on APTOS 2019 and IDRiD supplies direct evidence of cross source variation. EfficientNetB4 maintains all five ROAD measures above 97%. DiabFoRMaxNet exceeds 99% for every fundus and OCTA measure in its internal experiment. The correct interpretation is conditional suitability, because the difference between 98.97% and 99.69% cannot be separated from the change in dataset, label set, and model protocol.

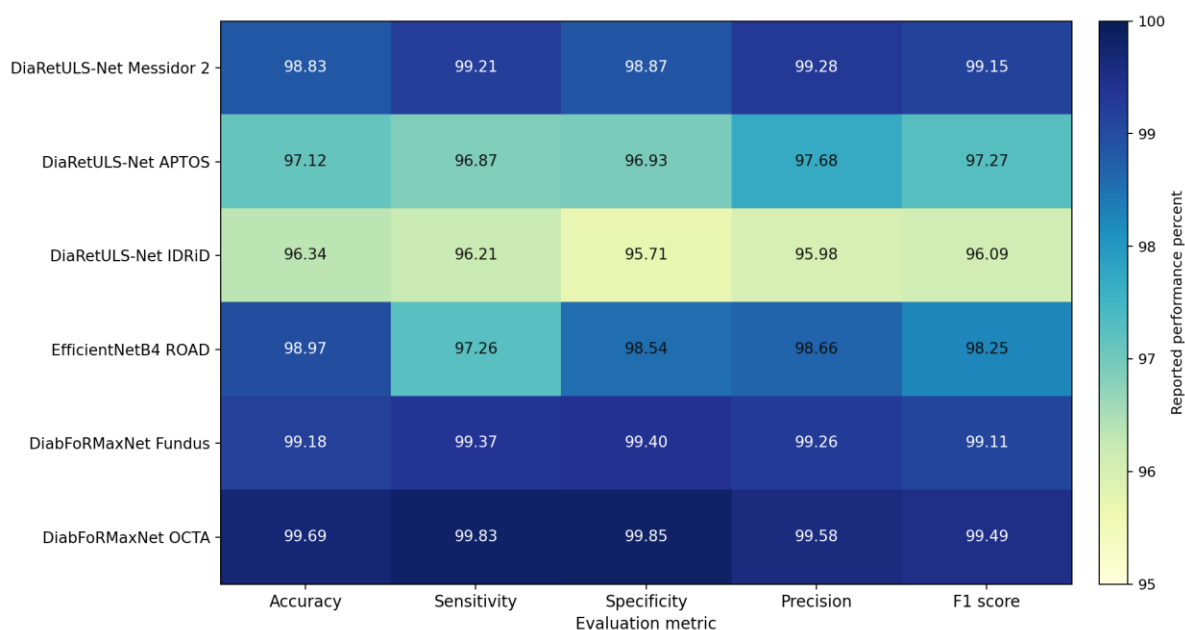


Fig. 3. Five reported measures across the fundus OCTA and multimodal experiments.

5.2 Error Patterns and Validation Evidence

Residual errors occur mainly between neighbouring stages. DiaRetULS-Net reports most confusion around Mild and Moderate DR, with limited confusion between Severe DR and PDR [2]. Study III identifies Mild NPDR as the most ambiguous OCTA class and reports a ten fold accuracy range of 98.12% to 99.10% [3]. DiabFoRMaxNet reports six fundus errors and three OCTA errors in its test matrices, with the remaining OCTA error concentrated near the Mild to Moderate boundary [4]. These patterns are clinically plausible because adjacent stages share lesions or vascular changes, but the published evidence does not include prospective adjudication of each disputed case.

Table 4 Error Pattern and Validation Evidence Across the Trained Studies

Framework	Principal error pattern	Validation evidence	Evidence boundary
DiaRetULS-Net	Mainly Mild versus Moderate; limited Severe versus PDR confusion	Three datasets; five fold by five runs; reported SD 0.14 to 0.21	Five grade fundus setting
EfficientNetB4	Mild NPDR carries the greatest residual ambiguity	Ten fold accuracy from 98.12% to 99.10%	One primary OCTA dataset
DiabFoRMaxNet	Six fundus and three OCTA errors; OCTA boundary mainly Mild to Moderate	Source level split before augmentation and five fold validation	Three classes and 222 original pairs



5.3 Architectural Progression

The architecture changes with the imaging question. Study I uses explicit edges and keypoints so that retinal structures can be inspected directly. DiaRetULS-Net combines handcrafted frequency and texture descriptors with learned segmentation and temporal representation. Study III removes the bespoke segmentation and classifier modules to create a controlled OCTA backbone comparison. Study IV returns to segmentation but adds modality dependent preprocessing, nature inspired feature refinement, and RankMax classification. The sequence shows that segmentation is most useful when lesion localisation is part of the intended explanation, while a conventional Softmax head is sufficient for a controlled comparison of backbone representation.

6. Implications for Diabetic Retinopathy Health Care

6.1 Screening and Referral Roles

Figure 4 and Table 5 translate the research evidence into health care roles without claiming clinical deployment. The Study I pipeline is suitable for teaching, quality inspection, and preliminary structural analysis, but it cannot issue a disease grade. DiaRetULS-Net is the best supported choice when five grade fundus referral is required because it covers No DR, Mild, Moderate, Severe, and PDR and has been evaluated on three fundus datasets. EfficientNetB4 is the best supported conventional backbone for a standalone ROAD OCTA classifier. DiabFoRMaxNet is the only framework in the group that processes both fundus and OCTA through one model family, making it the relevant research candidate when a health care pathway has access to both modalities.

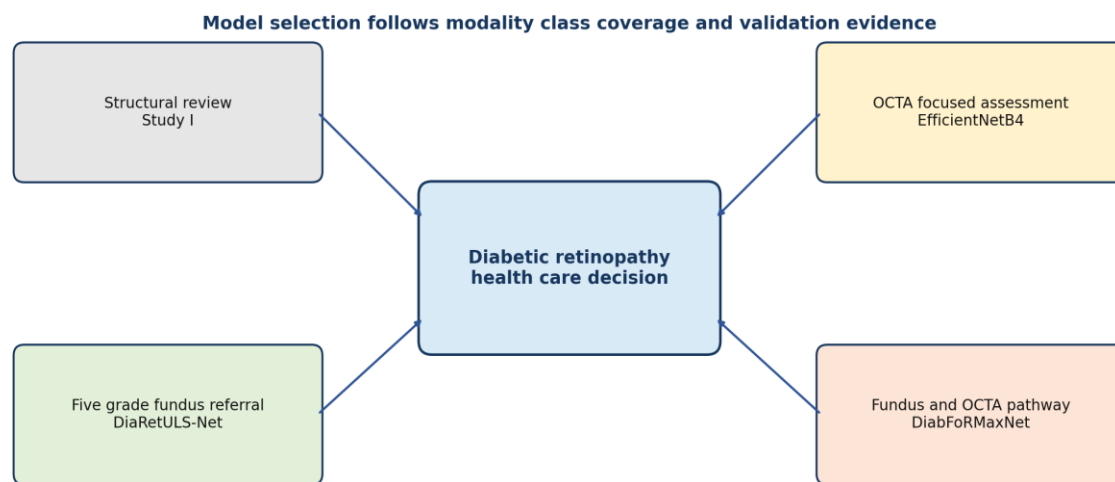


Fig. 4. Evidence based placement of the four studies within diabetic retinopathy health care research.

Table 5 Health Care Suitability of the Four Research Stages

Health care question	Best supported framework	Reason	Qualification
Preliminary retinal structure inspection	Study I pipeline	Visible edge and keypoint processing on DRIVE	No diagnostic classifier



Health care question	Best supported framework	Reason	Qualification
Complete five grade fundus referral	DiaRetULS-Net	Five grades with three dataset evaluation	Complex modular architecture
Standalone OCTA image classification	EfficientNetB4 with Softmax	First across five measures in a controlled backbone test	Three classes and one primary dataset
One framework for fundus and OCTA	DiabFoRMaxNet	Modality specific results within one architecture	Three classes and modest original paired sample
Cross source fundus evidence	DiaRetULS-Net	Messidor 2 APTOS 2019 and IDRid results	Performance decreases under dataset heterogeneity

6.2 Clinical Evidence Still Required

Retrospective image classification is one part of diabetic retinopathy health care. Prospective evaluation must also measure referral sensitivity, false referral burden, calibration, image rejection, device failure, patient level clustering, and performance across age, sex, diabetes duration, and coexisting retinal disease. OCTA adds device and scan protocol variation that may be less prominent in ordinary fundus photography. Quality control should distinguish true non perfusion from motion, shadow, and segmentation artefacts before a classifier assigns a severity label [11], [12].

Clinical comparison also requires a common label system. DiaRetULS-Net uses five grades, the ROAD study separates No DR, Mild NPDR, and PDR, and DiabFoRMaxNet separates No DR, Mild DR, and Moderate DR. A health care study that compares them prospectively should define one referral endpoint and one grading standard across modalities. Without this step, a higher three class accuracy may reflect an easier decision boundary rather than a model that is better for complete severity management.

7. Limitations

The analysis compares four connected publications and does not repeat model training. The values originate from different datasets, class definitions, and validation protocols, so no pooled accuracy or universal rank is reported. Study I is a processing study rather than a classifier. Studies III and IV do not cover all five diabetic retinopathy grades. Study IV uses extensive augmentation from 222 original paired images, and its strong internal results require confirmation on a larger independent multimodal cohort. None of the four studies reports prospective multicentre performance, calibrated uncertainty, real time referral workload, or a direct clinician comparison under one common protocol.

8. Conclusion

The four studies support different parts of diabetic retinopathy health care. Study I establishes interpretable fundus processing. DiaRetULS-Net supplies the widest evidence for five grade fundus classification and cross dataset behaviour. EfficientNetB4 provides the strongest controlled backbone result for three class ROAD OCTA images. DiabFoRMaxNet records the highest internal fundus and OCTA values within one multimodal architecture, while its three class scope and 222 original paired images define the limit of that evidence. The cross study result is a model selection rule based on modality, grade coverage, and validation depth rather than a single accuracy leaderboard. Future evaluation should use patient level multicentre data, a common clinical endpoint, explicit image quality rejection, calibrated probability estimates, and complete severity grading across fundus and OCTA inputs.



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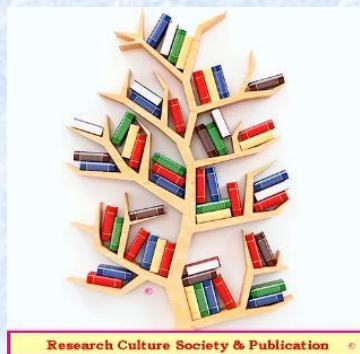


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