ISSN : 3059-9776 (PAPER)

Orchid Insights:

A Multi-Disciplinary Journal of Orchid College

Volume 2 | Number I | June 2026

Published by:
ORCHID INTERNATIONAL College

Gaushala, Kathmandu 977-1-4579744 | 977-1-4579745 www.oic.edu.np

Orchid Insights: A Multi- Disciplinary Journal of Orchid College
Volume 2. No. I

Publisher:
Research Managament Cell
Orchid International College
Gaushala, Kathmandu, Nepal
Phone: 01-4579744, 01-4579745
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We extend our sincere gratitude to the authors, reviewers, and editorial team for their dedication, and to the Principal, Director, and administration of Orchid International College for their continued support. We welcome constructive feedback and look forward to future contributions that enrich scholarly discourse.

Editor-in-Chief
Orchid Insights: A Multidisciplinary Journal of Orchid College

Language of Publication: English
Scope: Multi- Disciplinary (Business, Management, Technology and Social Science)
Article Processing Charge: Not Applicable
Policy: Double- blind Peer Review
Country of Publication: Nepal
Publication Ethics: Editorial Policy

TABLE OF CONTENT

Orchid Insights:
A Multi-Disciplinary Journal of Orchid College

Research Paper: Vol 2, pp 1–8, June/2026
Received: December 31, 2025
Accepted: May 23, 2026
ISSN: 3059-9776
https://doi.org/10.3126/oimjoc.v2i1.96043

Exploring Edupreneurship: A Qualitative Study of Private Colleges in Nepal

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Abstract:

This study explores how Nepali private colleges adopt edupreneurial practices. These new approaches are combining responsiveness to the market with their core academic missions. Institutional theory and entrepreneurial orientation offer a framework for examining the interplay between legitimacy and innovation in institutional practices. This provides insight into how competition and survival goals shape the strategic choices. This qualitative study thematically analyzed the collected data through online responses from the institutional leaders ($n_1 = 5$), faculty members ($n_2 = 5$), and senior students ($n_3 = 7$). The key insights highlight that Nepali private colleges mainly adopt edupreneurial strategies in several areas. They focus on strengthening their branding efforts, ensure regulatory compliance, integrate value-added programs and technology. Moreover, they work on expansion of faculty responsibilities, and focusing on career readiness. These strategies are driven not only by commercial success but also by the need for institutions to adapt to a changing environment, sustainability, and social aspects. As a result, edupreneurship emerges as a strategic response to institutional expectations, market pressures, and legitimacy concerns.

Keywords: *edupreneurship, Nepali higher education, institutional theory, entrepreneurial orientation*

1. Introduction:

Private colleges in Nepal have experienced a revolutionary change over the decades. They constitute more than half of Nepal's registered colleges and account for nearly one-third of students enrolled in higher education (UGC, 2025). This growth has profoundly redefined their institutional identity. Previously, the mission statements of colleges often focused on values such as literacy and discipline; however, they now emphasize innovation, global readiness, and leadership. This transformation reflects a broader shift in higher education toward market-oriented institutional practices. This blend of academic goals and market-driven strategies is known as educational entrepreneurship or edupreneurship. This trend is observable in how different universities around the world are working together and adopting new curricula. These developments reflect deliberate edupreneurial strategies aimed at securing competitive advantage within an increasingly marketized higher education environment.

However, there are key issues related to the market-oriented strategies adopted to achieve a balance between the need to establish trust and credibility within the particular market

environment (DiMaggio & Powell, 1983). It is necessary to distinguish between entrepreneurial efforts that genuinely promote learning and those that mainly aim to enhance the institution's image (Lumpkin & Dess, 1996). Despite the growth of the private sector, qualitative studies on how higher education institutions (HEIs) manage their pressures to conform to the conflicting demands of academic integrity and market survival are limited. Thus, this study aimed to explore how private colleges in Nepal are engaging in edupreneurial practices from the institutional and entrepreneurial lenses. In this regard, Institutional Theory and Entrepreneurial Orientation (EO) serve as the main framework for this study. These approaches provide an interpretive context in which to understand the dynamic link between innovation and legitimacy. Institutional theory explains how an institution responds to external influences to establish its legitimacy and EO explains how an institution can establish market leadership. This study looks at the balance where these two forces meet because colleges must follow regulators while trying to be different from their competitors.

DiMaggio and Powell (1983) state that institutions adopt different practices not just for efficiency but also to appear credible to regulators, parents, and peer institutions. This process is reflected in Nepal through three forms of isomorphism. 'Coercive isomorphism' happens when organizations must follow formal rules. Private colleges in Nepal follow the guidelines set by national agencies including the University Grants Commission (UGC), and their affiliated universities (UGC, 2025). Many institutions often imitate successful market leaders through 'mimetic isomorphism'. For instance, a college in Pokhara might copy a STEM-focused approach from Kathmandu University to reduce innovation costs and the risk of failure. Furthermore, 'normative isomorphism' refers to professional standards, in which the qualifications and norms of the faculty and the codes of practice are the same in most institutions, resulting in uniformity. In the Nepali higher education system, the need to maintain legitimacy can be met through compliance, imitation, and professional norms. These pressures result in the implementation of changes that are likely to prioritize uniformity over innovation unless the institution adopts an entrepreneurial mindset.

Edupreneurship is often defined as a paradigm shift in education that reflects the coordination of social purpose with market-centric strategies (Lehmann et al., 2024). This is noticeable in the Asian context through strategies like forming affiliations with foreign universities, implementing their global or glocalized courses, and investing in modern facilities. In this regard, EO covers proactiveness, competitive aggressiveness, autonomy, innovation, and risk-taking (Lumpkin & Dess, 1996). Proactiveness is seen in anticipating student needs ahead of other institutions, such as by providing artificial intelligence (AI)-focused programs. Competitive aggressiveness is reflected in efforts to outperform rivals in branding and attracting talent. Faculty teams themselves can demonstrate autonomy in the development of new courses and/or lesson plans. The preparedness of the universities to embrace new opportunities like the new courses, technologies, and programs such as Bachelor of Technology in Artificial Intelligence (BTech AI) can be viewed as attributes of innovation and risk taking.

The blend of these theories suggests that edupreneurship in Nepal is a strategic way to respond to institutional pressures. EO shapes the edupreneurial strategies, and colleges are encouraged to stand out in their own way while still following the formal rules required to comply for their survival. This establishes the way in which their entrepreneurship can be linked to their institutional goals. In the Nepali context, these trends have been noticed in the cities, where the competition between private colleges is very high. In such cases, the pressures on the institutions are to maintain academic standards and to compete for students, and the need to adapt and innovate, i.e., to become entrepreneurial, is a necessity for their survival and growth.

2. Materials and Methods:

A qualitative approach was adopted in this study to effectively explore less-studied real-world phenomena by capturing participants' perspectives in such concerns (Creswell & Creswell, 2018). Online responses were selected to allow participants greater flexibility, anonymity, and reflection when discussing institutional practices. It gave insights into how three key stakeholder groups: leaders, faculty, and students, respond to market pressures while upholding their educational values. Data were collected from open-ended Google Forms while exploring edupreneurship in private colleges. Data collection continued until responses began to show repetitive thematic patterns and no major new insights emerged. Participants were purposefully selected from five private colleges in Kathmandu that offer similar professional programs and operate under comparable regulatory conditions.

These participants were invited via email and messaging platforms, along with a customized Google Form link for each group to guarantee accessibility and asynchronous responses and facilitate convenience. In this context, institutional leaders ($n_1 = 5$), faculty members ($n_2 = 5$), and senior students ($n_3 = 7$), a total of 17 participants submitted their responses. Then, the data were thematically analyzed using the six-step process proposed by Braun and Clarke (2006). The process began with getting to know the data, reading the responses multiple times, and creating codes before finally creating larger patterns and identifying potential themes. The process was done manually to remain intimately connected to the data. In this regard, data from different participants' perspectives make the results more reliable (Lincoln & Guba, 1985, as cited in Creswell & Creswell, 2018). Moreover, participants were informed about the purpose of this study. They were asked to check a box to give their informed consent before completing their online forms. Participants were assigned pseudonyms (e.g., A1 for administrator, F1 for faculty member, and S1 for student) to maintain confidentiality. This qualitative study was limited to the participants' self-reported experiences.

3. Results and Discussion:

Brand Identity and Differentiation

Colleges have found ways to stand out beyond normal education. This enables them to strategically differentiate themselves. In this context, some administrators (A1, A2, A3) focus on affordability, innovation, or engineering, while others (A4, A5) emphasize community engagement as part of a curriculum designed to provide market-relevant education at competitive prices. Additionally, faculty members (F1, F2) highlight their long-term connections to collaboration, project work, and innovative practices. Faculty members, F3 and F4 mention global connections and opportunities offered by their colleges to students. Some students (S2, S3, S4) indicate that collaboration and transformation are their institutions' main strategies. Others (S3, S5) are influenced by the college's reputation and opinions of family, friends, and social circles or media. However, S1, S6, and S7 report that their colleges' facilities are inferior to what had been promoted during recruitment and marketing. This suggests a decoupling between the edupreneurial image presented by the leadership and the actual student experience on campus. Therefore, colleges are redefining their legitimacy by combining these market values with their academic traditions to establish a distinct position in the competitive education market.

Market Intelligence and Competitor Monitoring

Colleges engage in entrepreneurial proactiveness by monitoring their competitors, a process that normally culminates in mimetic isomorphism. This process often leads institutions to copy the strategies of successful rivals to maintain competitive parity. Administrators (A1, A2, A3) agree that they monitor their competitors to ensure innovation in their academic offerings through adaptation and restructuring. Another leader (A4) adds that

there is a mission statement that they have to follow, but they have to survey their competitors constantly. F1 and F4 faculty members agree that they have to incorporate innovation and be ready to compete globally through their teachings. Student feedback from S2, S3, S4, and S5 indicates that basic brand elements are well incorporated in their presentations and events. However, some students (S6, S7) feel that some sessions are too theoretical. This process is necessary in order to ensure that colleges respond to market dynamics.

Affiliations and Formal Compliance

Institutional legitimacy is often reinforced through isomorphic pressures. Administrators A1, A2, and A4 consider affiliations to be an essential indicator of whether the students and parents trust the institution. This represents an important balance of the push for innovation and the need to comply with national policy. Affiliation with top institutions is a prerequisite for gaining global recognition and acts as a form of coercive isomorphism where the colleges must follow strict academic rules to remain legitimate. From the faculty point of view (F5), these standardized norms are the parameters by which the academic boundaries are set; even within the entrepreneurial framework, the board exams were strictly governed by the university guidelines. From the students' (S3, S5, S7) perspective, these affiliations create a sense of belonging and confidence, which indicates that the legitimacy of the qualification is inextricably linked to the reputation of the parent university. However, some other students (S1, S7) felt that their enrollment decisions were based on more pragmatic factors.

Trust-Building and Quality Assurance

Colleges are increasingly moving beyond the boundaries of institutional compliance to establish professionalism through quality assurance. Administrators (A1, A2) claim that building trust is a product of institutional transparency, often showcased through the achievement of ISO certification. Another administrator (A4) indicates that institutional legitimacy is further demonstrated through the alignment between the curriculum and community engagement. Although faculty (F2) appreciate a level of autonomy in the curriculum, another faculty member (F5) indicates that the standardized examinations potentially stifle the creativity these institutions aim to foster. This creates a tension between the need for institutional legitimacy and the entrepreneurial goal of innovation. From the student point of view, although the legitimacy of the qualification is valued for its link to future employability (S3, S5, S7), there is a recognition that institutions must balance these coercive forces with the need to be entrepreneurial.

Value-Added Skills and Programs

Private colleges are broadening their traditional curriculum to stay competitive while still complying with regulations. Administrators (A1, A3, A4, A5) agree that value-added skills and programs are essential for staying competitive. This is particularly true for non-credit courses and idea incubators. This is crucial for the skill sets of the students and the overall market perception of the college. Some of the faculty members (F1, F3, F4) support these new initiatives through peer learning and data analytics sessions. Students S3, S4, and S7 all agree that these new initiatives have made a significant impact. Although some logistical issues were reported, high-level mentoring sessions and community-building events were highly valued.

Teaching Methods and Technology Integration

The shift towards an edupreneurial model is an integration of technology and collaborative learning. Administrators (A4, A5) shared the lab-studio idea that provides an opportunity for students to solve global issues through collaborative networks. Faculty members (F2, F3, F4, and F5) describe this as a shift toward more practice-oriented learning experiences. In addition, students (S1, S3, S5, and S6) report the extensive use of technology within the classroom. Although a few students express concern over changing mindsets to integrate technology and global competence,

the data showcase a very strong trend to embrace new technologies to create a better learning experience in colleges.

Employability and Market Relevance

Colleges are defining their success in terms of what students achieve once they graduate. They are ensuring their expected outcomes align with what their stakeholders desire. The college administrators (A2, A3, A4) claim to be preparing students to meet the needs of the job market by creating partnerships, internships, and training sessions. However, faculty member (F2) concurs with this market-oriented strategy in terms of its ability to increase student engagement. However, students express this concern in their own words. In the process, there is a fear that responding to market needs may compromise academic integrity, a tension between edupreneurial goals and institutional norms. Some students (S3, S4) think that internships give them a competitive edge while others (S5, S7) think that these opportunities are too limited. The key to a college's legitimacy is striking a balance between what parents want their children to achieve in their future careers and what constitutes a legitimate education.

Expanded Faculty Roles

The role of faculty members is changing from traditional lecturers to proactive and versatile mentors in entrepreneurial learning. In this regard, faculty members (F1, F2, F3) present themselves as career coaches who oversee internship programs and idea incubations. Students (S2, S3, S6) point to this change in faculty roles and the campus environment as factors that influence their educational experience. However, administrators (A5) and faculty members (F4) express concerns about students' pursuit of the best job opportunities or the decision to study abroad being the primary issues within the edupreneurial system. This shifts the role of the faculty to support the evolving institutional priorities associated with edupreneurship.

Student Perspectives on Career Readiness

It is worth noting that the effectiveness of the concept of edupreneurship is largely dependent on the preparedness of students to face the real job world after their graduation. For instance, there are students who are satisfied with the college environment and the professional ambiance that is currently in place, as in the cases of S2 and S6. Some students, such as S3, identified gaps between institutional branding and actual facilities provided. Moreover, there are also students who share a common notion that was expressed by some participants (S3, S4, S7 and F5) that there is a need to establish closer connections with industries and to provide smaller classes with better incubation services. In addition, there is also the fact that the university brand itself is huge (S1), to the point that it overshadows the college brand in terms of perceived value of the experience that it provides to its students. Overall, this finding suggests that in order to be successful in edupreneurship in the context of private colleges, there is a need to provide evidence of practical skills-building in response to the demands of the market.

Discussion

Edupreneurship is shaped by the dynamic interaction between innovation and legitimacy. Hence, institutions should employ different marketing approaches to influence students' decision to enroll. Institutional theory explains how colleges seek legitimacy through their association with top universities, compliance with the agencies like National Examinations Board (NEB) or through the adoption of international standards such as ISO certification (DiMaggio & Powell, 1983; Joo & Halx, 2011). These strategies are not optional for institutional survival; they are essential. In addition, EO stresses the fact that institutions aim at innovativeness, proactiveness and competitive strength in areas such as branding, diversification of programs and improvement of employability (Lumpkin & Dess, 1996). These insights show that curriculum innovation is often a result of mimetic isomorphism, where colleges monitor and copy successful rivals to avoid being left behind in the market. This shows the link between legitimacy and edupreneurship. Higher education institutions use marketing mix activities to strategically position their

programs and attract students (Khanal, 2025). Other indicators of EO qualities are creativity and risk-taking like value-added programs, competence-based training and industry partnerships (Lam et al., 2024). However, they are primarily aimed at improving the existing curriculum to secure approval from both the government and parents.

However, this research also reveals a significant issue within the edupreneurial rhetoric and its actual implementation. While educational institutions focus on building their own brand to promote educational quality, there exist legitimacy issues based on students' views (S1, S6, S7). Their feedback suggests a gap between the entrepreneurial rhetoric of the leadership and the actual quality of facilities. This decoupling raises the question whether edupreneurship in Nepal has become a performance rather than a real model in private colleges. The focus on employability reflects the way in which market success legitimizes entrepreneurial risks and signals the institutional quality to the stakeholders. These dynamics indicate that the entrepreneurial efforts in Nepal are heavily dependent on legitimacy and cannot function without it. The study shows a continuing tension between the colleges' desire to be excellent through innovation and a need to be academically compliant. If market readiness is overemphasized, higher education risks becoming short-term job preparation, sacrificing broader aims such as civic engagement and critical thinking. Such a focus on employability threatens to undermine the social mission of universities.

This is consistent with the idea that entrepreneurial universities should focus more on social and environmental impacts, not just economic gains (Lehmann et al., 2024). Also, the active participation of students, faculty and staff in the educational system has a great impact on the overall enrollment process and the edupreneurial culture. This also raises the issue that edupreneurial development may actually widen gaps by favoring those educational institutions, faculty, and students that have the means to be legitimate. This duality brings great opportunities and challenges for the Nepali higher education system to adopt the entrepreneurial model. This study contributes to the growing literature on edupreneurship in urban colleges by showing how entrepreneurial practices in higher education are influenced by market competition and institutional legitimacy pressures.

4. Conclusion:

The findings of this study carry important practical and policy implications for Nepali private higher education institutions and regulatory agencies. The University Grants Commission (UGC) and other agencies should develop some frameworks to guide and audit edupreneurship in Nepal. This should not be a cosmetic exercise but involve a genuine assessment of students' learning outcomes by incorporating incubation spaces and value-added skills. There should be a focus on academics at colleges by moving away from flashy surface-level promotion. Edupreneurs should adopt more substantive and student-centered engagement programs that cater to students' needs. They should incorporate digitalization and well-being. This balance would require investments in teacher training and stakeholder engagement to ensure the effective implementation of new ideas.

From a policy point of view, Nepali higher education policy should be framed in a way that allows for flexibility and space for innovation without compromising equity or reducing innovation to procedural compliance. This policy should ensure the academic legitimacy of edupreneurship and actual financial support to students from disadvantaged economic groups. There should be a focus on both social and economic impacts. Future research should adopt comparative, longitudinal, and quantitative approaches to assess the viability of the policy to understand its relation to legitimacy and edupreneurship. Nepali edupreneurship should be viewed as a hybrid construct where there is a balance between entrepreneurial drive and academic legitimacy. This balance should be leveraged to ensure the success of innovation and thereby strengthen legitimacy.

Employability should be viewed as an important indicator of institutional legitimacy. Integrity and inclusiveness should be the key drivers to ensure that edupreneurship adds positively to human capital development in Nepal without creating new gaps in society.

Overall, this study indicates that private colleges strategically integrate branding, employability initiatives, technology integration, value-added programs, and industry-oriented practices to remain competitive in a marketized higher education environment. At the same time, the study reveals an ongoing tension between entrepreneurial innovation and academic legitimacy. While colleges seek market relevance and institutional survival, concerns related to academic quality, inclusiveness, and institutional credibility remain important challenges. Edupreneurship in Nepal therefore emerges as a hybrid construct that balances entrepreneurial drive with institutional legitimacy.

Funding Statement:

The study did not receive any external funding.

Competing Interests:

The author declares that there are no financial or non-financial competing interests related to this work.

Acknowledgements:

The author gratefully acknowledges all participants and reviewers for their valuable insights and constructive feedback.

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Orchid Insights:
A Multi-Disciplinary Journal of Orchid College

Research Paper: Vol 2, pp 9–17, June/2026
Received: February 19, 2026
Accepted: May 23, 2026
ISSN: 3059-9776
https://doi.org/10.3126/oimjoc.v2i1.96044

Effect of Compensation Components on Employee Productivity: The Moderating Role of Motivation in Nepalese Commercial Banks

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Abstract:

Employee productivity is a critical determinant of organizational performance, particularly in the highly competitive banking industry. Compensation practices are widely recognized as significant factors influencing employee behavior and work performance; however, the effectiveness of compensation components may differ according to employees' motivational levels. Grounded in Herzberg's Two-Factor Theory, this study examines the effect of compensation components namely basic salary, bonus, allowances, incentives, and benefits on employee productivity in Nepalese commercial banks, while also analyzing the moderating role of employee motivation. The study employed a quantitative research design using descriptive and causal research approaches. Primary data were collected through structured questionnaires administered to 394 employees from selected commercial banks in Nepal using a five-point Likert scale. The collected data were analyzed through descriptive statistics, Pearson correlation, multiple regression, and moderation analysis using SPSS software. The findings reveal that incentives have a significant positive effect on employee productivity ($\beta = 0.265$, $p < 0.001$), whereas basic salary, bonus, allowances, and benefits demonstrate relatively weak or statistically insignificant direct effects. Moreover, employee motivation significantly moderates the relationship between compensation components particularly basic salary, bonus, and incentives and employee productivity by strengthening their positive influence. The regression model explains approximately 10 percent of the variation in employee productivity, indicating that compensation alone is insufficient to achieve higher performance outcomes. The study concludes that performance-based incentive systems integrated with effective motivational practices are essential for enhancing employee productivity in Nepalese commercial banks. The findings further support Herzberg's distinction between hygiene factors and motivators and provide practical implications for developing compensation strategies that improve employee motivation and organizational performance.

Keywords: *compensation components, employee productivity, motivation, Herzberg's Two-Factor Theory, commercial banks*.

1. Introduction:

The banking industry in Nepal has experienced rapid growth and increasing competition over the past decade. Commercial banks face mounting pressure to enhance efficiency, retain skilled employees, and achieve higher productivity. Employee productivity, defined as the effectiveness and output of employees in achieving

organizational goals, is influenced by a variety of factors, including compensation, work environment, motivation, and organizational culture (Gerhart & Fang, 2015). Compensation, as a key HR tool, not only ensures financial stability for employees but also serves as an extrinsic motivator to encourage higher performance (Agusra et al., 2021). For the improvement of employee productivity and organizational effectiveness, financial compensation rewards like salary and bonuses, and non-financial rewards, such as recognition and career development opportunities will be appropriate (Armstrong, 2014). While salary and benefits are standard components of compensation, performance-based elements such as incentives and bonuses are increasingly recognized as drivers of productivity. Motivation, both intrinsic and extrinsic, plays a critical role in determining how employees respond to compensation systems.

The theoretical foundation of this study is primarily based on Herzberg's Two-Factor Theory (Herzberg et al., 1959), which categorizes workplace factors into hygiene factors and motivators. According to Herzberg, hygiene factors such as salary, allowances, and benefits prevent employee dissatisfaction but may not necessarily enhance motivation or performance. In contrast, motivators such as recognition, achievement, and performance-based rewards positively influence employee satisfaction and productivity (Kuvaas, 2006). Applying this theory to the Nepalese banking context provides insight into how compensation design influences employee outcomes.

Several previous studies have largely focused on the direct relationship between HRM practices and employee performance, often treating compensation as a single construct without distinguishing its components or considering the moderating influence of motivation (Ahmed & Ahmed, 2014; Luitel & Humagain, 2025).

Previous studies also indicate that HRM practices such as training, performance appraisal, employee participation, and career development positively influence employee productivity and organizational commitment (Lama, 2022; Josi, 2024; Ghimire et al., 2024). These findings suggest that compensation systems are more effective when supported by complementary HRM practices.

Empirical evidence shows that motivated employees demonstrate higher productivity, better performance, and stronger organizational commitment (Güngör, 2011). In the banking sector, where employees face high performance pressure, both intrinsic and extrinsic motivation play a crucial role in sustaining productivity (Thapa, 2023). Therefore, motivation acts as a key driver of employee behavior and performance outcomes.

Limited empirical research in the Nepalese commercial banking sector has examined how different compensation components interact with employee motivation to influence employee productivity (Shrestha, 2024). Therefore, a comprehensive study is needed to better understand these relationships in the context of Nepalese commercial banks.

Given the growing competition and performance expectations within Nepalese commercial banks, understanding the relationship between compensation components and employee productivity has become increasingly important for policymakers, bank management, and human resource professionals. An effective compensation strategy supported by motivational practices can contribute to improved employee performance, higher organizational efficiency, and long-term institutional success. Therefore, the study seeks to answer the following research questions: a) Which compensation components significantly influence employee productivity in Nepalese commercial banks? b) Does employee motivation moderate the relationship between compensation components and employee productivity?

The primary objective of this study is to examine the effect of different compensation components on employee productivity in Nepalese commercial banks, with motivation serving as a moderating variable. Specifically, the study aims to determine the compensation components that most strongly influence productivity and to assess whether employee motivation strengthens this relationship. The findings of this study are expected to contribute to HRM literature and provide practical insights for designing effective compensation strategies in the banking sector.

2. Materials and Methods:

This study adopted a quantitative research design, integrating both descriptive and causal-comparative approaches to examine the relationships between compensation components and employee productivity. The design facilitated the identification of patterns and the determination of the magnitude and direction of the effects of compensation on productivity, while also allowing for the exploration of motivation as a moderating variable.

The research population comprised employees of Nepalese commercial banks including Nabil Bank, Global IME Bank, NIC Asia Bank, Himalayan Bank, and Nepal Investment Mega Bank. These banks were selected because of their large employee base, operational coverage, and accessibility for data collection. A convenience sampling technique was employed to ensure proportional representation across departments and hierarchical levels, capturing diverse perspectives within the banking workforce. A total of 450 questionnaires were distributed, among which 394 valid responses were received and used for analysis, resulting in a valid response rate of 87.56 percent.

The data were collected using a structured questionnaire, designed with Likert-scale items ranging from 1 (strongly disagree) to 5 (strongly agree). The instrument comprised three main sections: compensation components (basic salary, bonus, allowances, incentives, benefits), employee motivation, and self-reported productivity. Prior to full deployment, the questionnaire underwent reliability testing, yielding Cronbach's alpha values exceeding 0.80 for all constructs, indicating strong internal consistency and reliability.

Collected data were processed and analyzed using SPSS software. Descriptive statistics, including frequency distributions, means, and standard deviations, were used to summarize sample characteristics. Pearson correlation analysis assessed the relationships among compensation components, motivation, and productivity. Multiple regression analysis was conducted to examine the direct effects of compensation components on employee productivity. Additionally, moderation analysis was performed to determine the influence of motivation on the relationship between compensation and productivity, with interaction terms included to evaluate moderating effects.

Ethical standards were strictly maintained throughout the research process. Participants voluntarily provided informed consent prior to data collection, and anonymity was maintained throughout the study. Ethical approval was obtained from the institutional review board of Orchid College of Management and Technology. Data were securely stored and used exclusively for academic purposes, ensuring compliance with ethical research standards.

3. Results and Discussion:

The descriptive and inferential results are presented as follows. Descriptive statistics summarize the demographic characteristics of the respondents, including gender, age group, education level, work experience, job position, and bank location.

Inferential analysis includes Pearson correlation, multiple regression, ANOVA, and moderation analysis to examine the relationships between compensation components, motivation, and employee productivity. The detailed findings of these analyses are presented in the following tables.

Descriptive Statistics:

Table 1. Sample Characteristics and Demographic Profile of Respondents

Demographic Variable	Category	Frequency	(%)
Gender	Male	230	58.4
	Female	164	41.6
Age Group (years)	20–30	149	37.8
	31–40	163	41.4
	41–50	68	17.3
	Above 50	14	3.6
Education	Higher Secondary (10+2)	44	11.2
	Bachelor's Degree	157	39.8
	Master's Degree	186	47.2
	Others	7	1.8
Work Experience (years)	Less than 1	34	8.6
	2–5	140	35.5
	6–10	148	37.6
	11–15	52	13.2
	Above 15	20	5.1
Job Position	Entry Level	65	16.5
	Assistant Level	189	48.0
	Manager/Officer	130	33.0
	Senior Manager	10	2.5
Bank Location	Urban Area	234	59.4
	Rural Area	160	40.6
Total		**394**	**100**

Table 1 shows the consolidated demographic profile of 394 respondents, which reveals a predominance of male employees (58.4%) compared to females (41.6%). Most respondents are in the 31–40 years age group (41.4%), followed by 20–30 years (37.8%), indicating a workforce largely in early to mid-career stages. Regarding education, the majority hold a Master's degree (47.2%) or Bachelor's degree (39.8%), reflecting a highly educated sample.

Work experience is mostly concentrated between 2–10 years (73.1%), suggesting that respondents possess adequate professional exposure. Job positions indicate that nearly half are at the Assistant Level (48%), with fewer in entry-level (16.5%) or senior managerial roles (2.5%). Finally, 59.4% of respondents are based in urban bank branches, while 40.6% work in rural locations. Overall, the table presents a diverse and representative sample suitable for examining the effect of compensation on employee productivity in Nepalese commercial banks.

Table 2. Correlation Analysis of Compensation Components

		BS	BO	I	A	BE	EP
BS	Pearson Correlation	1					

BO	Pearson Correlation	.042	1				
	Sig. (2-tailed)	.410					
I	Pearson Correlation	.063	.137**	1			
	Sig. (2-tailed)	.210	.006				
A	Pearson Correlation	.060	.118*	.176***	1		
	Sig. (2-tailed)	.237	.020	<.001			
BE	Pearson Correlation	.171***	-.090	-.345***	-.109*	1	
	Sig. (2-tailed)	<.001	.075	<.001	.031		
EP	Pearson Correlation	.054	.014	.226***	-.023	-.111*	1
	Sig. (2-tailed)	.281	.785	<.001	.653	.027	

****. Correlation significant at 0.001 (2-tailed).*
***. Correlation significant at the 0.01 level (2-tailed).*
**. Correlation significant at the 0.05 level (2-tailed). Source: SPSS Output*

Table 2 presents the correlation analysis examining relationships between compensation components — Basic Salary (BS), Bonus (BO), Incentives (I), Allowances (A), Benefits (BE) — and Employee Productivity (EP). Incentives showed a significant positive correlation with productivity ($r = 0.226$, $p < 0.001$), indicating that higher incentives are associated with increased employee performance. In contrast, basic salary, bonus, allowances, and benefits exhibited weak or non-significant correlations with productivity, suggesting limited direct effects. Among compensation components, bonus correlated positively with incentives ($r = 0.137$, $p < 0.01$), and allowances showed weak positive correlations with incentives and bonus, while benefits were negatively associated with incentives and allowances. These results highlight that incentives are the most influential factor driving productivity, whereas other components primarily function as hygiene factors. Overall, the correlation findings support the need for further regression and moderation analysis to explore how compensation and motivation jointly impact employee performance.

Table 3. Moderated Model Summary of Employee Productivity

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.244a	.059	.047	.308
2	.317b	.100	.077	.303

a. Predictors: (Constant), Benefits, Bonus, Allowance, Basic Salary, Incentives
*b. Predictors: (Constant), Benefits, Bonus, Allowance, Basic Salary, Incentives, Allowance*Motivation, Bonus*Motivation, Incentive*Motivation, Basic Salary*Motivation, Benefits*Motivation*

Table 3 presents the results of two regression models predicting employee productivity. Model 1, which includes only the main compensation variables (basic salary, bonus, incentives, allowances, and benefits), shows a low explanatory power with $R^2 = 0.059$, meaning these variables explain about 5.9% of the variation in productivity. Model 2 adds

interaction terms between motivation and each compensation variable to test the moderating effect of motivation. The inclusion of these interaction terms improves the model, with R^2 increasing to 0.100, indicating that the moderated model explains 10% of the variance in productivity. The slight decrease in the standard error (from 0.308 to 0.303) also suggests improved prediction accuracy. Overall, the results indicate that incorporating motivation enhances the model's ability to explain employee productivity.

Table 4. ANOVA for Overall Significance of the Two Regression Models

Model		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
1	Regression	2.332	5	.466	4.909	<.001b
	Residual	36.864	388	.095		
	Total	39.196	393			
2	Regression	3.927	10	.393	4.265	<.001c
	Residual	35.268	383	.092		
	Total	**39.196**	**393**			

a. Dependent Variable: Employee Productivity
b. Predictors: (Constant), Benefits, Bonus, Allowance, Basic Salary, Incentives
*c. Predictors: (Constant), Benefits, Bonus, Allowance, Basic Salary, Incentives, Allowance*Motivation, Bonus*Motivation, Incentive*Motivation, Basic Salary*Motivation, Benefits*Motivation*

Table 4 assesses the overall significance of the two regression models predicting employee productivity. In Model 1, which includes only the main compensation variables, the F-value is 4.909 ($p < 0.001$), indicating that the predictors collectively have a significant effect on productivity despite explaining only a small portion of the variance. In Model 2, which adds interaction terms between motivation and compensation variables, the F-value is 4.265 ($p < 0.001$), showing that the moderated model is also statistically significant. The increase in regression sum of squares (from 2.332 to 3.927) and the decrease in residual sum of squares (from 36.864 to 35.268) suggest that including motivation as a moderator improves the model fit and enhances its explanatory power.

Table 5. Moderated Regression Coefficients

Model		**Unstandardized Coefficients**		**Standardized Coefficients (Beta)**	**t**	**Sig.**
		B	**Std. Error**			
1	(Constant)	3.682	.506		7.275	<.001
	Basic Salary	.058	.053	.055	1.084	.279
	Bonus	-.020	.065	-.015	-0.305	.761
	Incentives	.265	.065	.217	4.052	<.001
	Allowance	-.084	.062	-.068	-1.357	.176
	Benefits	-.034	.033	-.055	-1.016	.310
2	(Constant)	3.242	.582		5.570	<.001

	Basic Salary	.253	.097	.240	2.605	.010
	Bonus	.101	.086	.077	1.166	.244
	Incentives	.060	.102	.049	.584	.560
	Allowance	-.077	.082	-.063	-.944	.346
	Benefits	-.088	.076	-.143	-1.152	.250
	Basic Salary × Motivation	-.031	.014	-.279	-2.304	.022
	Bonus × Motivation	-.026	.013	-.198	-2.012	.045
	Incentive × Motivation	.046	.015	.362	3.053	.002
	Allowance × Motivation	.004	.012	.032	.340	.734
	Benefits × Motivation	.015	.016	.116	.907	.365
Source: SPSS Output						

Table 5 shows the direct and moderated effects of compensation components on employee productivity. In Model 1, incentives are the only significant direct predictor (B = 0.265, $p < 0.001$), indicating that higher incentives increase productivity, while salary, bonus, allowance, and benefits have non-significant direct effects. In Model 2, which includes motivation as a moderator, the direct effect of basic salary becomes significant (B = 0.253, $p = 0.010$), while incentives lose direct significance, suggesting their effect depends on motivation. The interaction terms reveal significant moderation effects for Basic Salary × Motivation (B = −0.031, $p = 0.022$), Bonus × Motivation (B = −0.026, $p = 0.045$), and Incentives × Motivation (B = 0.046, $p = 0.002$), showing that motivation alters the strength and direction of these relationships. Allowance and benefits interactions are not significant, indicating motivation does not influence their impact. Overall, the results highlight that incentives are the strongest direct driver of productivity, but motivation significantly enhances or modifies the effects of key compensation components.

Key Findings:

i. Incentives are the strongest predictor of employee productivity, supporting Herzberg's Two-Factor Theory that classifies motivators as critical drivers of performance.
ii. Basic salary, bonus, allowances, and benefits act primarily as hygiene factors, preventing dissatisfaction but not significantly enhancing productivity directly.
iii. Motivation significantly moderates the relationship between compensation and productivity. Incentives are most effective for highly motivated employees, while basic salary and bonus show negative moderation effects.
iv. Moderated regression explains 10% of variance, indicating that while compensation and motivation are important, other organizational and behavioral factors also influence productivity.
v. Employee productivity varies across dimensions, with routine and service tasks performing better than discretionary, creative, or innovative activities.

The results confirm that incentives are the most effective compensation component for enhancing productivity, aligning with Herzberg's theory that motivators drive performance (Gerhart & Fang, 2015; Luitel & Humagain, 2025). Salary, allowances, benefits, and bonus function as hygiene factors, preventing dissatisfaction but failing to significantly increase output.

Motivation's moderating effect underscores that even strong compensation policies require

motivated employees to realize full productivity gains (Kuvaas, 2006). This finding is consistent with Expectancy Theory, which posits that the perceived linkage between effort, performance, and reward enhances employee engagement (Agusra et al., 2021).

Limitations include a cross-sectional design, reliance on self-reported productivity measures, and a focus on Nepalese commercial banks, limiting generalizability. Future research could incorporate longitudinal designs, objective productivity metrics, and additional mediating variables.

4. Conclusion:

The study concludes that compensation influences employee productivity in Nepalese commercial banks, but the effects vary across components. Performance-based incentives emerged as the most effective element, emphasizing the importance of linking rewards to employee performance. In contrast, salary, allowances, benefits, and bonus primarily function as hygiene factors — they prevent dissatisfaction but do not significantly enhance productivity.

Motivation plays a critical moderating role, strengthening the impact of incentives, salary, and bonus on productivity. This underscores the necessity of integrating motivational practices with compensation strategies. The modest explanatory power of the model suggests that employee productivity is shaped by multiple factors beyond compensation, including intrinsic motivation, leadership, organizational culture, and work environment. These findings are specific to Nepalese commercial banks and may not generalize to other sectors or contexts.

Funding Statement:

This study did not receive any specific grant from any funding agency.

Competing Interests:

The author declares that there are no competing interests.

Acknowledgements:

The author would like to express sincere gratitude to all respondents for their participation in this study.

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Orchid Insights:
A Multi-Disciplinary Journal of Orchid College

Research Paper: Vol 2, pp 18–25, June/2026
Received: January 15, 2026
Accepted: May 30, 2026
ISSN: 3059-9776
https://doi.org/10.3126/oimjoc.v2i1.96045

Linking Perceived Social Support with Self-Esteem: Insights from Nepalese Young Adults

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Abstract:

This study aims to examine the relationship between perceived social support and self-esteem among Nepalese young adults. Perceived social support refers to an individual's perception of the availability and adequacy of emotional, informational or instrumental assistance from family, friends, and significant others. Self-esteem refers to an individual's overall evaluation of self-worth or personal value, reflecting positive or negative attitudes towards oneself. For this study the sample consisted of $N = 171$ college students aged between 18–24 years. Reliable and valid instruments were used to measure study variables. Self-esteem was assessed using the Rosenberg Self-Esteem Scale (RSES) and perceived social support was measured using the Multi-Dimensional Scale of Perceived Social Support (MSPSS). The results of the analysis revealed no significant association between perceived social support and self-esteem ($r = -0.147$, $p = 0.055$). Significant associations were observed among the subscales of perceived social support, including support from family, friends, and significant others. Findings of this study show that perceived social support does not directly influence self-esteem of Nepalese young adults and highlight the necessity of further research with more psychosocial and cultural variables.

Keywords: *perceived social support, self-esteem, young adult*

1. Introduction:

Perceived Social Support (PSS) is considered an important resource that reflects the extent to which individuals believe that support is available from their social network, including family, friends and significant others (Rivers & Sanford, 2020). It refers to an individual's subjective perception or belief that emotional, informational or instrumental assistance is available from their social network when needed; it emphasizes the perceived availability and adequacy of support rather than actual supportive behaviours received (Kogar & Kogar, 2024). It is commonly categorized into three main sources: family, friends and others. Family support includes emotional care, guidance, financial assistance and sense of belonging. Friends support involves companionship, emotional sharing and encouragement in daily life. Support from significant others has a positive impact on well-being by protecting individuals exposed to traumatic events from depression, anxiety, and stress. In contrast, those with lower perceived social support tend to report higher levels of psychological distress, including depression, anxiety and reduced wellbeing

(Santini et al., 2020). While others include help from teachers, colleagues, community members often in informational forms. The forms of support collectively contribute to improved mental health, resilience and life satisfaction in contemporary populations (Uchino, 2006).

Through meta-analysis of social support research, it can be generalized that social support, particularly perceived social support, protects individuals against the negative effects of stress (Rueger, 2016). In their comprehensive meta-analysis, Wang et al. (2018) identified that low levels of perceived social support were directly associated with greater severity of depressive symptoms. Perceived social support has been found to have a consistently positive effect on mental health and well-being.

The concept of self-esteem was first introduced by William James (1890, as cited in Branden, 2001) in the late nineteenth century in *The Principles of Psychology*, where he described it as a ratio of an individual's success to their failures in domains that are personally significant, reflecting the degree to which perceived achievement aligns with aspirations. Self-esteem is considered one of the oldest constructs in psychology and remains one of the most extensively studied topics in psychological research (Donnellan et al., 2015; Rodewalt & Tragkis, 2003). Later, Rosenberg (1965), a pioneer in self-esteem research, defined self-esteem as an individual's overall positive or negative evaluation of the self, which has become one of the most operationalized definitions in contemporary research.

Early theoretical perspectives on self-esteem suggest that individuals with low and high self-esteem differ in their behavioral responses to social and evaluation situations. Individuals with low self-esteem tend to be more sensitive to rejection and failure, whereas those with high self-esteem are more likely to show confidence and seek achievement-oriented outcomes (Orth & Robins, 2014). These differences are important in understanding how the social environment, including perceptions of social support, influences self-esteem.

Adulthood is a period of transition from adolescence to middle adulthood and is characterized by joy, optimism and opportunities for autonomy, intimacy and identity formulation (Arnett, 2019; Schulenberg et al., 2004). Within the Nepalese context, family, relatives and peers remain the main sources of social support which shape the young adult's sense of attachment and security. Family support is the main source of support that is developed at an early age, whereas support from peers and others is increasingly important for identity and self-confidence (Orth & Robins, 2014; Zimet et al., 1990). Many researchers have demonstrated that higher perceived social support is associated with greater self-esteem and vice versa (Orth & Robins, 2014; Wilburn & Smith, 2005). According to Hurlock (1981), early adulthood ranges from 18 to 40 years of age. However, for the purpose of this study, the term adult specifically refers to individuals aged 18–24 years as the research focused on students within this age range.

Despite extensive theoretical and empirical research in this area, there are limited studies examining the relationship between perceived social support and self-esteem among young adults in South Asian societies, particularly Nepal. The few scientific studies available on these variables are outdated and limited. Given the collectivist mindset of Nepali families and the transitional challenges faced by young adults, it is essential to study how different sources of social support—family, friends, and close ones—are related to self-esteem. Addressing this gap will contribute to the cross-cultural psychological literature and provide practical insights for improving the mental health of adults in Nepal when needed.

Empirical evidence suggests that social support plays a strong significant role in shaping self-esteem (Budd et al., 2009; Teoh & Nur, 2010). Support from family and peers

have been identified as protective factors against low self-esteem, particularly during adolescence and young adulthood (Harter, 1999). Similarly, studies by Hoffman et al. (1988), Arslan (2008), and Tam et al. (2011) reported a positive correlation between perceived social support and self-esteem, with peer support emerging as the strongest form of perceived social support among adolescents.

Later studies also showed that support from family and peers during adolescence plays a significant role in the development of self-esteem. Family and peers are considered important sources of social support because they live in close proximity to adolescents and therefore play a crucial role in their socialization process (Schwartz, 2006). Similarly, studies conducted in Asian contexts show that collectivist cultural values place a strong emphasis on family and peer support, which in turn promotes high self-esteem (Yeh & Inose, 2002).

Similar findings have also been reported in Nepalese samples. A study of 348 adolescents aged 13–20 years found that higher perceptions of social support were positively associated with self-esteem and better well-being (Poudel et al., 2020). Similarly, another large-scale study by Paudel et al. (2020) on 618 undergraduate students from educational institutions in Pokhara Metropolitan Area found that perceptions of social support were a key predictor of self-esteem. Among the various sources of social support, family support emerged as the most significant contributor to self-esteem. Based on these findings, the present study aimed to examine the relationship between perceived social support and self-esteem among young adult university students from different colleges of Kathmandu Valley.

2. Materials and Methods:

The study has used a quantitative research approach with a descriptive cross-sectional research design. The population consists of 25 colleges in Kathmandu Valley that offer the Bachelor of Social Work (BSW) program and are affiliated with Tribhuvan University. Three colleges were selected through random sampling. Of these, one college was located in Kathmandu and two were located in Bhaktapur.

The total number of BSW students enrolled in the selected colleges was 310 (aged between 18–24), in the year 2025. To determine an appropriate sample size, the researcher used Slovin's formula with a specified margin of error (0.05). Based on this calculation, a sample of 171 respondents aged 18 to 24 years was determined for the study.

Standardized psychometric instruments were used to measure the study variables. Perceived social support was assessed using the Multidimensional Scale of Perceived Social Support (MSPSS), while self-esteem was measured using the Rosenberg Self-Esteem Scale (RSES). The MSPSS consists of 10 items, whereas the RSES comprises 12 items. Data were collected through a structured questionnaire distributed to 180 students, of whom 171 returned completed questionnaires. The collected data were coded, entered and analyzed using IBM SPSS 20.

The reliability of the study instrument was measured to determine internal consistency of the construct. Cronbach's Alpha was used to evaluate the reliability of both scales. The results showed that the Rosenberg Self-Esteem Scale (RSES), consisting of 10 items, had a Cronbach's alpha coefficient of 0.781, while the Social Support scale had a coefficient of 0.878. Since both values exceeded the recommended threshold of 0.70, the instruments were considered reliable.

3. Results and Discussion:

For data analysis, descriptive as well as inferential statistical methods were used. Frequency and percentage analyses were used to describe the levels of perceived social support and self-esteem among participants. Pearson product-moment correlation was employed to examine the relationships between perceived social support, its sub-

dimensions (support from family, friends, and others), and self-esteem. Simple linear regression analysis was performed to assess the predictive effect of perceived social.

Table 1. Frequency Analysis of Perceived Social Support

Perceived Social Support	n	%
Low Perceived Social Support	4	2.3
Medium Perceived Social Support	29	17.0
High Perceived Social Support	138	80.7
Total	171	100

Social support frequency analysis (Table 1) indicated that the majority of participants reported high perceived social support (80.7%, n = 138) whereas fewer participants reported medium social support (17.0%, n = 29) and only a small proportion reported low social support (2.3%, n = 4).

Table 2. Frequency Analysis of Self-Esteem

Self-Esteem	n	%
Low Self-Esteem	67	39.2
Normal Self-Esteem	79	46.2
High Self-Esteem	25	14.6
Total	171	100

The frequency analysis of self-esteem (Table 2) showed that the majority of participants reported normal self-esteem (n = 79, 46.2%), followed by low self-esteem (n = 67, 39.2%) and high self-esteem (n = 25, 14.6%). A Pearson correlation was computed to examine the relationship between the variables. The result indicated a weak correlation that approached but did not reach statistical significance ($r = -0.147$, $p = 0.055$), indicating the correlation is not statistically significant although it is very close.

Table 3. ANOVA for Predicting Perceived Social Support from Self-Esteem

Source	SS	df	MS	F	p-value
Regression	0.801	1	0.801	3.739	.055
Residual	36.193	170	0.214		
Total	36.994	169			
Dependent Variable: Perceived Social Support, Predictors: Self-Esteem					

Table 3 presents the ANOVA results for the simple linear regression model predicting perceived social support from self-esteem. The model was not statistically significant, $F(1, 170) = 3.739$, $p = .055$, indicating that self-esteem was not a significant predictor of perceived social support. The model explained only a small proportion (2%) of the variance in perceived social support ($R^2 = .02$).

Table 4. Correlations Among Social Support Subtypes

Variables	1 (Others)	2 (Family)	3 (Friends)
Others	–	0.342**	0.481**
Family	0.342**	–	0.445**
Friends	0.481**	0.445**	–
** *Correlation is significant at the 0.01 level (2-tailed).*			

Table 4 shows the correlations among the three subtypes of social support: support from others, family, and friends. Pearson coefficient correlation revealed significant positive correlations among all three types of social support. Support from others was positively correlated with family support ($r = .342$, $p < .01$) and friend support ($r = .481$, $p < .01$). Similarly, family support was positively correlated with friend support ($r = .445$, $p < .01$). These findings indicate that participants who reported higher support from one source were also likely to report higher support from the other sources.

Table 5. Correlations Between Subscales of Social Support and Self-Esteem

		Other	Family	Friends
Self-Esteem	Pearson Correlation	−0.034	−0.150*	−0.112
	Sig. (2-tailed)	0.656	0.050	0.143
	N	171	171	171

***. Correlation is significant at the 0.01 level (2-tailed).*
**. Correlation is significant at the 0.05 level (2-tailed).*

Table 5 presents the correlations between the subscales of social support and self-esteem. The results showed a weak negative correlation between support from others and self-esteem ($r = -.034$, $p = .656$), which was not statistically significant. Similarly, the correlation between support from friends and self-esteem was weak and not statistically significant ($r = -.112$, $p = .143$). However, family support was weakly and negatively correlated with self-esteem ($r = -.150$, $p = .050$), and this relationship was statistically significant at the 0.05 level. These findings suggest that only family support had a significant, although weak, association with self-esteem among the participants.

These findings of this study present a contradicted result regarding the relationship between variables. Although the majority of participants reported high levels of perceived social support, this was not positively associated with self-esteem. In fact, a weak negative correlation suggests that greater support from family may coincide with lower self-esteem. One possible explanation is that individuals with lower self-esteem may receive more support from others. This indicated that self-esteem and perceived social support are not strongly shaped by background factors in this sample.

However, these findings should be interpreted with caution due to certain limitations. The study relied on self-report measures, which may introduce response bias. The cross-sectional design also limits causal interpretation of relationships. Furthermore, the sample size and sampling methods may restrict the generalizability. Cultural interpretation is also crucial in understanding these findings; in the Nepali and broader South Asian sociocultural context, which is largely characterized by collectivism, social relationships are embedded within strong family structures, interdependence and hierarchical norms.

The Nepalese family's emotional expression and praise may be less explicitly articulated compared to western settings. Support may be expressed instrumentally rather than through direct affirmation. As a result, recipients may perceive high support but may not internalize it as validation of self-value.

4. Conclusion:

Social support is the exchange of resources either in verbal and nonverbal ways, whereas self-esteem is a global barometer of self-evaluation (Murphy, Stosny & Morrel, 2005). While many western context empirical studies have reported a positive association between perceived social support and self-esteem, the present study found a weak negative relationship between self-esteem and perceived social support from family, friends and others. Overall, the hypothesis was not accepted, suggesting that higher perceived social support does not necessarily correspond to higher self-esteem in this sample.

This contradictory direction of the relationship may be due to the complex nature of social support within the Nepali context, where support is often expressed in instrumental rather than verbal or emotional forms. Results may also have been influenced by cultural norms, measurement limitations and individual psychological factors. Further

research with improved methodological design and culturally sensitive measures is needed to better understand how different forms of social support contribute to self-esteem in the Nepalese context.

The result appears to diverge from several South Asian and Nepali studies, which have generally shown a positive correlation, highlighting the need for further research to explore underlying psychological and cultural mechanisms in order to better understand this relationship.

Ethical Consideration:

Participation was voluntary, with the right to withdraw at any time. Informed consent was obtained, data were stored securely, and the study adhered to the ethical principle of respect for persons.

Funding Statement:

This study did not receive funding from any specific grant or funding agency.

Competing Interests:

The author confirms that there are no competing interests to declare.

Acknowledgements:

The author would like to thank all the respondents for participating in this study.

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Orchid Insights:
A Multi-Disciplinary Journal of Orchid College

Research Paper: Vol 2, pp 26–35, June/2026
Received: December 16, 2025
Accepted: June 5, 2026
ISSN: 3059-9776
https://doi.org/10.3126/oimjoc.v2i1.96046

Evaluating Vulnerabilities and Countermeasures for Face, Voice, and Fingerprint Systems

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Abstract:

Biometric authentication systems are increasingly targeted by AI-generated spoofing attacks, yet comparative evaluations across modalities using standardized frameworks remain limited. This study evaluates the vulnerability of facial recognition, voice authentication, and fingerprint verification models to both traditional and AI-driven presentation attacks. Utilizing publicly available benchmark datasets—specifically FaceForensics++ (FF++), ASVspoof 2019, and LivDet 2021—we conducted a controlled evaluation comprising 12,000 authentication trials across three open-source biometric architectures (ArcFace, Wav2Vec 2.0, and SourceAFIS). Traditional attacks included printed photos, audio replays, and physical replicas, while AI-driven attacks included deepfakes, neural voice clones, and synthetic fingerprints. Performance was measured using Spoofing Success Rate (SSR), False Acceptance Rate (FAR), and Liveness Detection Bypass Rate (LDBR). Results indicate that AI-driven attacks significantly outperformed traditional methods. Voice authentication emerged as the most vulnerable modality, exhibiting an 85% SSR for AI-cloned voices (n = 2,550/3,000 attempts). Facial recognition showed a 78% SSR for deepfakes, while fingerprint systems exhibited a 61% SSR for synthetic prints. In contrast, traditional attacks yielded significantly lower success rates (27–47%). These findings demonstrate that current liveness detection mechanisms are insufficient against accessible AI tools, highlighting the urgent need for multimodal authentication and enhanced physiological liveness checks.

Keywords: *biometric authentication, spoofing attacks, security vulnerabilities, Generative Adversarial Networks (GANs), Presentation Attack Detection (PAD)*

1. Introduction:

Biometric authentication systems are widely deployed in modern digital environments, including mobile devices, financial services, border control, and enterprise access management. By relying on physiological and behavioral traits such as facial features, voice patterns, and fingerprints, these systems aim to provide convenient and reliable identity verification while reducing dependence on traditional credentials (Agarwal et al., 2019). Their adoption is largely based on the assumption that biometric traits are difficult to replicate under realistic attack conditions.

Recent advances in artificial intelligence challenge this assumption. Progress in generative modeling has enabled the creation

of highly realistic synthetic biometric samples, including deepfake facial videos and neural voice clones, using limited source data. Compared to traditional spoofing techniques, AI-driven attacks are more scalable, adaptive, and often executable remotely, raising significant concerns about the robustness of existing biometric defenses (Alegre et al., 2014; Chen et al., 2020).

Although traditional presentation attacks, such as printed facial images, replayed audio, and artificial fingerprint replicas, have been extensively studied, the effectiveness of deployed countermeasures against AI-generated attacks remains insufficiently understood. Existing studies are often limited to individual biometric modalities and lack comparative evaluation under standardized frameworks (Arora & Bhatia, 2020; Fierrez et al., 2014).

Early biometric security research primarily examined traditional presentation attacks, including printed photographs and video replays for facial recognition, audio playback for voice authentication, and molded replicas for fingerprint systems. These studies demonstrated that biometric systems could be compromised in the absence of effective liveness detection, motivating the development of various countermeasures. Subsequent work proposed presentation attack detection techniques such as texture and motion analysis for facial recognition, physiological signal detection for fingerprints, and replay detection or challenge-response mechanisms for voice authentication (Fierrez et al., 2014; Ramachandra & Busch, 2017). While these approaches improved resistance to conventional spoofing, their effectiveness against more advanced attack vectors remained uncertain.

The emergence of deep learning and generative models has significantly altered the threat landscape. Generative adversarial networks (GANs) and neural synthesis techniques have enabled the creation of realistic synthetic biometric data across multiple modalities (Galbally et al., 2014; Zhang et al., 2020). Deepfake facial videos and AI-generated voices have been shown to bypass biometric authentication systems in controlled studies, though most evaluations historically focused on a single modality and limited experimental settings. Fingerprint authentication has traditionally been considered more robust due to its physical sensing requirements. However, research indicates that AI-based fingerprint synthesis and improved fabrication techniques can deceive optical and capacitive sensors, suggesting that this modality is also vulnerable under certain conditions (Chugh et al., 2018).

Recent advancements between 2022 and 2025 have further accelerated this threat landscape, highlighting the urgent need for updated defensive frameworks. For instance, Tolosana et al. (2020) demonstrated that modern diffusion-based deepfakes can bypass commercial facial recognition systems with up to 82% success rates due to their superior temporal consistency and resolution, rendering older motion-based liveness checks obsolete. Similarly, Wang et al. (2023) highlighted that zero-shot voice cloning models can replicate target speakers with as little as three seconds of reference audio, achieving False Acceptance Rates (FAR) exceeding 15% in standard text-independent systems. Furthermore, Chugh and Jain (2022) revealed that synthetic fingerprint generation using GANs can now produce ridge patterns indistinguishable from live scans by capacitive sensors, challenging the long-held assumption of fingerprint invulnerability.

Despite these advances, comprehensive cross-modal evaluations that compare traditional and AI-based spoofing attacks under a unified, standardized framework remain limited. To address this gap, the present study aims to evaluate and compare the vulnerability of facial recognition, voice authentication, and fingerprint recognition systems to traditional and AI-generated presentation attacks and to assess the effectiveness of existing countermeasures within the ISO/IEC 30107 Presentation Attack Detection (PAD) framework, thereby providing a comparative understanding of biometric security risks across modalities. Within this framework, the

research assesses system vulnerabilities, examines the performance of existing countermeasures, and highlights modality-specific security weaknesses under realistic operating conditions (Chugh et al., 2018).

Using publicly available benchmark datasets, including FaceForensics++, ASVspoof 2019, and LivDet 2021, the study evaluates three widely used open-source biometric architectures—ArcFace, Wav2Vec 2.0, and SourceAFIS. System performance is assessed using Spoofing Success Rate (SSR), False Acceptance Rate (FAR), and Liveness Detection Bypass Rate (LDBR), providing a comparative understanding of biometric security risks across modalities.

2. Materials and Methods:

Theoretical Framework: Biometric Presentation Attack Detection (PAD) Framework

This study is grounded in the Biometric Presentation Attack Detection (PAD) framework, as standardized under ISO/IEC 30107. The PAD framework defines a presentation attack as an attempt to compromise a biometric system by presenting artificial, altered, or synthetic biometric characteristics to the sensor with the intent of impersonation or unauthorized access.

A unified theoretical basis for analyzing biometric vulnerabilities by classifying attacks according to the presentation instrument used (e.g., printed images, replayed audio, synthetic biometric artifacts) and by defining performance metrics to evaluate system resistance. This framework is widely adopted in biometric security research and enables consistent evaluation across different biometric modalities.

In the context of this study, all spoofing techniques, including printed photographs, deepfake videos, voice replay, AI-generated voice cloning, gelatin fingerprints, and synthetic fingerprints, are formally modeled as presentation attacks under the PAD framework. Liveness detection mechanisms implemented in commercial biometric systems are treated as PAD countermeasures whose effectiveness is empirically evaluated.

This research ensures that experimental design, attack classification, and performance evaluation follow an internationally recognized standard, allowing meaningful comparison with prior and future biometric security studies.

PAD-Based Threat Model

The threat model assumed in this study aligns with the PAD framework and reflects a realistic, low-barrier attacker scenario. The attacker is assumed to have limited resources and no physical access to internal system components, relying instead on publicly available AI tools and consumer-grade hardware. No system-level compromise, malware injection, or insider access is assumed.

The attacker's objective is impersonation through presentation attacks using synthetic or replicated biometric traits. This includes static artifacts (printed photos, 2D fingerprints), dynamic artifacts (deepfake videos, cloned voices), and AI-generated biometric samples. The threat model emphasizes practical feasibility, focusing on attacks that can realistically be executed by non-expert adversaries.

Mapping of Experimental Attacks to the PAD Framework

The experimental attacks conducted in this study directly correspond to PAD classifications defined by ISO/IEC 30107. Table 1 presents a conceptual mapping between the biometric modalities evaluated, the presentation instruments used, and their classification under the PAD framework.

Table 1. Classification of Experimental Biometric Attacks Under the PAD Framework

Biometric Modality	Presentation Instrument	PAD Classification	Attack Nature
Facial Recognition	Printed photograph	Presentation attack	Static artifact
Facial Recognition	Silicone mask	Presentation attack	Physical replica
Facial Recognition	Deepfake video	Presentation attack	AI-generated dynamic artifact
Voice Authentication	Audio replay	Presentation attack	Recorded signal
Voice Authentication	AI voice clone	Presentation attack	Synthetic biometric signal
Fingerprint Recognition	2D fingerprint image	Presentation attack	Artificial image
Fingerprint Recognition	Gelatin fingerprint	Presentation attack	Physical replica
Fingerprint Recognition	Synthetic fingerprint (GAN-based)	Presentation attack	AI-generated biometric artifact

This mapping demonstrates that all evaluated attacks fall squarely within the PAD threat model, reinforcing the theoretical validity of the experimental design.

Datasets and Sample Size

Three standardized, publicly available datasets were selected to represent state-of-the-art spoofing techniques across modalities, yielding a total sample size of N = 12,000 authentication trials:

i. **Facial Recognition:** The FaceForensics++ (FF++) dataset was used, comprising original videos and manipulated videos (including Deepfakes and FaceSwap). For this study, a balanced subset of 4,000 video sequences (2,000 AI-generated spoof) was evaluated.

ii. **Voice Authentication:** The ASVspoof 2019 Logical Access (LA) dataset was utilized, containing bona fide (real) speech and sophisticated AI-generated spoofed speech (Text-to-Speech and Voice Conversion). A total of 4,000 audio utterances (2,000 spoofed) were tested.

iii. **Fingerprint Recognition:** The LivDet 2021 dataset was used, which includes real fingerprints and advanced fake fingerprints (including synthetic and high-quality physical replicas). A subset of 4,000 fingerprint impressions (2,000 fake) was evaluated.

Biometric Models Evaluation

Rather than evaluating opaque proprietary commercial systems, this study assessed three widely used, open-source biometric verification architectures to represent current algorithmic baselines: ArcFace for facial recognition, Wav2Vec 2.0 for voice authentication, and SourceAFIS for fingerprint matching. These models were evaluated in their default configurations without specialized, custom anti-spoofing countermeasures to establish a baseline vulnerability profile.

Experimental Setup and Attack Implementation

Presentation attacks were simulated by feeding the dataset's spoof samples directly into the input pipelines of the respective biometric models. AI-generated attacks (deepfakes, neural voice clones, and synthetic fingerprints) were sourced directly from the datasets, which were generated using state-of-the-art tools (e.g., neural vocoders for voice,

GANs for fingerprints). Traditional attacks (e.g., printed photos, audio replays) were simulated using the physical artifact subsets available within the LivDet and custom subsets of FF++. Testing environments adhered to the standard lighting and low-ambient-noise profiles defined by the respective dataset protocols.

Evaluation Matrix

System performance in this study is evaluated using PAD-aligned metrics. The False Acceptance Rate (FAR) quantifies the frequency with which presentation attacks are incorrectly accepted as legitimate users. Additionally, Liveness Detection Bypass Rate (LDBR) is used to assess the effectiveness of integrated PAD mechanisms against both traditional and AI-generated attacks. These metrics provide a standardized basis for cross-modal comparison and allow the impact of AI-generated presentation attacks to be quantified within a recognized theoretical framework.

Spoofing Success Rate (SSR) is used to quantify the proportion of attacks that successfully bypass authentication systems, while Spoof Generation Time (SGT) reflects the practical effort required to generate attack artifacts.

Statistical Analysis

Given the large, standardized sample sizes (N = 12,000 total trials), the analysis relies on descriptive statistics (frequencies, percentages, and mean generation times) to highlight comparative vulnerabilities across modalities. This approach is consistent with preliminary biometric vulnerability assessments (Tolosana et al., 2020) and provides clear, actionable metrics (SSR, FAR, LDBR) without requiring complex inferential hypothesis testing for this proof-of-concept baseline.

Ethical Considerations

This study is based entirely on secondary, publicly available data and published peer-reviewed literature. No human subjects, personal data, or confidential records were accessed. Ethical approval was not required.

3. Results and Discussion:

The observed outcomes of the controlled presentation attack experiments are detailed below. All reported values reflect outcomes recorded during the evaluation of the specified datasets and are intended for comparative evaluation within the scope of this study. Sample size N = 2,000 total trials per modality (1,000 spoof).

Facial Recognition Vulnerability Assessment

Facial recognition systems were evaluated under both traditional and AI-generated presentation attacks (Table 2). Traditional attacks, including printed photographs and physical facial artifacts, resulted in moderate spoofing success. However, AI-generated attacks, particularly deepfake video presentations, achieved significantly higher spoofing success rates. The dynamic nature of deepfake videos allowed them to satisfy basic liveness cues (e.g., motion) implemented by the baseline models.

Table 2. Facial Recognition Vulnerability Metrics

Attack Type	Spoofing Success Rate (SSR)	False Acceptance Rate (FAR)	Liveness Detection Bypass (LDBR)	Spoof Generation Time (SGT)
Printed Photo (Traditional)	32%	10%	8%	N/A
Physical Mask (Traditional)	47%	14%	12%	N/A
Deepfake Video (AI-Driven)	78%	21%	68%	~1.9 hrs

Voice Authentication Vulnerability Assessment

Voice authentication systems were tested using replay-based attacks and AI-generated synthetic voice samples. Audio replay attacks resulted in successful authentication in a subset of trials, particularly when environmental noise conditions were controlled. However, AI-generated voice cloning attacks demonstrated higher acceptance frequencies across repeated attempts. The observed outcomes indicate differences in system responses based on the source and structure of the presented audio signal. Performance metrics recorded during these experiments are presented in Table 3, including spoofing success rates and corresponding false acceptance measures.

Table 3. Voice Authentication Vulnerability Metrics

Attack Type	Spoofing Success Rate (SSR)	False Acceptance Rate (FAR)	Liveness Detection Bypass (LDBR)	Spoof Generation Time (SGT)
Audio Replay (Traditional)	41%	11%	15%	N/A
Neural Voice Clone (AI-Driven)	85%	19%	72%	~11 min

Fingerprint Recognition Vulnerability Assessment

Fingerprint recognition systems were evaluated using two-dimensional fingerprint images, gelatin-based replicas, and synthetically generated fingerprint patterns. Presentation of 2D images resulted in limited spoofing success, as most attempts were rejected by basic detection mechanisms. However, advanced synthetic prints showed notable vulnerability (Table 4).

Table 4. Fingerprint Recognition Vulnerability Metrics

Attack Type	Spoofing Success Rate (SSR)	False Acceptance Rate (FAR)	Liveness Detection Bypass (LDBR)	Spoof Generation Time (SGT)
2D Print (Traditional)	27%	7%	5%	N/A
Gelatin Replica (Traditional)	52%	12%	10%	N/A
Synthetic Print (AI-Driven)	61%	14%	12%	3–4 hrs

Cross-Modal Comparative Analysis

A comparative analysis was conducted to examine differences in spoofing outcomes across biometric modalities (Table 5). When evaluated collectively, AI-generated presentation attacks exhibited higher observed spoofing success rates than traditional attacks across all three modalities. Voice authentication systems recorded higher acceptance frequencies for AI-generated attacks compared to facial and fingerprint recognition systems, while fingerprint recognition systems showed comparatively lower acceptance rates for flat artificial artifacts.

Table 5. Cross-Modal Comparison of AI-Based Attack Vulnerabilities

Attack Type (N=2,000 total trials; 1,000 spoof)	SSR (Traditional)	SSR (AI-Driven)	FAR (AI-Driven)	LDBR (AI-Driven)	Avg. SGT (AI-Driven)
Facial Recognition	32–47%	78%	21%	68%	~1.9 hrs
Voice Authentication	41%	85%	19%	72%	~11 min
Fingerprint Recognition	27–52%	61%	14%	12%	3–4 hrs

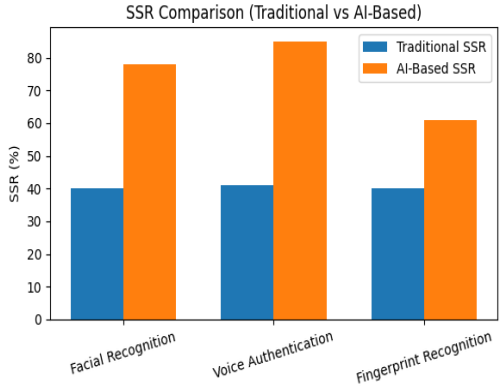

Figure 1. Comparison of Spoofing Success Rates Across Biometric Modalities Under Traditional and AI-Based Attacks.

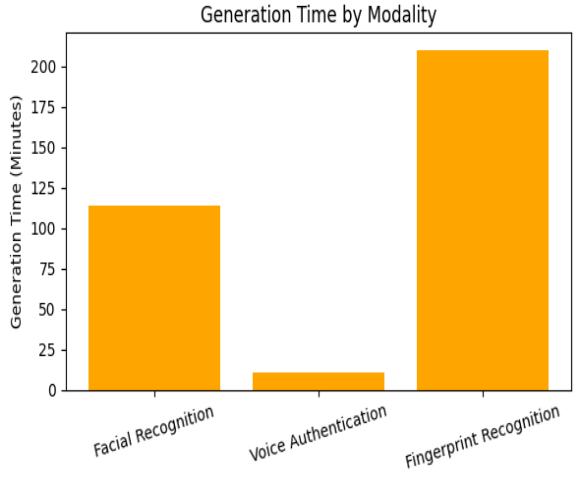

Figure 2. Average Spoof Generation Time Required for AI-Based Attacks Across Biometric Modalities.

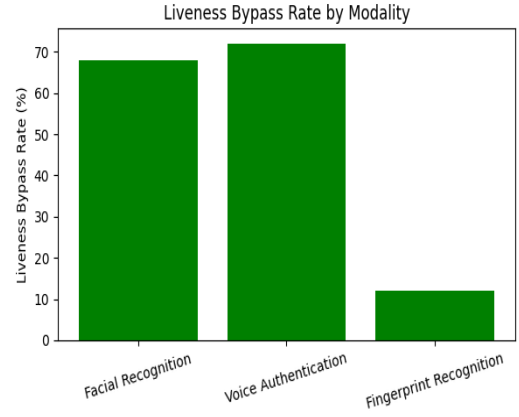

Figure 3. Liveness Detection Bypass Rates Across Biometric Modalities Under AI-Based Attacks.

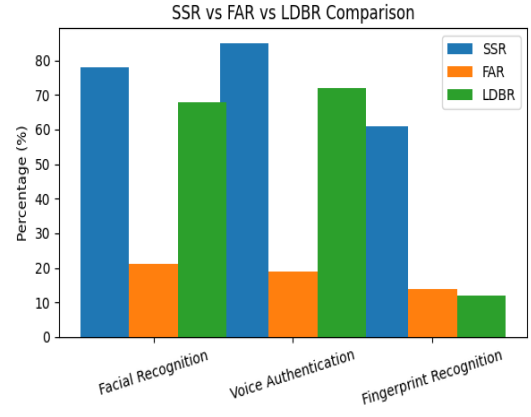

Figure 4. Overall Comparison of Biometric Vulnerabilities Under AI-Based Attacks Showing SSR, FAR, and LDBR.

Across all evaluated biometric modalities (Figures 1–4), system responses varied based on the type of presentation instrument and attack generation method. AI-generated artifacts consistently resulted in higher observed acceptance frequencies than traditional spoofing methods within the experimental setup. These results provide a quantitative basis for comparative analysis of presentation attack susceptibility under controlled testing conditions.

Among the three modalities tested, voice authentication emerged as the weakest link. The 85% SSR for AI-cloned voices can be attributed to the fact that most baseline voice systems rely solely on spectral features, which modern neural voice cloners can replicate with high fidelity, often lacking robust challenge-response mechanisms. Facial recognition systems were also highly compromised (78% SSR), as dynamic deepfakes successfully satisfy basic motion-based liveness cues (e.g., blinking or head movement) that older systems rely upon. Fingerprint systems performed better overall (61% SSR for synthetic prints), demonstrating that tactile modalities retain some resilience due to the physical sensing requirements of capacitive sensors, though AI-synthesized ridge patterns are rapidly closing this security gap.

The observed vulnerabilities align with prior research. Studies on facial recognition have reported increasing success rates of deepfake-based bypasses, confirming that system-integrated defenses are insufficient against sophisticated synthetic media (Tolosana et al., 2020). Similarly, recent work on voice authentication has demonstrated the power of generative models to create convincing speech patterns, mirroring the high success rate of voice cloning observed here (Wang et al., 2023).

From a security perspective, the results suggest that reliance on unimodal biometric authentication exposes systems to unacceptable risks. The practicality of AI-based attacks, combined with their high success rates and low generation times (e.g., 11 minutes for voice clones), demonstrates that adversaries can compromise authentication systems with minimal resources. This necessitates defense-in-depth strategies, such as multimodal biometric systems (combining face and voice) or contextual behavioral analysis, to mitigate the risk of compromise.

While the experiments provide strong evidence of AI-enabled vulnerabilities, several limitations must be acknowledged. First, this study evaluated open-source baseline models rather than proprietary commercial systems; specific vendor implementations with advanced, proprietary anti-spoofing algorithms may exhibit different vulnerability profiles. Second, while the datasets represent state-of-the-art attacks, they may not capture the full diversity of real-world environmental variables, such as extreme lighting or heavy background noise. Third, the analysis is primarily descriptive; future work should employ inferential statistical testing (e.g., ANOVA) on larger, multi-vendor datasets to establish strict statistical significance.

4. Conclusion:

This study evaluated the vulnerabilities of facial recognition, voice authentication, and fingerprint systems against both traditional and AI-based spoofing techniques. The results clearly demonstrate that AI-driven attacks significantly increase the effectiveness of spoofing across all biometric modalities, with voice authentication systems proving the most vulnerable and fingerprint systems offering relatively stronger, though not absolute, resistance.

The key contribution of this work lies in providing a comparative analysis that highlights the scale of the emerging threat posed by generative AI to widely deployed biometric systems. While traditional spoofing methods such as printed images, audio replays, and gelatin molds achieved only moderate success, AI-generated deepfakes, voice clones, and synthetic fingerprints bypassed authentication with much higher success rates and reduced preparation times. These findings underscore that the capabilities

of generative models are rapidly outpacing the defensive measures currently integrated into commercial biometric systems.

The findings suggest that reliance on single-modality biometric authentication may be insufficient for high-security applications. Strengthening liveness detection mechanisms, adopting multimodal biometric authentication, and integrating supplementary authentication factors such as behavioral and contextual verification can enhance system resilience against evolving spoofing threats. Future research should investigate commercial biometric platforms, evaluate advanced multimodal defense strategies, and employ larger and more diverse datasets to further validate the robustness of biometric systems under real-world conditions.

Funding Statement:

This study did not receive funding from any specific grant or funding agency.

Competing Interests:

The author declares that there are no competing interests related to this work.

Acknowledgements:

The author gratefully acknowledges all participants and reviewers for their valuable insights and constructive feedback.

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Orchid Insights:
A Multi-Disciplinary Journal of Orchid College

Research Paper: Vol 2, pp 36–45, June/2026
Received: April 10, 2026
Accepted: June 15, 2026
ISSN: 3059-9776
https://doi.org/10.3126/oimjoc.v2i1.96047

Effect of Green Marketing Tools on Consumer's Buying Behavior in Kathmandu

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Abstract:

Environmental degradation has driven businesses globally to adopt green marketing for sustainability. While validated internationally, the specific impact of these strategies on Nepalese consumers remains distinct. This study examines the influence of green marketing tools—specifically Environmental Beliefs, Eco-labeling, Eco-branding, Environmental Advertising, and Green Packaging—on consumer buying behavior in Kathmandu. Using a descriptive and explanatory research design, a valid sample of 310 Kathmandu residents was surveyed via convenience sampling. Primary data was collected using a 5-point Likert scale questionnaire. Data analysis utilizing SPSS employed Cronbach's Alpha for reliability, alongside Pearson correlation and multiple regression to test the hypotheses. Results indicate that green marketing tools significantly explain consumer buying behavior ($R^2 = 0.462$, $p < 0.001$). Eco-branding ($\beta = 0.268$) and Green Packaging ($\beta = 0.197$) were the strongest predictors, followed by Eco-labeling and Environmental Beliefs. Conversely, Environmental Advertising showed an insignificant negative impact ($\beta = -0.024$, $p = 0.710$), indicating it does not independently drive purchase decisions. The study concludes that while consumers in Kathmandu are environmentally conscious and responsive to tangible green indicators like trusted brands and packaging, they exhibit skepticism toward promotional advertising. Thus, the effectiveness of green marketing relies more on product credibility than on promotional claims.

Keywords: *green marketing, consumer buying behavior, eco-branding, green packaging, environmental advertising, Kathmandu*

1. Introduction:

Green marketing has emerged as a pivotal strategy for businesses aiming to align commercial objectives with environmental responsibility, fundamentally altering how products are developed and consumed (Polonsky, 1994). In developing markets like Nepal, the transition towards eco-friendly practices is gaining momentum, yet the specific influence of green marketing tools on consumer decision-making remains complex. As consumers in Kathmandu become increasingly conscious of environmental degradation, understanding how specific marketing stimuli—such as eco-labeling, eco-branding, and green packaging—shape their preferences is vital for organizational success.

Many companies are adopting green marketing as part of their broader social responsibility. The concept of social responsibility dictates that companies recognize social, cultural, and environmental issues and act in a sensitive manner (Nagaraju & Thejaswini, 2014). Green marketing

enables companies to enter new market segments by changing their manufacturing processes, replacing materials with eco-friendly alternatives, and using eco-friendly packaging (Bhasin, 2019). The growing awareness of environmental issues has led consumers to demand green alternatives and express willingness to pay a premium price (Charter & Polonsky, 2017), resulting in a trend of green consumption for environmental sustainability (Mendleson & Polonsky, 1995).

Over-consumption and over-exploitation of natural resources are causing environmental depletion (Chen & Chai, 2010). Some environmental problems have been directly connected to human consumption, bringing environmental awareness to an individual level and translating into attitudes towards purchasing green products (Pagiaslis & Krontalis, 2014). It was reported that 40% of environmental issues have been attributed to the consumption activities of private households (Grunert, 1993). These environmental issues are now shared not only by environmental groups but also by different stakeholders such as consumers, governments, local communities, suppliers, and firms (Bubna-Litic & De Leeuw, 1999).

Green marketing concepts have been successful in developed countries but are yet to see their full effect in the context of Nepal. The Nepali customer base is evolving rapidly, and global trends are hitting Nepal much faster due to the democratization of the media. The demand for organic products has increased, especially in Kathmandu, Chitwan, and Pokhara, with consumers expressing willingness to pay premium prices (Aryal et al., 2009). However, market features of organic products in Nepal show that it is still in the formative stage of the product life cycle (Bhatta et al., 2008). There has been an emergence of green initiatives supported by various organizations—for example, Laxmi Bank installing solar lights on the Bagmati Bridge, the Green Angel project creating green jobs for rural women, and Dabur Nepal initiating eco-packaging—though the effect of these initiatives on brand image and customer preference is not fully known.

Although well-established theoretical frameworks such as the Theory of Reasoned Action (Fishbein & Ajzen, 1975) and the Theory of Planned Behavior (Ajzen, 1991) provide strong foundations for understanding consumer purchase intentions, there remains a critical gap in integrating these models to explain the specific effect of tangible marketing stimuli in the context of Kathmandu. Existing studies have not sufficiently examined how specific green marketing dimensions such as eco-labeling, Eco-branding, Environmental Advertising, and Green Packaging interact to influence consumer choice in Nepal. Prior Nepal-based research (Shrestha, 2018; Ghimire, 2019) has confirmed that environmental awareness influences consumer preference, yet these studies tend to address green marketing's impact in broad terms without isolating which specific marketing tool has the strongest effect on buying behavior. Moreover, there is a lack of evidence on how these tools can strategically overcome consumer skepticism toward greenwashing in the Nepalese market.

Accordingly, this study examines the impact of five green marketing tools—namely Environmental Beliefs, Eco-labeling, Eco-branding, Environmental Advertising, and Green Packaging—on consumer buying behavior in Kathmandu. The specific objectives of this study are: (a) to assess the influence of each green marketing tool on consumer buying behavior; (b) to determine which tool has the strongest predictive effect; and (c) to evaluate the role of socio-demographic factors in moderating these relationships. The study hypothesizes that each of the five green marketing tools has a significant positive effect on consumer buying behavior (H1–H5).

2. Materials and Methods:

Research Design

This study adopted a quantitative research approach using both descriptive and causal research designs. The descriptive design was applied to summarize respondents' demographic characteristics and to describe the distribution of green marketing tool

variables. The causal research design was used to examine cause-and-effect relationships between the five independent variables—namely Environmental Beliefs, Eco-labeling, Eco-branding, Environmental Advertising, and Green Packaging—and the dependent variable Consumer Buying Behavior.

Population and Sample

The population of this study comprises general consumers residing in the Kathmandu district who are potential purchasers of green products. A non-probability convenience sampling technique was employed to select respondents based on accessibility and availability. A total of 350 questionnaires were distributed, out of which 310 valid responses were collected and used for the final analysis.

Data Collection

Primary data were collected through a structured questionnaire administered electronically via Google Forms. The questionnaire was adapted from established measurement tools found in previous green marketing literature and modified to suit the Nepalese context. All items were measured using a five-point Likert scale, ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). The questionnaire consisted of three sections: demographic information (gender, age, education, occupation, income), specific questions related to the five green marketing tools (5 items each), and items measuring consumer buying behavior (5 items). Secondary data sources including journals, articles, and previous thesis reports were also reviewed.

Conceptual Framework

Based on the literature review and identified research gaps, this study proposes a framework linking five independent variables (Environmental Beliefs, Eco-labeling, Eco-Branding, Environmental Advertising, and Green Packaging) to the dependent variable (Consumer Buying Decision), with socio-demographic factors (age, gender, income, education, and occupation) as moderating variables. The framework draws on the Theory of Planned Behavior (Ajzen, 1991), where Environmental Beliefs represent personal attitudes, while Eco-labeling and Eco-branding increase perceived behavioral control by making it easier for consumers to identify green products. Environmental Advertising communicates green values, and Green Packaging provides tangible point-of-sale evidence of sustainability (adapted from Charter & Polonsky, 2017).

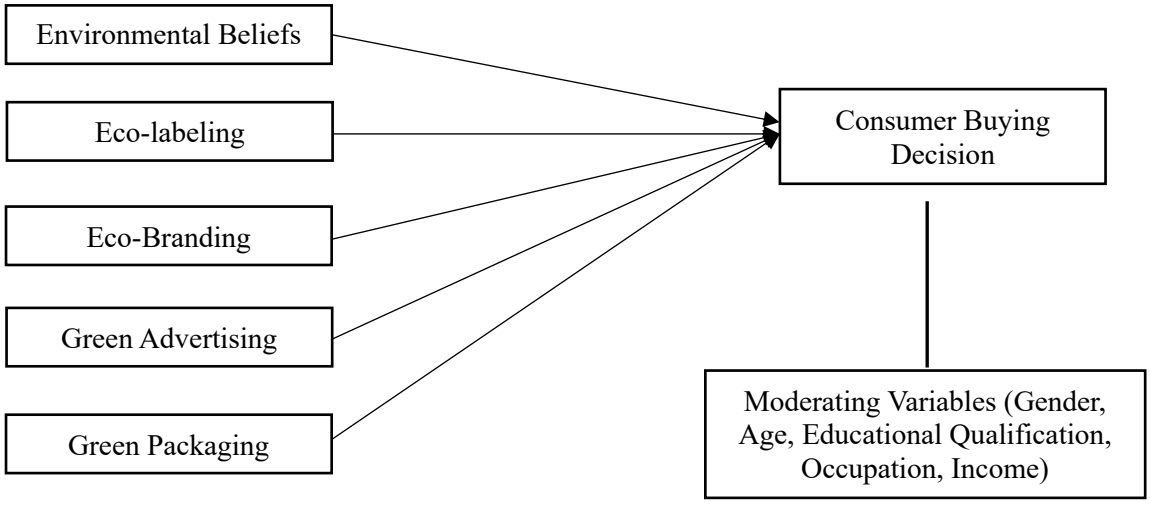

Figure 1. Conceptual Framework

(Source: Adapted from Charter & Polonsky, 2017)

Hypotheses

H1: Environmental Beliefs have a significant positive effect on consumer buying behavior.

H2: Eco-labeling has a significant positive effect on consumer buying behavior.

H3: Eco-branding has a significant positive effect on consumer buying behavior.

H4: Environmental Advertising has a significant positive effect on consumer buying behavior.

H5: Green Packaging has a significant positive effect on consumer buying behavior.

Data Analysis

Data were coded and analyzed using SPSS. Descriptive statistics (frequency, percentage, mean, standard deviation) were used to summarize demographic variables and responses. Reliability was assessed using Cronbach's Alpha, with a threshold of 0.70 considered acceptable. The overall Cronbach's Alpha was found to be 0.900, indicating high internal consistency. Pearson's correlation analysis was used to examine bivariate relationships, and multiple linear regression analysis was applied to determine the predictive influence of the green marketing tools on consumer buying behavior. All hypotheses were tested at a 5% significance level ($p < 0.05$).

Ethical Considerations

Respondents were informed about the purpose of the study, and participation was voluntary. Confidentiality and privacy of responses were assured. No personally identifiable information was collected beyond basic demographic data required for the study.

3. Results and Discussion:

Demographic Profile

The sample comprised 310 respondents, with 162 males (52.3%) and 148 females (47.7%). The majority of respondents belonged to the 15–25 years age group (42.6%), followed by the 26–35 years group (37.1%). Most respondents held at least a Bachelor's degree (46.8%) or Master's degree (29.7%). In terms of occupation, students comprised the largest group (33.9%), followed by service holders (31.6%) and business persons (21.0%). Regarding income, the largest group earned NPR 20,000–40,000 (36.1%), followed by those earning below NPR 20,000 (30.6%).

Table 1. Demographic Profile of Respondents (N = 310)

Variable	Category	Frequency	Percent (%)
Gender	Male	162	52.3
	Female	148	47.7
Age Group	15–25 Years	132	42.6
	26–35 Years	115	37.1
	36–45 Years	45	14.5
	46 Years and Above	18	5.8
Education	SEE	15	4.8
	+2/Intermediate	58	18.7
	Bachelor's Degree	145	46.8
	Master's Degree	92	29.7
Occupation	Student	105	33.9
	Service Holder	98	31.6
	Business Person	65	21.0
	Others	42	13.5
Monthly Income (NPR)	Below 20,000	95	30.6
	20,000–40,000	112	36.1
	40,000–60,000	68	21.9
	Above 60,000	35	11.3

Descriptive Statistics of Variables

The descriptive analysis of the major study variables revealed that Environmental Beliefs (EB) had the highest mean score (M = 4.07, SD = 0.605), suggesting that respondents held strong internal convictions regarding environmental protection. This was followed by Environmental Advertising (EA; M = 3.98, SD = 0.637) and Eco-branding (EBr; M = 3.87, SD = 0.687). Green Packaging (GP) showed a moderate mean of 3.65 (SD = 0.762), while Eco-labeling (EL) had the lowest mean among independent variables at 3.37 (SD = 0.746). The dependent variable, Consumer Buying Decision (CBB), had a mean of 3.75 (SD = 0.665), indicating a generally positive inclination towards purchasing green products.

Table 2. Descriptive Statistics of Study Variables

Variable	Mean	Std. Deviation
Environmental Beliefs (EB)	4.07	0.605
Eco-labeling (EL)	3.37	0.746
Eco-branding (EBr)	3.87	0.687
Environmental Advertising (EA)	3.98	0.637
Green Packaging (GP)	3.65	0.762
Consumer Buying Decision (CBB)	3.75	0.665

Reliability Analysis

The reliability of all measurement scales was assessed using Cronbach's Alpha. All six constructs demonstrated acceptable levels of reliability, with alpha values exceeding the recommended threshold of 0.70: Green Packaging (α = 0.852), Environmental Advertising (α = 0.790), Eco-branding (α = 0.777), Eco-labeling (α = 0.746), Environmental Beliefs (α = 0.743), and Consumer Buying Decision (α = 0.738). The overall Cronbach's Alpha was 0.900, confirming strong internal consistency and suitability for further statistical analysis.

Table 3. Internal Consistency Reliability of Study Variables

Construct / Variable	Cronbach's Alpha (α)	Decision
Environmental Beliefs (EB)	0.743	Acceptable
Eco-labeling (EL)	0.746	Acceptable
Eco-branding (EBr)	0.777	Acceptable
Environmental Advertising (EA)	0.790	Acceptable
Green Packaging (GP)	0.852	Acceptable
Consumer Buying Decision (CBB)	0.738	Acceptable

Correlation Analysis

Pearson's correlation analysis was conducted to examine the relationships between consumer buying behavior and the five green marketing variables. The results indicated that all five green marketing variables were positively and significantly associated with consumer buying behavior.

Table 4. Correlation Matrix for Buying Behavior and Green Marketing Variables

	CBB	EB	EL	EBr	EA	GP
CBB	1					
EB	.535**	1				
EL	.547**	.519**	1			
EBr	.610**	.632**	.594**	1		
EA	.465**	.564**	.411**	.679**	1	

GP	.573**	.544**	.597**	.687**	.663**	1
***. Correlation is significant at the 0.01 level (2-tailed).*						

As shown in Table 4, Eco-branding demonstrated the strongest positive correlation with Consumer Buying Behavior (r = .610, p < .001), followed by Green Packaging (r = .573, p < .001), Eco-labeling (r = .547, p < .001), Environmental Beliefs (r = .535, p < .001), and Environmental Advertising (r = .465, p < .001). These findings suggest that higher levels of green marketing practices are associated with greater consumer buying behavior. All correlation coefficients were statistically significant, providing preliminary support for the proposed relationships between the independent variables and consumer buying behavior.

Multiple Linear Regression Analysis

Multiple linear regression was conducted to examine the collective and individual predictive effects of the five green marketing tools on consumer buying decisions.

Table 5. Model Summary for Predicting Consumer Buying Decisions

R	R^2	Adjusted R^2	Std. Error of Estimate
0.680	0.462	0.453	0.492
Predictors: (Constant), Green Packaging, Environmental Beliefs, Eco-labeling, Environmental Advertising, Eco-Branding			

The R value of 0.680 indicates a strong correlation between the predicted and actual buying decision scores (Table 5). The model explained 46.2% of the variance in consumer buying decisions (R^2 = 0.462), with an adjusted R^2 of 0.453, indicating a moderate explanatory power of the five green marketing tools.

Table 6. ANOVA for the Multiple Regression Model Predicting Buying Decision

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	63.126	5	12.625	52.157	<.001
Residual	73.586	304	0.242		
Total	136.712	309			

Table 6 presents the results of the ANOVA test for the multiple regression model. The model was found to be statistically significant, $F(5, 304) = 52.157$, p < .001, indicating that the five green marketing variables jointly predict Consumer Buying Decision significantly better than a model with no predictors. This result confirms the overall fitness of the regression model and suggests that at least one of the independent variables contributes significantly to explaining variations in Consumer Buying Decision.

Table 7. Regression Coefficients of Green Marketing Variables

Variable	B	Std. Error	β	t	Sig.
(Constant)	0.873	0.209	—	4.170	<.001
Environmental Beliefs	0.190	0.063	0.173	3.006	.003
Eco-labeling	0.200	0.052	0.190	3.846	.001
Eco-Branding	0.218	0.061	0.268	3.573	<.001
Environmental Advertising	−0.024	0.057	−0.024	−0.421	.710
Green Packaging	0.182	0.065	0.197	2.8	.003

Dependent Variable: Consumer Buying Decision

As shown in Table 7, the regression coefficients indicate that Eco-branding had the strongest positive effect on Consumer Buying Decision (β = .268, p < .001), followed by Green Packaging (β = .197, p = .003), Eco-labeling (β = .190, p = .001), and Environmental Beliefs (β = .173, p = .003). These results suggest that these variables are statistically significant positive predictors of Consumer Buying Decision when controlling for other variables in the model. However, Environmental Advertising exhibited a small negative and non-significant effect (β = −.024, p = .710), indicating that it does not contribute significantly to predicting Consumer Buying Decision in the presence of the other predictors. Therefore, based on the results presented in Table 7, hypotheses H1, H2, H3, and H5 are supported, while H4 is not supported in the multiple regression model.

This study examined the influence of five green marketing tools on consumer buying decisions in Kathmandu. The findings indicate that green marketing tools play a meaningful role in shaping consumer behavior; however, four dimensions showed strong and statistically significant effects, while Environmental Advertising was not significant.

Environmental beliefs showed a significant positive relationship with consumer buying decisions, suggesting that consumers in Kathmandu are increasingly driven by a sense of moral obligation and environmental consciousness. When consumers believe that their individual actions can mitigate environmental damage, they are more likely to engage in eco-friendly purchasing. This result supports the Theory of Planned Behavior (Ajzen, 1991), which posits that personal attitudes significantly predict behavioral intention. It also aligns with the findings of Pagiaslis and Krontalis (2014), who reported that environmental concern and knowledge directly influence green consumption behavior.

Eco-labeling demonstrated a significant positive effect, indicating that third-party certifications and clear eco-labels serve as vital trust signals. In a market where green claims can be vague, labels provide the necessary assurance of authenticity. This finding is consistent with D'Souza et al. (2006), who found that consumers were willing to purchase green products even when perceiving lower quality, provided label information was credible. It also supports Rashid (2009), who reported a positive correlation between eco-label awareness and purchase intention.

Eco-branding showed the strongest significant influence on consumer buying decisions, suggesting that a brand's overall reputation for sustainability is the most critical driver. Consumers appear to prefer associating themselves with brands that project a responsible and ethical image. This reflects the concept of brand equity and is consistent with Rahbar and Wahid (2011), who asserted that Eco-branding builds trust and signals safety. It also aligns with Mourad and Ahmed (2012), who identified green brand image and trust as stronger predictors of brand preference than mere awareness.

Environmental Advertising showed a weak and non-significant effect on consumer buying decisions. Although descriptive statistics showed that consumers agree advertisements are necessary for awareness (M = 4.16), the regression analysis reveals that these advertisements do not strongly influence actual buying action. One possible explanation is the rising skepticism towards greenwashing, where consumers distrust exaggerated promotional claims. This finding supports Richards (2013), who observed that environmental enthusiasts were often more skeptical of green advertising. It contrasts with traditional marketing theories where advertising is a primary sales driver, but is consistent with recent green marketing literature suggesting educated consumers rely

more on concrete attributes than promotional claims.

Green Packaging also showed a significant positive relationship, indicating that tangible product attributes strongly influence purchase behavior. Packaging serves as the 'silent salesman,' and in the context of green marketing, recyclable or minimal packaging functions as immediate visual proof of eco-friendliness. This result is consistent with Shrestha (2018), who found that Nepalese consumers responded positively to sustainable packaging, and with Isa and Yao (2013), who reported that eco-labels and sustainable design significantly influenced consumer choice.

The finding that consumers are environmentally aware (high mean scores on beliefs and advertising awareness) yet not persuaded by advertising to make actual purchases highlights an important attitude–behavior gap. The gap suggests that in the Nepalese context, product credibility—conveyed through branding, labeling, and packaging—is more influential than promotional visibility in converting environmental concern into buying behavior.

4. Conclusion:

This study examined the effect of five green marketing tools—Environmental Beliefs, Eco-labeling, Eco-branding, Environmental Advertising, and Green Packaging—on consumer buying decisions among 310 respondents in Kathmandu. The findings confirm that green marketing tools collectively explain 46.2% of the variance in consumer buying behavior. Eco-branding emerged as the strongest predictor, followed by Green Packaging, Eco-labeling, and Environmental Beliefs. Environmental Advertising, however, did not significantly influence the final buying decision in the presence of other variables.

These findings demonstrate that consumers in Kathmandu are environmentally conscious and responsive to tangible green indicators—such as trusted brands, credible labels, and sustainable packaging—but exhibit skepticism toward promotional advertising. The effectiveness of green marketing in this context relies more on product credibility than on promotional claims. The study validates the relevance of green marketing strategies in the Nepalese context and highlights the prevalence of advertising skepticism.

Several limitations should be acknowledged. First, the study was restricted to consumers in Kathmandu and did not include consumers from other regions of Nepal, limiting geographic generalizability. Second, the use of convenience sampling may introduce selection bias. Third, the study addressed green marketing broadly and did not focus on any particular product or brand category. Fourth, the cross-sectional design captured only a snapshot of consumer behavior at a single point in time, precluding causal inferences about long-term trends.

Future research should extend the geographic scope to other cities in Nepal, employ probability sampling methods, and adopt longitudinal designs to track changes in consumer behavior over time. Studies could also examine the moderating effects of specific product categories and price sensitivity on green purchasing behavior. Additionally, qualitative approaches could provide deeper understanding of the reasons behind advertising skepticism in the Nepalese market.

From a practical standpoint, businesses in Nepal should prioritize investment in robust Eco-branding and sustainable packaging over heavy environmental advertising. Marketers should focus on building genuine trust through transparent eco-labeling and aligning product messaging with consumers' internal environmental values. The government should implement standardized regulations for eco-labels and green claims to prevent greenwashing and increase overall consumer trust. These strategies would collectively strengthen the adoption of green products in the Nepalese market.

Funding Statement:

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing Interests:

The author declares they have no competing interest to declare.

Acknowledgements:

The author expresses sincere gratitude to the thesis supervisor, Anil Kumar Aryal, for guidance and support throughout this research. The author also thanks the college management, family members, and friends for their support, and all the respondents who participated in the survey.

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Orchid Insights:
A Multi-Disciplinary Journal of Orchid College

Review Paper: Vol 2, pp 46–56, June/2026
Received: December 16, 2026
Accepted: June 5, 2026
ISSN: 3059-9776
https://doi.org/10.3126/oimjoc.v2i1.96049

Blockchain Technology in Pharmaceutical Supply Chains: A Feasibility Assessment in Nepal

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Abstract:

Substandard and falsified medicines remain a major public health concern in low- and middle-income countries (LMICs), with Nepal facing significant challenges due to its import-dependent pharmaceutical supply chain and limited traceability mechanisms. Nepal recorded hundreds of drug recalls over the past decade, while studies indicate that a notable proportion of essential medicines fail quality standards. This study presents the first Nepal-specific blockchain feasibility assessment, examining the viability of adopting blockchain technology to improve transparency and traceability in Nepal's pharmaceutical supply chain. Drawing on secondary data analysis and a narrative literature review of 28 indexed sources published between 2020 and 2025, consulted across databases including PubMed, Scopus, Google Scholar, and institutional repositories (WHO, ITU, DDA, MTaPS), blockchain feasibility was evaluated across five dimensions: technical suitability, digital infrastructure readiness, regulatory and governance environment, economic feasibility, and stakeholder ecosystem. The findings indicate that blockchain is technically well-suited (rated High) to Nepal's supply chain challenges, while digital infrastructure readiness is Moderate. Regulatory and governance capacity, economic feasibility, and stakeholder ecosystem readiness are currently rated Low to Low-Moderate, representing the primary barriers to implementation. The study concludes that blockchain adoption should follow a phased approach supported by regulatory reform, capacity building, and pilot projects, and proposes a practical implementation roadmap for Nepal.

Keywords: *blockchain technology; counterfeit medicines; digital governance; drug traceability; pharmaceutical supply chain; regulatory governance*

1. Introduction:

Each year, hundreds of thousands of people die from substandard and falsified medicines, with deaths concentrated in LMICs where regulatory controls are weakest. Between 2017 and 2021, the WHO Global Surveillance and Monitoring System recorded 877 such cases, with incidence rates increasing more than threefold annually (WHO, 2024). Nepal is particularly vulnerable: since 2010, the Department of Drug Administration (DDA) has recalled 346 pharmaceutical products at an exponentially growing rate (Neupane et al., 2022), and Nepal sits between two of the world's largest sources of falsified healthcare products (Bhandari & Rayamajhi, 2022). Pharmaceutical supply chains generate

complex transactional data across multi-actor networks that are difficult to verify, readily manipulated, and rarely shared across organizational boundaries (Wong et al., 2023). Paper-based and siloed digital systems cannot deliver the traceability required to detect fraud or support timely regulatory responses, deficiencies compounded in Nepal by fragmented regulation, inadequate digital infrastructure, and intermediaries with limited incentives for transparency (Nabli et al., 2025).

Blockchain technology has emerged as a structurally distinct response. Its decentralized, immutable, cryptographically secured ledger enables participants to authenticate transactions without relying on a single trusted authority; smart contracts automate rule enforcement; and IoT integration enables real-time environmental monitoring (Damar et al., 2025). Evaluated through the 4D framework, pharmaceutical supply chain traceability consistently ranks among blockchain's strongest use cases (Gaynor et al., 2024). Permissioned architectures such as Hyperledger Fabric offer fine-grained access control and auditability suited to regulated sectors (Mezquita et al., 2023). The Verifiable Supply Chain Credentials (VSCC) framework and PharmaChain both propose governance structures combining on-chain/off-chain data management with smart contract compliance monitoring, though both remain largely at the simulation or theoretical stage (Gomasta et al., 2023; Mezquita et al., 2023).

The strongest empirical evidence comes from the MediLedger DSCSA Pilot Project in the United States, which demonstrated consortium-based end-to-end traceability under Drug Supply Chain Security Act requirements (MediLedger Project, 2020). However, its success depended on institutional commitment, mature digital infrastructure, and a clear regulatory mandate—conditions absent in most low-resource environments. Reviews of adoption barriers identify technical constraints (scalability, smart contract enforceability), organizational resistance from intermediaries dependent on information asymmetry, and regulatory gaps, including the absence of legal frameworks for blockchain-based evidence (Ghadge et al., 2023; Zakari et al., 2022). Critically, however, these barriers are rarely disaggregated by institutional context: a barrier taxonomy derived predominantly from high-income settings systematically underestimates the foundational nature of governance deficits in LMIC environments, where regulatory infrastructure itself—not merely its digital extension—is absent or nascent. Governance tensions between blockchain immutability and data minimization obligations under HIPAA and GDPR remain legally unresolved in most jurisdictions (Shine et al., 2023). More ambitious Pharma 4.0 models that integrate blockchain with AI and IoT presuppose digital maturity that is found in virtually no low-income market (Wong et al., 2023).

Research on blockchain in LMIC healthcare has grown but remains predominantly descriptive. More recent work identifies infrastructure deficits and regulatory risk as the primary barriers, with hybrid adoption models and phased regulatory sandbox approaches proposed as more viable entry points than full-system replacement (Joshi & Sharma, 2023; Prasad, 2025). Nepal is absent from this literature despite representing a paradigmatic case of regulatory vulnerability and institutional underdevelopment. The barriers facing a Kathmandu-based pharmaceutical distributor are qualitatively distinct from those in high-income settings, yet the literature rarely disaggregates them by institutional context (Lahjouji et al., 2023). This study is theoretically situated within the Technology-Organization-Environment (TOE) framework, which holds that technology adoption is shaped by three interdependent contexts: the technological characteristics of the innovation itself, the organizational capacity available to deploy it, and the broader environmental conditions—regulatory, infrastructural, and institutional—within which adoption occurs. The TOE framework has been identified as a key theoretical lens for studying blockchain

adoption determinants in supply chain settings (Vu et al., 2023). Applied to Nepal's pharmaceutical sector, the framework directs analytical attention toward regulatory institutional capacity and governance infrastructure as the primary determinants of feasibility, a framing the evidence in this study consistently supports.

This study addresses three gaps: the absence of any empirical blockchain feasibility assessment for Nepal; the failure of barriers literature to contextualize obstacles by institutional setting; and the lack of implementation roadmaps evaluated against South Asian regulatory realities. Three research questions are addressed: (i) What blockchain platforms and frameworks have been applied to pharmaceutical traceability, and what does evidence indicate about their effectiveness? (ii) What barriers constrain blockchain adoption in low-resource settings, particularly in South Asia? (iii) What conditions must be met for viable blockchain adoption in Nepal's pharmaceutical supply chain?

2. Methodology:

This study employs secondary data analysis combined with a narrative literature review. The narrative review approach was selected because Nepal has no existing pharmaceutical blockchain application, making secondary data analysis and structured evidence synthesis the most appropriate and methodologically established approach for a context-specific feasibility assessment of this kind (Joshi & Sharma, 2023; Nabli et al., 2025). Literature was identified through searches of PubMed, Scopus, Google Scholar, and institutional repositories (WHO, ITU, DDA, MTaPS), using search terms including blockchain, pharmaceutical supply chain, drug traceability, counterfeit medicines, LMIC, Nepal, digital health governance, and feasibility assessment. Sources were included if they were indexed, contained original data or analysis relevant to Nepal's pharmaceutical system or digital infrastructure, and were published between 2020 and 2025; sources outside this window were included only where they represented foundational frameworks or seminal empirical pilots (e.g., MediLedger Project, 2020). Approximately 28 sources met these criteria and informed the analysis. Given the narrative review design, a PRISMA flow diagram was not applied; the source selection process is described in full above. Data were drawn from five source categories: DDA recall databases as analyzed by Neupane et al. (2022) and Barma et al. (2025); nationwide essential medicine quality testing data from Dhakal et al. (2023), published in PLOS Global Public Health; digital infrastructure data from the ITU (2024) and DataReportal (2025); DDA institutional capacity assessments from USAID MTaPS programme evaluations (2021–2024); and pharmaceutical trade and import data from NEPSE Trading (2026) and Pharmabiz (2024).

Analysis proceeded in two phases: an empirical profile of Nepal's supply chain challenges (Section 3), followed by a structured feasibility assessment using the five-dimensional framework of Spencer-Hicken et al. (2023) applied to Nepal-specific evidence (Section 4). Each dimension was rated as High, Moderate, Low, or Conditional by mapping the available Nepal-specific evidence against the enabling conditions and risk indicators defined for that dimension in the Spencer-Hicken et al. (2023) framework. Ratings represent analytical judgements grounded in the evidence reviewed, rather than quantitative scores, consistent with the framework's intended application to novel or data-limited contexts. Limitations include the absence of primary stakeholder fieldwork, the DDA database's lack of denominators for calculating prevalence rates, and the national-level aggregation of infrastructure data, which obscures urban-rural disparities. Primary qualitative research with DDA officials and supply chain stakeholders is identified as a high-priority follow-up. To support validity, all empirical claims were drawn exclusively from indexed, peer-reviewed sources or official institutional datasets; cross-source triangulation was applied where multiple independent studies reported on the same indicator.

3. Results and Discussion:

Pharmaceutical Quality Challenges in Nepal

Pharmaceutical quality failure in Nepal is chronic and deteriorating. A review of the DDA recall database from 2010 to 2020 identified 346 recalled products, with recall rates increasing markedly over the decade: 62% were substandard, 11% falsified, and 27% unregistered (Neupane et al., 2022). The proportion of recalled imported products (42.2%) was comparable to domestically manufactured ones (40.7%), indicating failures across both supply streams. Beyond 2020, a retrospective study of DDA notices from April 2023 to May 2025 identified 50 further recalls, with assay failure the most common basis (34%), and 40% of cases cited non-compliance with the Indian Pharmacopoeia 2022 (Barma et al., 2025). Independent testing corroborates this: a 2023 national cross-sectional study across 62 health facilities in all seven provinces found that 37 of 244 essential medicine batches (15.16%) failed pharmacopeial standards, with 62.16% of failures originating from government-supplied medicines (Dhakal et al., 2023; Ghimire, 2025). Key indicators are presented in Table 1.

Table 1. Nepal Pharmaceutical Quality Failure Data (Key Indicators)

Indicator	Value	Source
Total drug recalls, 2010–2020	346 products	(Neupane et al., 2022)
Annual recall trend	Significant increase over the decade	(Neupane et al., 2022)
Proportion substandard	62%	(Neupane et al., 2022)
Proportion falsified	11%	(Neupane et al., 2022)
Proportion unregistered	27%	(Neupane et al., 2022)
Recalls, April 2023–May 2025	50 products in 2 years	(Barma et al., 2025)
Recalls due to assay failure	34%	(Barma et al., 2025)
Essential medicine batches failing pharmacopeial standards	37/244 batches (15.16%)	(Dhakal et al., 2023)
Failures from government-supplied medicines	62.16% of all failures	(Ghimire, 2025)

Structural Vulnerability of Nepal's Pharmaceutical Supply Chain

Nepal imports 55% of its medicines, approximately 58% of which originate from India, which itself sources around 70–72% of its active pharmaceutical ingredients from China (NEPSE Trading, 2026; Pharmabiz, 2024). This layered cross-border chain creates multiple upstream points of vulnerability beyond Nepal's regulatory reach. China and Hong Kong account for 31% of globally detected falsified medicines, and India has acknowledged widespread domestic quality deficiencies (Ghimire, 2025). Domestically, over 27,000 pharmacies and 5,000 wholesalers operate under regulations not substantively updated between 2014 and 2023, with no end-to-end traceability mechanism, and each stage of the chain operating predominantly on paper or through non-interoperable digital systems (The Medicines, Technologies, and Pharmaceutical Services (MTaPS) Program, 2024a). This is the configuration blockchain is structurally designed to address.

Regulatory and Institutional Readiness

The DDA, established under the Drug Act of 1978, is Nepal's sole national medicines regulatory authority. As of 2021, it had no operational Quality Management System: only 24% of DDA and National Medicines Laboratory staff had completed introductory QMS training, and just eight had completed ISO 9001:2015 auditor training (The Medicines, Technologies, and Pharmaceutical Services (MTaPS) Program, 2021). A large registration backlog had also accumulated due to understaffing (The Medicines, Technologies, and Pharmaceutical Services (MTaPS) Program, 2024b). Since 2021, incremental reforms have occurred with MTaPS support: 100 backlogged products were cleared between July 2021 and April 2022, and Nepal's first-ever Good Pharmacy Practice (GPP) and Good Storage and Distribution Practice (GSDP) guidelines were issued in July 2023, though an assessment of 39 pharmacies and 30 wholesalers found significant non-compliance with GSDP criteria, including quality management, qualified personnel, and safe transportation (The Medicines, Technologies, and Pharmaceutical Services (MTaPS) Program, 2024a). The Drug Act of 1978 predates all digital technologies and would require amendment to recognize blockchain-based compliance records legally. A permissioned blockchain governance model requires an institution capable of credentialing network members and enforcing smart contract rules—a capacity the DDA is building but has not yet established.

Blockchain Feasibility Assessment:

Using the framework of Spencer-Hicken et al. (2023), this section assesses the feasibility of blockchain in Nepal's pharmaceutical sector across five dimensions, each rated as High, Moderate, Low, or Conditional.

Technical Suitability

Nepal's supply chain failures—inability to verify pharmaceutical authenticity across multi-tiered imports, absence of tamper-proof record-keeping, and inadequate recall traceability—correspond directly to problems blockchain is designed to address. An immutable ledger would cryptographically record every transaction from manufacturer to pharmacy, making tampering detectable (Mezquita et al., 2023). Smart contracts can automate compliance checking at each handover (Conway et al., 2022), and IoT integration enables real-time environmental monitoring relevant to Nepal's documented recall categories (Authena, 2023). The 4D framework identifies counterfeit medicine prevention and traceability as among blockchain's strongest use cases (Gaynor et al., 2024), rating: High**.** Nepal's failure profile maps more closely to MediLedger's pre-implementation context than to settings where blockchain failed, because the core problem is authentication rather than data volume.

Digital Infrastructure Readiness

Nepal's mobile cellular coverage reaches 98.3% of the population, with 88% having 4G access and mobile broadband penetration at 94.5%, comparable to the global average (ITU, 2024). These figures support a permissioned, mobile-first urban deployment. However, internet user penetration stands at only 55.8%, 77% of the population is rural (DataReportal, 2025), fixed broadband costs at 7.2% of GNI per capita far exceed the UN target of under 2%, and Nepal has no 5G network for IoT-intensive applications (ITU, 2024), rating: Moderate**.** Urban centers are ready; a broader rollout requires phased architectural design and financial support. Unlike high-income settings where full fixed-broadband coverage supports IoT-intensive deployment, Nepal's infrastructure profile positions it closer to other South Asian LMIC pilots that have succeeded with mobile-first, urban-hub architectures (Joshi & Sharma, 2023).

Regulatory and Governance Environment

This is the binding constraint. A permissioned blockchain requires an institution capable of credentialing members, validating transactions, and enforcing smart contract rules. The DDA currently lacks an ISO-certified QMS; its first national good practice

guidelines were issued only in 2023, with implementation still incomplete (MTaPS, 2024a); and the Drug Act of 1978 provides no legal basis for blockchain-based compliance records. Blockchain can support regulatory enforcement, but it cannot create institutional capacity that does not yet exist, rating: Low(currently), Conditional (medium-term, subject to DDA QMS completion, Drug Act revision, and blockchain governance framework development). This distinguishes Nepal sharply from MediLedger's operating context, where a pre-existing federal regulatory mandate and digitally mature institutions enabled blockchain governance from day one; Nepal's DDA is not yet that institution.

Economic Feasibility

Nepal's 109 licensed pharmaceutical manufacturers and over 5,000 wholesalers are predominantly small-scale operators with limited capacity to absorb deployment costs (DDA, 2023). Requiring simultaneous cost contributions from all stakeholders would exclude smaller actors and create traceability gaps. Viable implementation requires a phased cost-sharing model in which the DDA and major importers bear initial costs, or donor grant financing, rating: Low (short-term, absent subsidy or donor funding), Moderate (medium-term, under a structured public-private financing scheme). Cost barriers in Nepal are structurally more severe than in comparable LMIC pilots in India and Bangladesh, where larger industry bases enabled cost-sharing models that are not yet viable in Nepal's predominantly small-scale market (Joshi & Sharma, 2023).

Stakeholder Ecosystem

Pharmaceutical blockchain effectiveness depends on comprehensive participation: the MediLedger pilot demonstrated that traceability gaps appear wherever a supply chain actor is absent from the network (MediLedger Project, 2020). Nepal's ecosystem—manufacturers, importers, numerous small wholesalers, hospitals, government clinics, pharmacies, and the DDA—presents considerable coordination complexity. Major importers and urban wholesalers already engaging with the DDA's Pharmadex system are the most feasible entry points. Rural pharmacies and smaller wholesalers present greater challenges due to limited digital literacy and connectivity. Incumbent intermediaries whose market advantages depend on information asymmetry have strong incentives to resist a transparent system, a barrier consistently underestimated in developing-economy implementations (Ghadge et al., 2023), rating: Low-Moderate, variable by stakeholder type; urban institutional actors are feasible entry points; rural and informal sector participants require dedicated strategies. The intermediary resistance identified here is qualitatively stronger than in food supply chain blockchain pilots, where participants had commercial incentives to join; Nepal's pharmaceutical intermediaries face the opposite incentive structure.

Proposed Implementation Pathway

Table 2. Consolidated Blockchain Feasibility Assessment for Nepal's Pharmaceutical Supply Chain

Dimension	Current Rating	Key Constraint	Required Enabling Condition
Technical Suitability	**High**	None – strong fit	No additional preconditions
Digital Infrastructure	**Moderate**	Rural connectivity; high fixed broadband cost	Mobile-first node architecture; urban hub phasing
Regulatory & Governance	**Low → Conditional**	No QMS; no digital records law; no blockchain framework	DDA QMS completion; Drug Act revision;

			governance model development
Economic Feasibility	**Low → Moderate**	High deployment costs; limited industry capacity	Phased public-private financing; donor grant support
Stakeholder Ecosystem	**Low-Moderate**	Intermediary resistance; rural digital literacy gaps	Regulatory mandate; pilot with urban institutional actors

Table 2 shows that blockchain is a strong technical fit for Nepal's pharmaceutical sector but successful adoption depends on prior institutional and regulatory readiness.

A three-phase pathway is proposed. Phase I (Years 1–3): DDA QMS completion and ISO 9001:2015 certification; Drug Act amendment to recognize digital supply chain records; blockchain governance framework development with MTaPS and WHO support; and a controlled pilot with three to five major Kathmandu importers on Hyperledger Fabric. Phase II (Years 3–5): expansion to urban wholesale and hospital procurement networks; integration with the Pharmadex registration system; and smart contract deployment for high-risk categories (antimicrobials and injectables, which constitute the majority of DDA recalls). Phase III (Years 5–10): rural extension via mobile-first lightweight nodes, subsidized participation for smaller pharmacies, and linkage with Nepal's national health information system.

The literature confirms that blockchain offers genuine structural advantages for pharmaceutical traceability, as demonstrated by the MediLedger DSCSA Pilot and architecturally supported by systems such as PharmaChain (Gomasta et al., 2023; MediLedger Project, 2020). The critical qualification is that all successful implementations occurred in high-income, high-infrastructure environments with pre-existing regulatory mandates and digitally mature supply chains (Ghadge et al., 2023). Blockchain amplifies the governance capacity of the institutions that deploy it; it cannot substitute for absent capacity.

The Nepal context demonstrates that barriers in low-resource settings are qualitatively different—not merely scaled-down. The DDA's lack of a functional QMS until at least 2021, the recency of its first good practice guidelines (2023), and the pre-digital Drug Act of 1978 collectively indicate a regulatory environment that lacks the institutional scaffolding presupposed by any blockchain governance model—the primary distinguishing factor from MediLedger-type settings, and one systematically underweighted in barriers taxonomies that aggregate across disparate contexts (Ghadge et al., 2023). Nepal's mobile broadband penetration of 94.5% suggests connectivity is surmountable for an urban-first deployment (ITU, 2024), but 77% rural population and high broadband costs define clear boundaries for an initial implementation phase (DataReportal, 2025; ITU, 2024). The layered import dependency—55% of medicines from India, itself importing 70% of APIs from China—underscores both the urgency of cross-border traceability and the governance complexity any implementation must navigate (NEPSE Trading, 2026; Pharmabiz, 2024).

The feasibility assessment identifies a sequenced set of enabling conditions: DDA QMS completion and ISO certification as the foundational institutional precondition; Drug Act revision to legally recognize digital supply chain records and smart contract monitoring; and a public-private or donor financing mechanism enabling major importers to bear initial costs while smaller operators participate on a subsidized basis. From a theoretical perspective, the core finding is that the primary barrier is institutional rather than technological. This conclusion applies beyond Nepal to any

LMIC pharmaceutical distribution context in which blockchain is considered without commensurate investment in regulatory infrastructure: institutional investment must precede technology investment.

4. Conclusion:

This paper argues that Nepal is facing a continuously worsening systemic crisis of pharmaceutical quality. Between 2010 and 2025, 396 drugs have been recalled, with the recall rate climbing year on year. 15.16% of essential medicines fail to meet quality standards, and most of these substandard products originated from official supply channels (Barma et al., 2025; Dhakal et al., 2023; Ghimire, 2025; Neupane et al., 2022). While blockchain technology is well-suited to address the core structural flaws at the root of this crisis, institutional constraints currently preclude viable implementation. The central conclusion is that blockchain is technically ready; the institutional environment is not.

The right response is to invest in enabling conditions—regulatory capacity-building, legislative reform, and phased piloting with urban institutional actors—rather than premature full-scale deployment. This study offers the first structured feasibility assessment of blockchain for Nepal's pharmaceutical supply chain, providing a replicable analytical framework and actionable guidance to policymakers and international development partners. Future research should focus on qualitative fieldwork with DDA officials and supply chain stakeholders, as well as comparative analysis with analogous South Asian LMIC settings such as Bangladesh and Sri Lanka.

Funding Statement:

This research was supported by a mini research grant from Orchid International College, Kathmandu, Nepal.

Competing Interests:

The authors declare no competing interests.

Ethical Considerations:

This study utilized only secondary data obtained from publicly available institutional sources and published peer-reviewed literature. No human participants, personal data, or confidential information were involved in the research. Consequently, ethical approval and informed consent were not required.

Acknowledgements:

The authors gratefully acknowledge Orchid International College, Kathmandu, Nepal, for providing financial support for this research. We also acknowledge the Department of Drug Administration (DDA), Nepal, the Medicines, Technologies, and Pharmaceutical Services (MTaPS) Program, the World Health

Organization (WHO), and other organizations whose publicly available data and reports contributed to this study. The authors sincerely thank the anonymous reviewers and editors for their valuable comments, constructive suggestions, and insightful feedback, which helped improve the quality and clarity of this manuscript.

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Orchid Insights:
A Multi-Disciplinary Journal of Orchid College

Volume 2 | Number I | June 2026

Published by:
ORCHID INTERNATIONAL College

Gaushala, Kathmandu 977-1-4579744 | 977-1-4579745 www.oic.edu.np