VOLUME 17

ISSN NO. 2091-1742

SCITECH NEPAL

Journal of Scientific and Technical Studies

Nepal Engineering College

Changunarayan-4, Bhaktapur
Phone: 01-5221006
(DAO Bhaktapur Regd No. 552-2060)

VOLUME 17 | ISSUE 1 NOVEMBER 2023

NOVEMBER 2023

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Editor's Note

Generation and sharing of knowledge gained through research activities is a fundamental basis of the development of science and technology. Publication of research papers in a peer-reviewed professional journal is a basic parameter of the achievements of scientists and technical human resources around the world; publication of original research papers is an undisputed method of sharing knowledge among the peers. Institutes like Nepal Engineering College has been providing a platform sine 1995 to the scientists and engineers by regular publication of SCITECH Nepal Journal, and thereby creating an avenue of sharing research experiences.

This issue of SCITECH Nepal Journal has attracted the more scientists and engineers from different universities and research institutes of Nepal to publish their research papers. The readers will find a large spectrum of interesting and useful disciplines covered in this volume of the Journal. The areas covered range from biology, organic chemistry to the emerging technological issues like the artificial intelligence, including the computer modeling of multistoried structures to find techniques to enhance seismic safety.

The paper contributors are the ultimate backbone and heroes of the success of SCITECH Nepal. The editorial board has done an excellent job to ensure quality of the published research papers. I am sure the readers of this volume of SCITECH Nepal will find the contents highly satisfying and worthy of their time invested in reading the papers.

Wish you all a very Happy New Year 2024.

Hari K Shrestha

Prof. Dr. Hari Krishna Shrestha
Chief Editor

November 2023

ISSN NO. 2091-1742

SCITECH NEPAL Journal of Scientific and Technical Studies

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ISSN NO. 2091-1742

SCITECH NEPAL

Journal of Scientific and Technical Studies

Nepal Engineering College, Pokhara University

Research Article

DOI:10.3126/scitech.v17i1.60457

Effect of Steel Jacketing Thickness on Seismic Performance of Bridge

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Received: March 12, 2023

Accepted: May 7, 2023

Abstract:

The bridges of Nepal are getting older and old bridges were designed without considering the seismic forces, hence have low seismic capacity. The capacity of these bridges needs to be enhanced and should perform well during seismic events. The jacketing technique can be used to upgrade the bridge's structural performance. This research paper mostly focuses on the seismic performance enhancement after the application of steel jacketing on the bridge pier. The variable that has been varied is the thickness of the steel jacket. The capacity of a bridge pier is evaluated using displacement-controlled nonlinear static analysis (Pushover). The time history load is applied to the structure to determine the seismic demand of the bridge. The quantification of the enhancement of the bridge structure after the application of Steel Jacketing is evaluated by plotting the fragility curve. The modeling of the bridge is done in CSI Bridge V20.2.0. The different damage state is defined using the strain values obtained from the pushover analysis. For different damage states, the capacity and demand value are used to obtain the probability of exceeding at different PGA levels. The fragility curve is developed using the First Order Second Order Method (FOSM). From the study, it is found, that the vulnerability of the bridge after the use of jacketing for extensive damage state, the probability of failure reduced from 28.22% to 14.24% at 1.0g PGA. Similarly, the vulnerability of the bridge after the use of jacketing for collapse damage state, the probability of failure decreased from 16.93% to 7.22% at 1.0 PGA.

Key words: Seismic Performance; Fragility curve; Damage state; Pushover analysis; Time history analysis; Steel Jacketing.

Introduction

Nepal lies in a highly diversified zone with higher Himalayan ranges in the North and flat plain Terai in the South. There are a large number of rivers within a 200 km distance. Bridges play a major role in the transportation system of Nepal, which saves traveling time, fuel, and energy. As per the Department of Roads (DoR) of Nepal, there are more than 2020 bridges already constructed (2022). Most of them are reinforced concrete bridges. Bridges are essential in ensuring that road traffic can flow continuously throughout the year.

Bridges built before 1970 in Nepal did not have sufficient seismic resistance as they lacked the inclusion of ductility provisions in their design. As a result, those bridges have low seismic resistance and are vulnerable to significant damage even from moderate earthquakes (Patil and Pawar 2018). For the consideration of structural performance under severe seismic situations, the concepts of capacity design and ductility design are required (Priestley et al 1996). Even functional damage to bridge structures during severe earthquakes is undesirable because of the immense significance of bridge structures in the transportation system. In order to evaluate the seismic performance of structures constructed in compliance with the allowed stress, non-linear analysis approaches such as the capacity spectrum approach or response history analysis should be applied. For developing countries like Nepal, the retrofitting method should be both technologically and economically viable. Hence, this study evaluated Steel Jacketing as a retrofitting technique for an existing structure.

Jacketing is a technique used to strengthen the existing bridges in order to increase the capacity of the bridges, which helps to confirm to the current bridge design standards. Bridges are a very important and crucial element of the transportation facilities. If timely inspection and maintenance are not provided then the transportation chain could be disturbed for a longer time frame. The damages that could occur in the bridge due to seismic force can be prevented by seismic jacketing prior to seismic events. Due to inadequate shear capacity, a lack of transverse steel and confinements, improperly lapped longitudinal steel, and early termination of longitudinal steel, there is a higher risk of failure in the pier, abutments, or foundations. The efficiency of bridges is negatively impacted by these flaws. Among the bridge's structural components, the piers are the most vulnerable elements under the action of seismic loads. To improve the piers bending capacity, different techniques are employed to retrofit the structures, RC jackets, steel jackets, CFRP jackets, external prestressed cables, or even the inclusion of new elements (Navarrete et al. 2016).

Past earthquakes such as the 1971 San Fernando Earthquake, the 1994 Northridge Earthquake, the 1995 Great Hanshin Earthquake in Japan, and the 1999 Chi-Chi earthquake in Taiwan have demonstrated that bridges are vulnerable to earthquakes (Hsu and Fu 2004) (Mitchell, et al. 1995, Maragakis and Jennings 1987). Since bridges are one of the most critical components of highway systems, it is necessary to evaluate the seismic performance of the bridges which helps in making correct decisions.

Objectives

1. To determine the seismic response of the existing bridge pier excited by different ground motion time histories.
2. To develop fragility curves for both existing and steel jacketed bridge pier.
3. To quantify the seismic performance of jacketed (Steel Jacketing) bridge pier excited by different ground motion time histories.

Methodology

Bridge Description

An existing bridge in Nepal was selected for the research purpose. The bridge lies in the Kathmandu district over the Bagmati River. The as-built drawing of the bridge is collected from DoR, Government of Nepal. Figure 1 represents the cross-section of the selected bridge. The selected bridge is the RCC T-girder Bridge which is 75m long with two numbers of spans each 37.5m long. The total width of the bridge superstructure is 11m wide which has a footpath of width 1.750m on each side and a 7.50m carriageway in the middle. The superstructure consists of four longitudinal prestressed rectangular main girders which is 1900 x 750 mm and five cross girder each of size 1600 x 400 mm at an equal end of spans in each of the spans. The thickness of the deck slab is 200mm. All the components of the superstructure are constructed monolithically using M45-grade concrete.

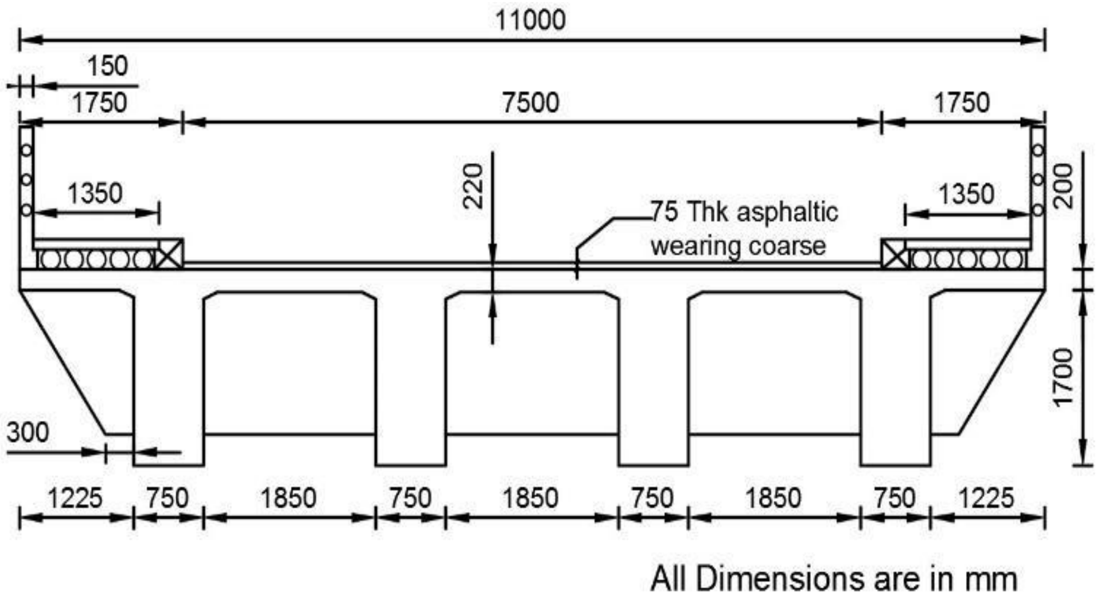

Figure 1: Cross-section of the bridge

The connection between the superstructure and substructure is done using Polyterrafluoroethylene (PTFE) POT bearing. The PTFE POT-fixed bearing is placed at bents which restricts translation in all directions and allows rotation. Similarly, PTFE POT-free bearing is placed at an abutment which restricts translation in the longitudinal direction while it allows translation in the transverse and vertical direction and allows rotation. The size of the bearing is 0.8 x 0.6 x 0.075 m. The substructure comprises of cantilever retaining wall as an abutment and one hammerhead single-column bent pier. The diameter of the pier is 2.7m with a clear height of 6.247m. The dimensions of the pier cap are 10.5m x 4.5m x 2m. The pier column has 36 numbers of 32 mm diameter longitudinal reinforcement and 12 mm diameter bars at 100 mm and 150 mm C/C transverse reinforcement. The material used in the pier and abutment is M25 grade concrete and Fe500 reinforcement.

Most of the old bridges constructed before 1990 AD have a longitudinal reinforcement ratio of 0.005 (Navarrete, et al. 2016). Hence the model with a longitudinal reinforcement ratio of 0.005 in pier has been used and is denoted with the name “existing” in the analysis. Similarly, the steel jacketed models are denoted with “Steel 10 mm” for the jacket thickness of 10 mm of steel Fe 345 and “Steel 20 mm” for the jacket thickness of 20 mm of steel Fe 345.

The footing of the pier rests on a group of sixteen piles and that of the abutment in a group of twelve piles. The diameter of the pile is 1.0m and 22 m deep. The M25 grade concrete and Fe 500 rebar have been used.

Bridge Modelling

A three-dimensional Finite Element Model of the bridge is modelled in CSI bridge V20.2.0. (Computer and Structures Inc: CSI Bridge 2020). The as-built drawings provided by DoR are used to define geometric dimensions and material properties accurately. The (Mander, Priestley, and Park 1998) Model is used to represent the stress strain relationship for confined and unconfined concrete. The effect of confinement increases the compressive strength and ultimate strain of the concrete.

The moment-curvature relation is the plot of unit angle cross-sectional deformation in radians due to bending or both bending and axial load to the structure. The moment curvature relation gives a clear idea about the stiffness, ductility properties, and strength of the cross-section of the column.

Mathematically,

Curvature (□) = $\frac{d\theta}{dy} = \frac{d2y}{dx2} = \frac{1}{\rho}$

Curvature (□) = $\frac{M}{EI}$

where,

□ = Curvature

EI = Flexural Stiffness

Moment curvature relationship can be evaluated by two methods, analytically and experimentally. In this research, the moment-curvature relation is obtained using an analytical method. The relationship is automatically plotted in the FEM software (CSI Bridge) when the section is defined by the section designer. The moment-curvature relation for different models for our research is plotted in Figure 2. The plot shows that the moment capacity of the section increases with the application of RC jacketing. Furthermore, it increases on increasing the ductility percentage of the jacketing. Hence, the strength and stiffness of the bridge pier gets increased

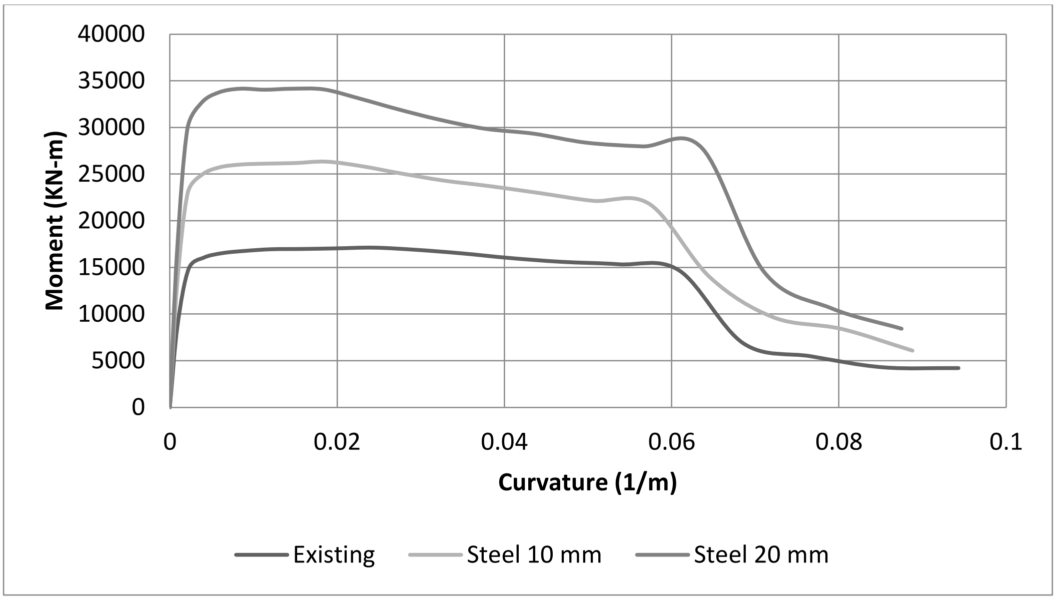

Figure 2: Moment Curvature Relationship

The figure-3 represents the spline model of the selected model in CSI Bridge. In the FEM software, the displacement-controlled pushover analysis is carried out to determine the capacity of a bridge pier in the form of base shear versus pier displacement plot. Non-linear direct integration time history analysis is performed to determine the response of the structure in terms of top pier displacement using recorded accelerograms.

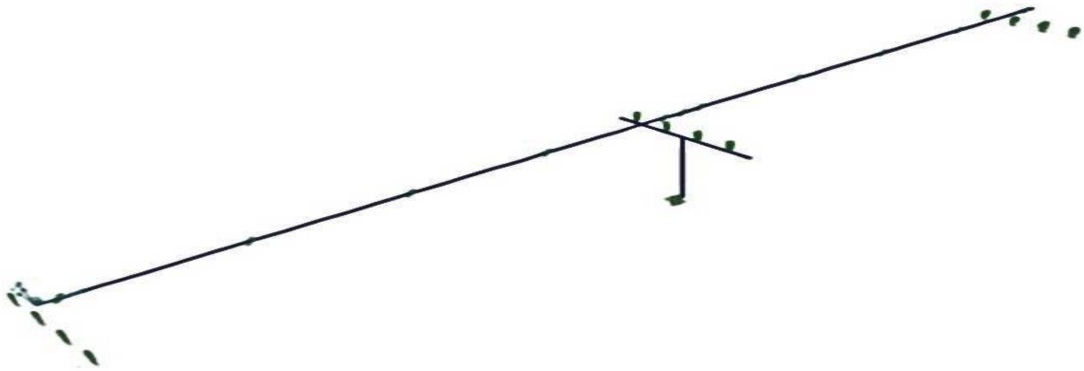

Figure 3: Global Finite Element Model

All the loads and forces were transferred to the substructure through PTFE POT bearing which has been modelled as the linear link element. The bearing positioned over the pier cap and abutment is represented by an idealized, linear elastic bearing model. The bearing over the hammer head pier cap is restrained along three directions but is made free in rotation. Similarly, bearing over the abutment is restrained along the longitudinal direction but is free along the transverse and vertical directions and is free in rotation.

The components of the superstructure are longitudinal girder, cross girder, and deck slab. In the FEM software, modeling of the deck slab is done as an elastic shell element and girder as linear 3D frame elements. During the seismic events, the response of the bridge girder is expected to be in the elastic range (Mander, et al. 2007). The model can be simplified to the Beam stick model for analysis purposes. In the simplified beam stick model the superstructure is represented by a single beam element which has the equivalent property of the entire deck. Bents are modeled as 3D beam-column frame elements. The software automatically maintains the connection between the bridge components to ensure the continuity of the model using rigid link elements. The Caltrans fiber section is defined by the section designer of CSI Bridge which helps to depict the nonlinear characteristic of the pier during seismic loading. The defined fiber section is assigned at the plastic hinge formation zone, at the top and bottom of the pier near fixity.

The length of a plastic hinge can be evaluated by using the following relation suggested by FHWA-1995 ((FHWA) 1995)

$$L_p = 0.08 * h + 0.022 * f_y * D_b$$

Where h is the height of bridge pier (m), f_y is the yield stress of longitudinal rebar (MPa) and D_b is the diameter of the longitudinal rebar (m). The hinge length is compared to the twice value for the minimum hinge length, described as $L_p = 0.022 * f_y * D_b$, and the larger value is used. After the hinge lengths have been determined, the hinges are placed on the bent columns at each end of the column at distances from each end equal to 1/2 the hinge length.

The column of the pier is jacketed using Steel of Fe 345. The thickness of steel is the parameter that has been varied. In the FEM model, it is assumed that there is a perfect bond between the original pier and the Steel jacket (Navarrete, et al. 2016). The retrofitted cross section consists of two confined cores, longitudinal reinforcement layer and outer steel jacketed layer. This hypothesis allows the estimation of the column's capacity and behavior with the available models for traditional RC members in flexo-compression, including the expression used to estimate the plastic hinge length (Paulay and Park 1975).

3.1 Selection of Ground Motion Data

The nonlinear response of the structure relies on the structural modelling technique and ground motion characteristics. Precautions should be taken while choosing the ground motion data, as it directly affects the evaluation process. The ground motion data are selected on the basis of magnitudes, fault types, and spectral content. Table 2 represents the earthquake selected and the station for the selected earthquake.

Ground motion parameters might be acceleration, velocity, and displacement or all combined. Acceleration is recorded and other parameters are derived from it. Actual ground motion near to the site should be selected for better results. However, actual earthquake records in Nepal are not available remarkably. The earthquake which resembles to the site should be considered. For this, the target spectrum is defined according to IS 1893(part I): 2016. The earthquake data is taken from the PEER Earthquake Database (NGA West 2) (PEER Ground Motion Database 2022). The downloaded data are the raw input data for time history. It is matched using Seismomatch software considering the target spectrum. The output from the Seismomatch software gives matched time history data which is used for nonlinear time history analysis.

Table 1: Selected Ground Motion data

RSN	**Event (years)**	**M_w**	**Station**	**Fault Mechanism**
6	Northridge -01 (1994)	6.95	EL-centro Array #9	Strike-slip
1083	Imperial Valley -02 (1940)	6.69	Suland-Mt. Gloason Ave	Normal + Reverse
1108	Kobe, Japan (1995)	6.90	Kobe University	Strike slip
1131	Kocaeli (1999)	7.51	Gebze	Strike slip
22	EL Alamo (1950)	6.80	EL Centro Array #9	Strike slip
3548	Loma Prieta (1989)	6.93	Los Gatos – Lexington Dam	Reverse Oblique
879	Landers (1992)	7.28	Lucerene	Strike slip

3.2 Probabilistic Fragility Function

Fragility curve gives the conditional probability of attainment or exceeding of a damage state for a given intensity "X" of ground excitation. The quality of the fragility curve relies mostly on, the modeling of the bridge structure, selection of ground motion, and definition of damage state. According to Melchers (2001), the fragility curve can be represented by a lognormal cumulative distribution function and is given by;

$$P_f = ȸ\left[\frac{lnln\frac{Sd}{Sc}}{\sqrt{\beta d^2+\beta c^2}}\right]$$

where, ȸ () is the standard normal distribution function, S_c is the median value of structural capacity defined for the damage state, S_d is the seismic demand response due to imposed ground motion parameter into the structure, βc is the lognormal standard deviation of the structural capacity, βd is the lognormal standard deviation for the demand.

$\sqrt{\beta d^2 + \beta c^2}$ Represents the composite logarithmic standard deviation which includes the uncertainties and randomness for both capacity and demand. Its value is defined in (Federal Emergency Management Agency: HAZUS Technical Manual 2003) as 0.55 for slight and moderate damage state and 0.7 for extensive and collapse damage state.

For all seismic intensity levels, the capacity of the bridge pier for a given damage type is constant. It is defined using nonlinear static analysis in accordance with a predefined strain limit. The strain limits are taken from the Mander model for material nonlinearity from the section designer of CSI Bridge (Mander, Priestley, and Park 1998). The guideline HAZUS- MH 2003 is been used for the qualitative definition of bridge pier damage state (Federal Emergency Management Agency: HAZUS Technical Manual 2003). The quantitative definition of damage state is carried out using the qualitative definition and ductility displacement is obtained accordingly (Basnet and Suwal 2019). The strain value for each damage state as mentioned in Table 3 is used to calculate the median capacity of the bridge pier for all conditions separately. The obtained values are tabulated in Table 4 and these values depict the capacity of the bridge pier and are used for the development of fragility functions. Similarly, the seismic demand of models is assessed from linear regression analysis of response data from nonlinear time history analysis using a power model

$$S_d = aIM^b$$

Multiplying both sides by natural log,

$$\ln (S_d) = \ln(a) + b\ln (IM)$$

where, a and b are regression coefficients, IM is the seismic intensity measure.

Displacement ductility (μ_d) = Δ_T / Δ_y (Caltrans: Seismic Design Criteria 2004)

where, Δ_T is maximum top pier displacement and Δ_y is the rebar first yield displacement.

Table 2: Damage state according to displacement ductility. (Basnet and Suwal 2019)

Damage state	**Qualitative Definition (HAZUS-MH-2.1)**	**Description**	**Rebar strain**	**Concrete strain**
Slight	Minor spalling of column	First yielding of extreme rebar	0.0025	-
Moderate	Spalling in column	Maximum compressive strain at cover concrete =0.002	-	0.002
Extensive	Column degradation without collapse	Maximum compressive strain at core concrete	-	0.0028
Collapse	Column collapsing	Ultimate compressive strain at core concrete	-	0.0076

Table 3: Bridge median capacity ratio in terms of displacement ductility for different conditions

Damage State	**Existing**	**Steel 10 mm**	**Steel 20 mm**
Slight	1.66	1.62	1.68
Moderate	3.3	3.24	3.31
Extensive	6.2	6.16	6.2
Collapse	8.15	8.10	8.18

Results and Discussions

Free vibration analysis of the bridge structure was carried out in FEM software along the transverse direction using the linear elastic analysis method. The obtained fundamental time period of vibration with a modal participation factor which is more than 90% in the transverse direction (Table 4).

Table 4: Transverse Vibration period of Bridge

Condition	Transverse Vibration Period (s)
Existing	0.67791
Steel 10 mm	0.67659
Steel 20 mm	0.6241

On increasing steel thickness in Steel Jacketing, the lateral stiffness and bending capacity of the bridge pier increases which eventually decreases the time period of the bridge structure. The nonlinear pushover analysis is carried out to obtain the capacity characteristic of the bridge pier in CSI Bridge V20.2.0. Displacement controlled pushover analysis method was used where the pier was displaced in the transverse direction up to 350 mm displacement. The nonlinear characteristics of the bridge pier are captured with the help of fiber PMM hinges which were assigned near the point of fixity of the pier, top and bottom ends. The load is applied monotonically in the transverse direction. In this research, the structure was pushed up to 350mm for all model cases. The damaged state of the bridge pier was obtained from the pushover curve with the help of predefined stain yield values of reinforcement, unconfined concrete, and confined concrete for all bridge model cases. The obtained capacity displacement curve is analyzed and plotted as shown in Figure 3. The pushover curve depicts that the base shear reaction increases along with top pier displacement as the thickness of steel in steel jacketing increases. From the pushover curve data, we can clearly observe that on applying Steel Jacketing the base shear reaction of the structure increases. It gets increased by 13.72% and 27.67% for Steel 10 mm and Steel 20 mm respectively. The increase in base shear of the bridge pier is due to an increase in lateral stiffness and bending capacity due to the addition of a layer with certain structural characteristics.

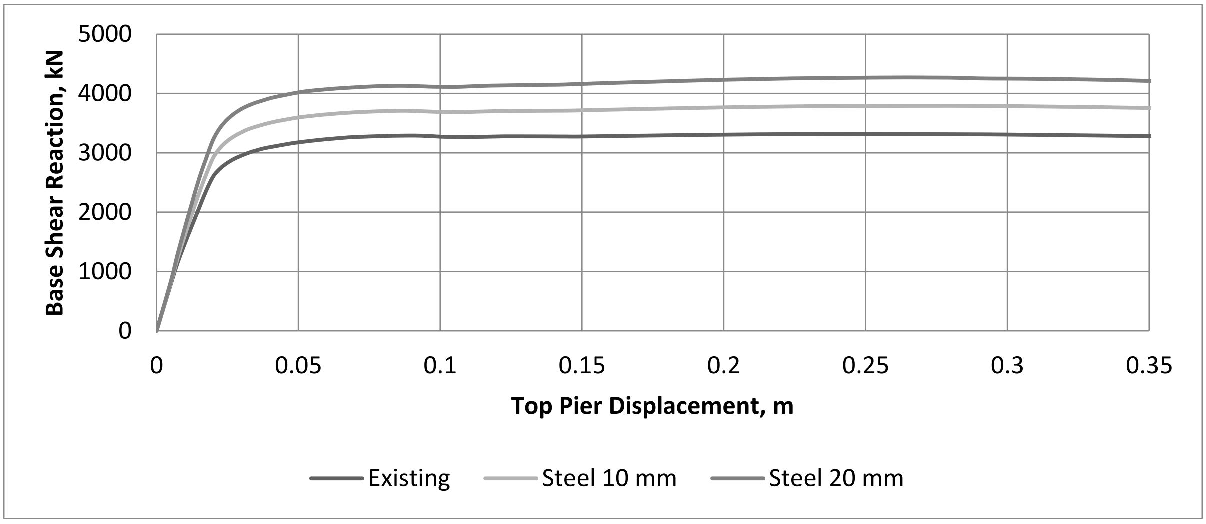

Figure 4: Pushover Curve

In this research, seven ground motion data were selected as listed in Table 2 and its component were applied in both transverse and longitudinal directions. The top pier displacement for each intensity level from 0.1g to 2.0g at an interval of 0.1 for each ground motion was recorded. While scaling Peak Ground Acceleration (PGA), the linear scale method was used. The displacement ductility for each data recorded for each intensity level was calculated using CALTRANS 2004 formulae. Linear regression analysis on the logarithmic value of displacement ductility and Pga is carried out to obtain the median demand line. The fragility curve is developed using the damage state defined earlier and the median demand line. Figure 5 shows the fragility curve of the bridge pier with no jacketing ’Existing’ Model. It depicts 95.36%, 65.57%, 28.22%, and 16.93% probability of failure for slight, moderate, extensive, and collapse damage states respectively at 1.0g PGA. The above data shows the probability of failure for different cases at 1.0g PGA.

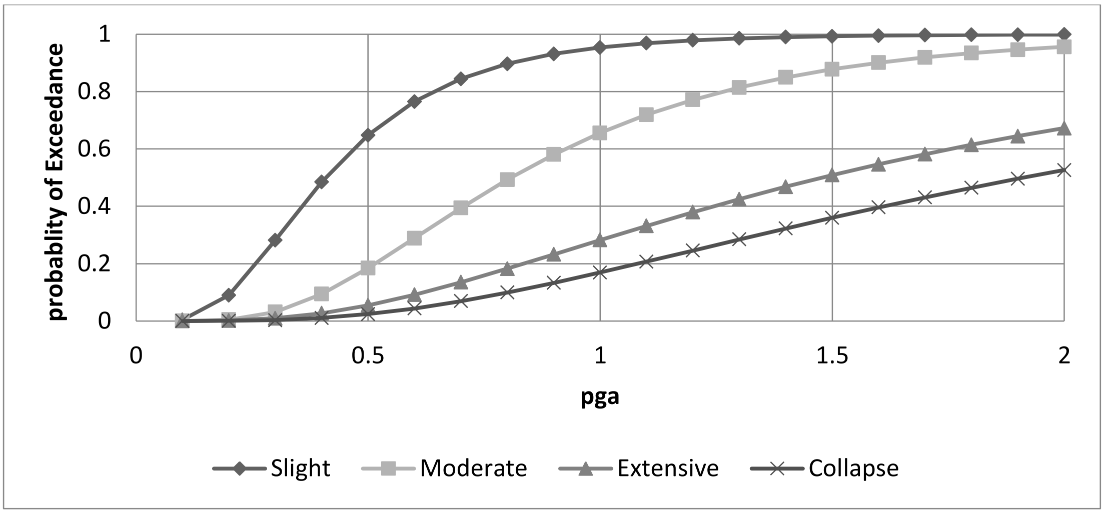

Figure 5: Fragility function for Existing Model

Similarly, 91.95%, 55.63%, 20.99%, 11.54% probability of failure of Steel 10 mm for slight, moderate, extensive and collapse damage state respectively at 1.0g PGA and is shown in Figure 6.

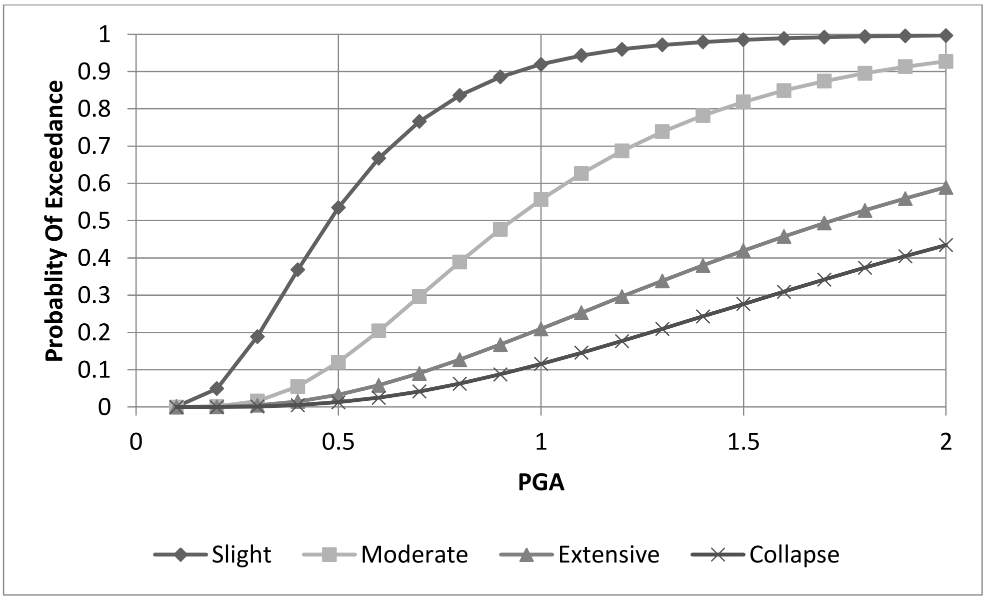

Figure 6 Fragility function for Steel 10 mm Model

Similarly, for Steel 20 mm the probability of failure is 84.96%, 41.51%, 14.25%, 7.21% for slight, moderate, extensive and collapse damage state respectively at 1.0g PGA and is shown in figure 7.

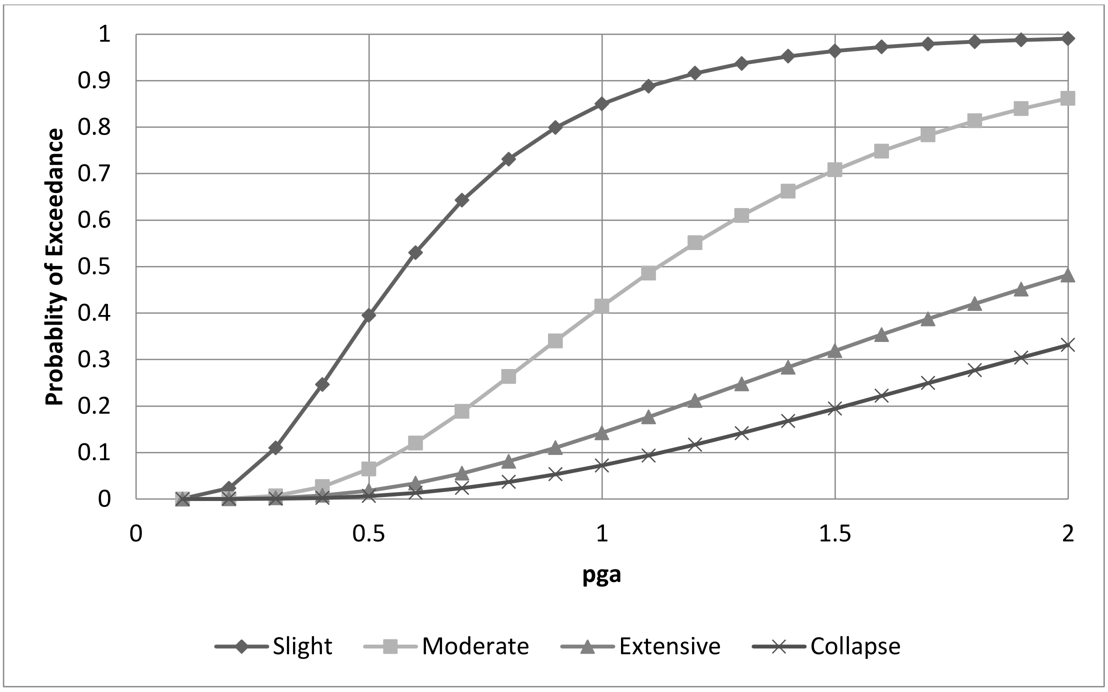

Figure 7: Fragility function for Steel 20 mm Model

Conclusion and Recommendations

Fragility curves are plotted for the two-span continuous hammer head bridge pier jacketed with Steel jacketing with varying steel thickness using an analytical method. These curves help to quantify the improvement of seismic performance after the use of Steel Jacketing at different ductility percentages. The major conclusions are:

- The transverse vibration period of the bridge decreases with the application of Steel Jacketing. The time period of the bridge decreases with the increase of steel jacket thickness. As the structure is retrofitted with a Steel Jacket the stiffness of the pier increases, due to which the time period of the structure decreases.

- From nonlinear static analysis, the capacity of the bridge increases with an increase in steel jacketing thickness. The base shear reaction of the structure increased by up to 27.67 % on the application of a steel 20mm thickness jacket.

- From nonlinear dynamic analysis, the displacement ductility of bridge pier decreases along transverse direction in great extent with increase of steel thickness in Steel Jacketing.

- So, the probability of exceedance for collapse damage state decreased as the thickness of steel in the Steel Jacket increases. It decreased from 16.93% to 7.21% for collapse damage state for the 'Existing' model to steel 20 mm model at 1.0 PGA level. As the thickness of steel in the steel jacket increases, the stiffness of lateral load resisting increases and the bending capacity of the pier increases. Hence, increases the performance of the bridge.

Thus, this study concluded that the performance of the two-span bridges with single-bent column can be increased by the application of Steel Jacketing. For further study, the seismic performance of the abutment, the effect of the isolation system, soil structure interaction at the abutment and foundation, bent column P-delta effect, and bridge pounding effects of a bridge can be done.

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ISSN NO. 2091-1742

SCITECH NEPAL

Journal of Scientific and Technical Studies
Nepal Engineering College, Pokhara University

Research Article

DOI:10.3126/scitech.v17i1.60465

Behavior And Optimum Location Of Outrigger And Belt Truss System In High-Rise Buildings Subject To Seismic Loading

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Received: April 2, 2023
Accepted: October 4, 2023

Abstract

This study is focused on the efficient use of the lateral load-resisting system for high-rise concrete buildings subjected to earthquake load. 32-storey three-dimensional models of OMRF, SMRF, core, core with outrigger (OT), core with outrigger and cap truss, and core with belt truss (BT) and core with belt truss and their cap truss systems are analyzed and compared to find the lateral displacement, storey drift and time-period reduction. The modelling and analysis were performed using finite element software ETABS 2016. The analysis has been carried out to study the effect and performance of the outrigger system and belt truss system in the building. These systems are provided at different levels along the height of the building. The coverage of the outrigger and belt trusses are equal to the height of the typical story and maintained the same in all the models. For finding the optimum position of the outrigger and belt truss system and also with their cap truss, the result is illustrated in terms of the reduction of top-storey lateral deflection, the maximum reduction in storey drift and the maximum reduction in the time period of the building. All the parameters are obtained for the structure without an outrigger system and they are compared with the values obtained by introducing an outrigger and belt truss. A total of 51 models are studied for finding the optimum location and behaviour of the systems when introduced on the building. A comparison is made to find the best system among all the systems, which are introduced in the model. Among the entire systems, an outrigger with a belt truss is found to be the best system in terms of reducing deflection, drift, time and base shear. The optimum position is found to be at 0.375 times the height of the total structure when the user system is outrigger and its belt system in terms of reduction in deflection and time, whereas the optimum position is at mid-height when the selection criterion is lateral drift.

Keywords: *- Outrigger; Belt truss system; Earthquake; Lateral displacement. Out-outrigger; OFT-Outrigger fixed at the top and another variable; OBT-Outrigger and Belt Truss system*

Introduction

Background

Due to the increasing population in the city areas such as Kathmandu, the problem of housing has increased to a large extent (UN-HABITAT, 2010). Very few land areas are available in the core part of the town. If a taller building is constructed, then it can replace several other houses and the problem of housing can also be lowered. A large number of people can be accommodated in a tall building.

The main problem with the talls buildings is to resist lateral loads such as earthquakes and wind (Gupta et al 2020. A number of people died and structures collapsed due to the Gorkha earthquake in 2015, Nepal.

The risk to the life of people and damage to the structure is more due to the collapse of such structures during an earthquake. So, it is more important to consider the lateral stiffness of the structures. One of the ways to introduce the lateral load-resisting system in high-rise buildings is to use the outrigger system (Nanduri et al, 2013) in an optimum location in a slender building to reduce the effect of the earthquake forces (Kian, 2001).

Outriggers

In the past, mainly structures were aimed to carry gravity loads only. With the advancement of building materials and new structural systems of design, building weight is largely reduced. As the building starts to grow in height, increasing the slenderness in which it is necessary to resist the majority of the lateral forces such as earthquakes by the horizontal load-resisting system of the building (Shivacharan et al 2015). One of the significant criteria for the design of a slender structure is lateral drift and deflection at the top which should be within acceptable limits. As the slenderness increases, the flexibility of the building increases. So, it becomes necessary to identify a suitable load-resisting system in such a structure to minimize the effect of lateral forces depending upon the height of the structure (Gupta et al 2020).

Some of the essential systems to resist the lateral loads in the building are rigid frame arrangement, braced frame and shear wall framed arrangement, braced framed system, shear walled framed system, outrigger arrangement, framed tube system, braced tube system, bundled tube system.

The outrigger structural system consists of a main concrete/steel core connected to the exterior column utilizing outriggers. Outriggers are relatively stiff members which may be one or two stories deep truss/deep beam/ deep walls which extend from these cores towards the exterior columns which helps in keeping the columns in their position reducing the sway and drift (Gadkari & Gore 2016). The system also helps in reducing the moment at the core base.

The core may be positioned in the middle with outriggers projecting from both sides, or it may be positioned on one side with outriggers reaching the building columns along that side (Figure 1).

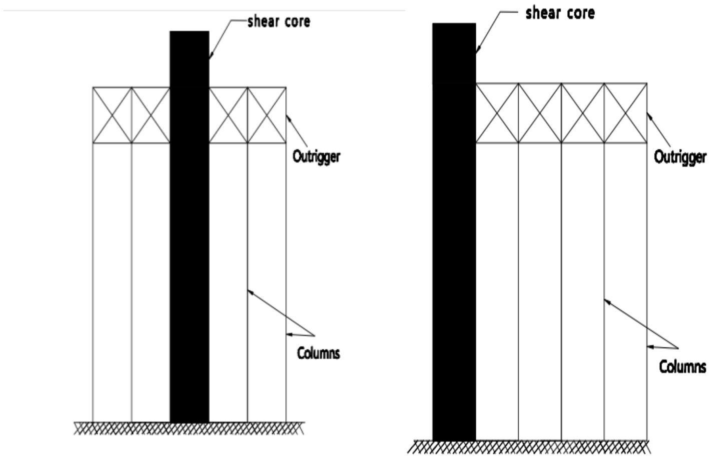

Figure 1: Outrigger with centrally located core and outrigger with an offset core

Belt truss which is one or two storeys deep ties the peripheral columns which in turn reduces the excessive deflection and drift (Gadkari & Gore 2016).. The damage level can be minimized by utilizing an outrigger and belt truss system.

Behaviour of outrigger and outrigger with belt truss

The structural response of this type of system is simple. When the building is exposed to seismic forces, the column-restrained outriggers balance the rotation of the core thus reducing the lateral deflection of the building and the moment at the base of the core also gets smaller than a free-standing cantilever structure.

If there is only a simple cantilever structure the external moment is resisted mainly by the core. By the introduction of the outriggers, the external moment is also resisted by the generation of axial compression and tension developed in the external columns connected to the outriggers (Figure 2). As a result, the effective depth of structure for resisting bending moment is enlarged by the introduction of tension in the windward column and compression in the leeward column when the core tries to flex as a vertical cantilever (Taranath 2007).

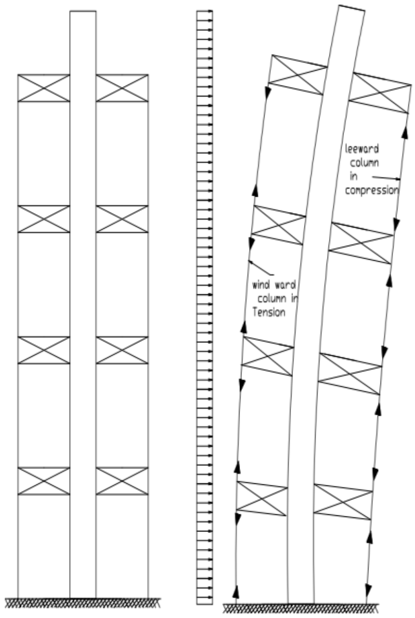

Figure 2: Behavior of outrigger when subjected to lateral load

In addition to the columns, it is also possible to mobilize the entire perimeter column to restrain the rotation of the core. It is done by tying all the perimeter columns by a one or two-storey deep beam, wall or truss referred to as a belt wall or belt truss system. Further, the belt system is connected to the outrigger and if they are not connected to the outriggers they are referred to as a virtual outrigger system. The one or two-storey outrigger and belt wall system depends on the efficiency and it should be noted that they are used in increasing the flexural stiffness; the shear resistance is not increased which must be carried out mainly by the core (Taranath 2007)..

To simply recognize the behaviour of the outrigger let us consider a one-storey deep outrigger with a truss used to stiffen the building at its top.

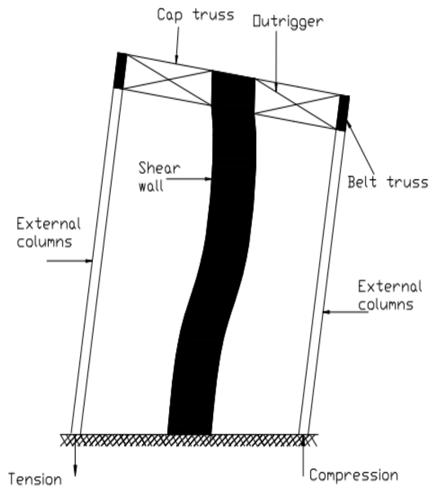

Figure 3: Cap truss outrigger with belt truss

In Figure 3, since the outrigger is used at the top, the outrigger is called a cap truss or hat truss outrigger system. The tie-down action of the cap truss creates a restoring couple at the structure's top, causing the occurrence of a point of contra flexure at some distance down the top of the building. The reversal of curvature in turn diminishes the bending moment of the core and henceforth the building drifts (Nanduri et al 2013).

Perception of Outrigger

The sailing ships use the outrigger to fight back the wind and wave force during their sails (Gadkari & Gore 2016). If we relate the various parts of the ship with the outrigger system of the building, the mast of a sailing ship is a tall spar, or arrangement of the spars, erected more or less vertically on the centerline of a ship or a boat; a spreader is a spar in a sailboat used to deflect the shrouds to allow them to better support the mast; the shrouds are pieces of standing riggings which holds the mast up from side to side; rigging is the ropes, chains, etc. that support the mast and spars of a sailing vessel, adjusting the sails.

Comparing the building structure with the sailing ship structure, the core of the building is related to the mast of the ship and the outriggers act as spreaders. Exterior columns are related to the stays or shroud of the ship (Figure 4).

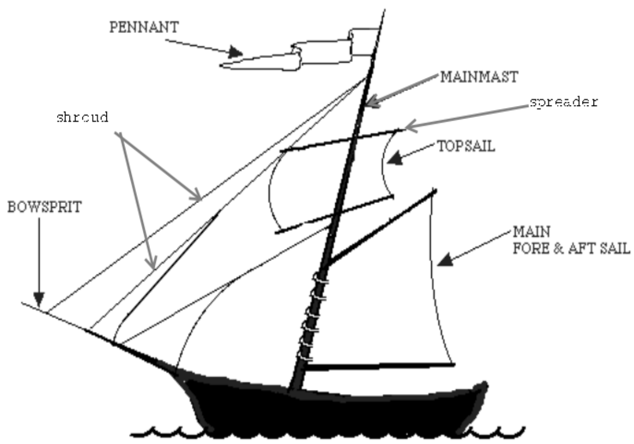

Figure 4: Parts of the sailing ship compared with the outrigger of building

The narrow boat will overturn when toss by an unexpected wave but a small amount of flotation (upward) or weight (downward) acting through the outrigger is sufficient to avoid overturning. In the same way, outriggers are connected to the columns to help in resisting the overturning of the building.

Methodology

Various research papers showed the use of outriggers in the building whose storey height was in the multiple of 5. And most of the papers showed the importance of the outrigger system only to reduce the deflection and drift of a building. A regular building of 32 storeys was selected for this study. The building is modelled in ETABS 2016.1, loading analysis was done in this software and checked if the model design passed the design criteria. Response spectrum analysis is done as mentioned in IS 1893:2002 and loading is done as per IS 875 part 1 and part 2. Firstly, the system without outriggers was modelled and named a cantilever model. The size of the elements was kept varying till the model passed the design criteria. After the model passed the design criteria, four systems were introduced to this model which are listed in Table 1. The System 1 is Table is 1 is the model without an outrigger.

Table 1: Systems to be introduced in the model

S.No.	System
1	without an outrigger (cantilever)
2	Outrigger varying at different positions in building
3	Outrigger fixed at top (OFT) and next varying at different positions of building (Outrigger with cap truss)
4	Outrigger and belt truss (OBT)
5	OBT fixed at top and next varying (OBT with cap truss)

Response spectrum analysis is carried out for all of these models by varying individual system at various locations of the building. All the models passed the design criteria. These models were created to study the optimum location of each individual system. The top storey deflection and storey drift were calculated after introducing the systems on the modelled building to find the optimum location based on their maximum reduction (Code Of Practice For Design Loads 2023). Comparisons among these systems, when they are placed at various levels of the building were made. Finally, all the five systems were compared to choose the best system among them when they are at their optimum position.

Modelling and Analysis

Model Descriptions:

Geometry: Square

Location: Nepal

Structural System: RCC frame structure with Outrigger system

No of bays: 5(in both direction)

c/c distance between columns: 5m

No. of stories:32

Floor height: 3.5m

Total Building height: 112m

Material property: M40 and Fe500

Frame sections:

Beam: 0.3mx0.5m

Column: 0.7mx0.7m (up to 15 storey)

0.6mx0.6m (16 to 32 storey)

Outrigger: 0.45mx0.45m (concrete)

Slab: 170mm

Shear wall: 350mm

Loadings:

Super Imposed Load

This comprises the floor finish, partition walls, permanent furniture etc. A floor finish of 1 N/m^2 is considered.

Live Load (LL)

The live load comprises the self-weight of humans and they are highly variable. Thus, the Indian code suggests taking 3kN/ m^2. The live load for the roof is taken 0.75KN/ m^2 (IS : 875, 2003).

Lateral load due to Earthquake:

The structure is considered in the Nepal region. The earthquake loads are calculated according to IS 1893(PART 1) – 2002. Since the building lies in zone V the seismic zone factor is considered as 0.36. The importance factor of the building is taken at 1.5 and the response reduction factor is taken at 5. The percentage of live load considered is 0.25 (since the live load is 3kN/m^2) and the percentage of live load considered in the roof is zero (IS-1893:2002 2002).

For the analysis, ETABS version 2016 software was used. Firstly, the analysis of the cantilever structure (one without an outrigger) was done. Secondly, a single outrigger was varied in every four storeys and the optimum position of the outrigger is found.

In the third type of analysis, one outrigger was fixed at the top and the positions of other outriggers was varied in every fourth storey to find the optimum position for this type of outrigger system. In the fourth type of analysis, OBT (outrigger with belt truss) was introduced and varied on every fourth floor to find the optimum position. Finally, one OBT was fixed at the top and similarly, the other position of the outrigger is varied to find the optimum position. The summary of the various outrigger positions in given in Table 2.

Table 2: List of models analyzed

SN	Model	
1	Cantilever (freely standing model without outrigger)	Cantilever
2	Outrigger at storey 32	Outrigger variable
3	Outrigger at storey 28	
4	Outrigger at storey 24	
5	Outrigger at storey 20	
6	Outrigger at storey 16	
7	Outrigger at storey 12	
8	Outrigger at storey 8	
9	Outrigger at storey 4	
10	Outrigger fixed at the top and storey 28	Outrigger fixed at top and variable at other storeys
11	Outrigger fixed at the top and storey 24	
12	Outrigger fixed at the top and storey 20	
13	Outrigger fixed at the top and storey 16	
14	Outrigger fixed at the top and storey 12	
15	Outrigger fixed at the top and storey 8	
16	Outrigger fixed at the top and storey 4	
17	OBT at storey 32	OBT variable
18	OBT at storey 28	
19	OBT at storey 24	
20	OBT at storey 20	
21	OBT at storey 16	
22	OBT at storey 12	
23	OBT at storey 8	
24	OBT at storey 4	
25	OBT fixed at the top and storey 28	OBT fixed at

26	OBT fixed at the top and storey 24	the top and variable at other storeys
27	OBT fixed at the top and storey 20	
28	OBT fixed at the top and storey 16	
29	OBT fixed at the top and storey 12	
30	OBT fixed at the top and storey 8	
31	OBT fixed at the top and storey 4	

Table 3: lists of models for final optimization

SN	Model	
1	Outrigger at storey 13	Outrigger variable
2	Outrigger at storey 14	
3	Outrigger at storey 15	
4	Outrigger at storey 17	
5	Outrigger at storey 18	
6	Outrigger fixed at the top and storey 13	Outrigger fixed at top and variable at other storeys
7	Outrigger fixed at the top and storey 14	
8	Outrigger fixed at the top and storey 15	
9	Outrigger fixed at the top and storey 17	
10	Outrigger fixed at the top and storey 18	
11	OBT at storey 13	OBT variable
13	OBT at storey 14	
13	OBT at storey 15	
14	OBT at storey 17	
15	OBT at storey 18	
16	OBT fixed at the top and storey 13	OBT fixed at the top and variable at other storeys
17	OBT fixed at the top and storey 14	
18	OBT fixed at the top and storey 15	
19	OBT fixed at the top and storey 17	
20	OBT fixed at the top and storey 18	

For finding the optimum position total number of the model created is 51 (Table 2 and 3).

The plan view of the building model is shown in Figure 5. The Figures 6 to 11 show the model nodes for the systems listed in Table 1.

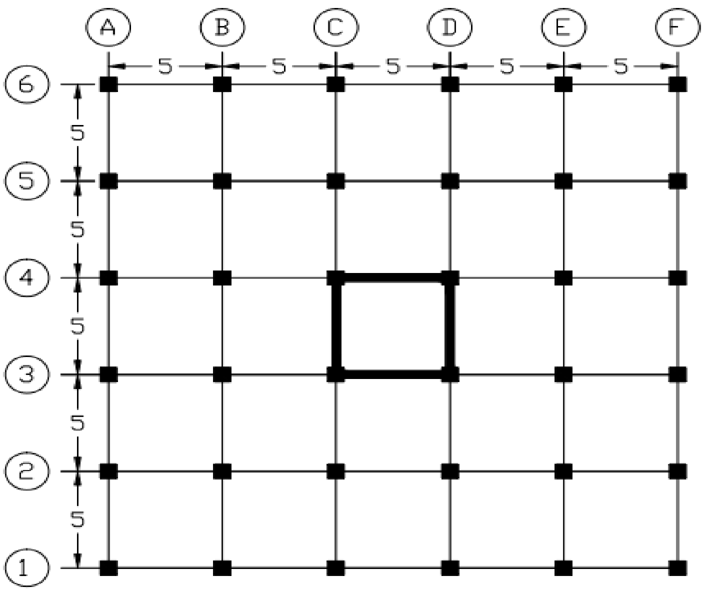

Figure 5 Plan of Model

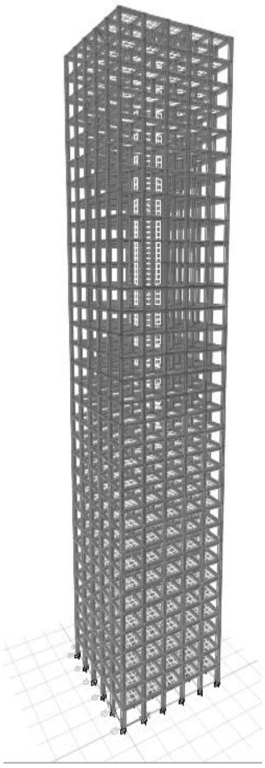

Figure 6 Cantilever Model

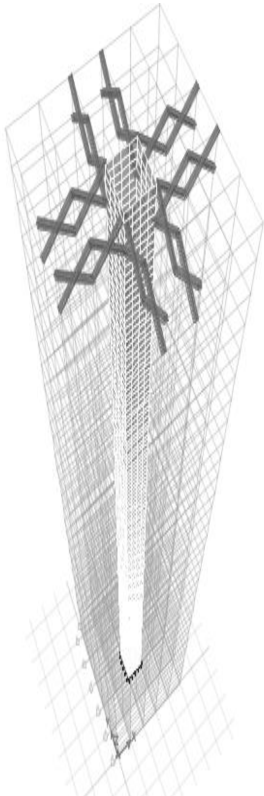

Figure 7 Outrigger Cap truss

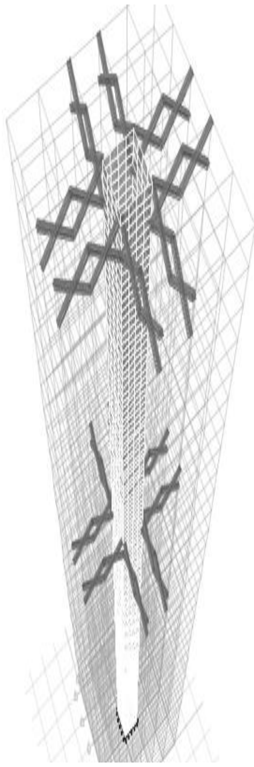

Figure 8 Cap truss fixed and other outrigger varying

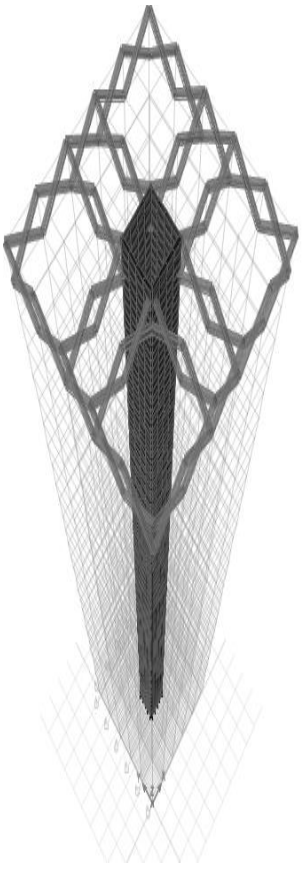

Figure 9 OBT with cap truss

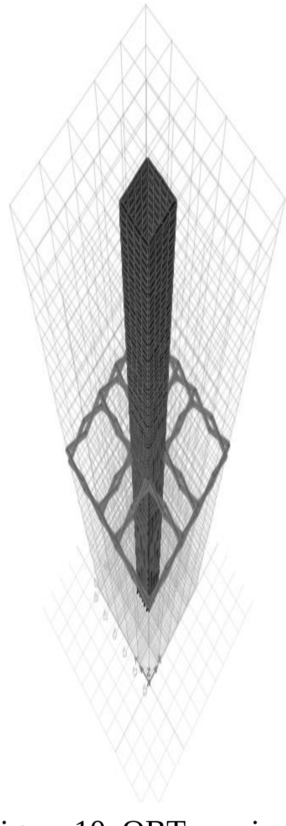

Figure 10 OBT varying along building height

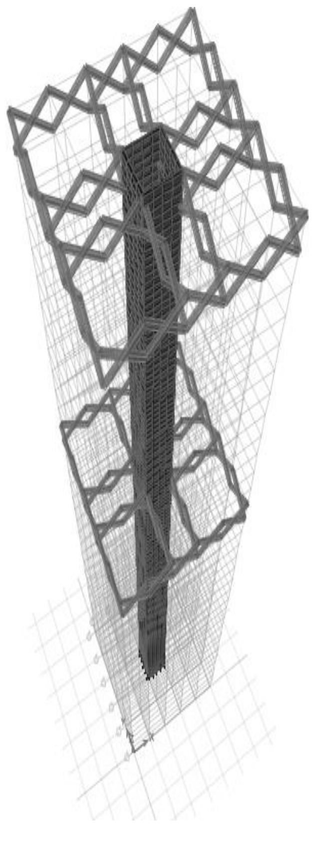

Figure 11 OBT varying along building height with cap OBT fixed

RESULT AND DISCUSSION

Deflection

Figures 12 to 15 show the variation of deflection in a storey where the outrigger is placed. The nature of the curve for each system is quite similar. The main observations to be noticed in these figures is the variation of the deflection at the top of the building.

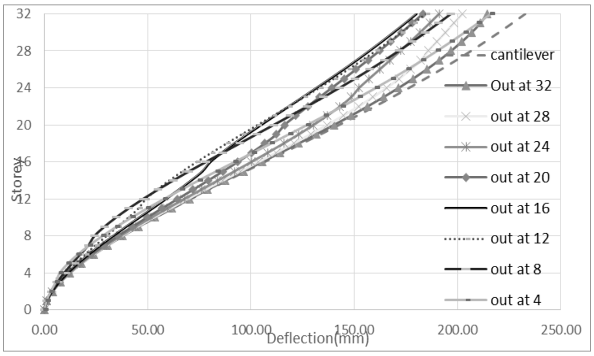

Figure 12 Lateral deflection of building with outrigger

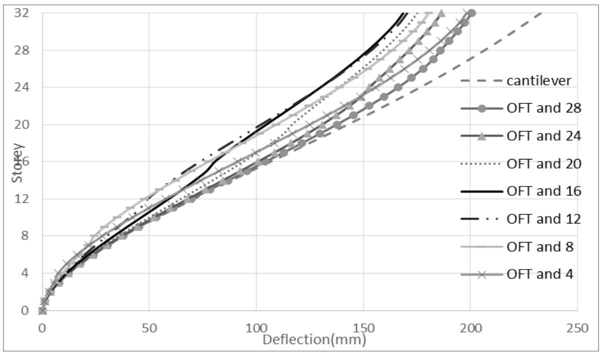

Figure 13 Lateral deflection of building with cap truss and outrigger

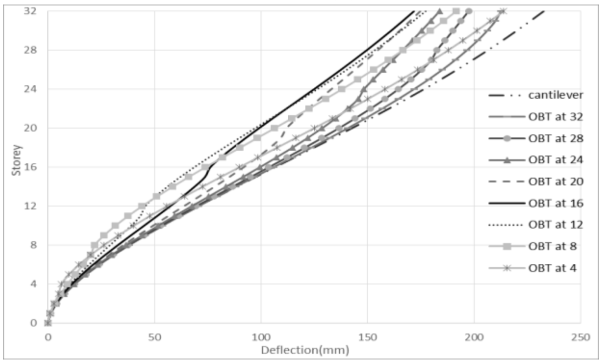

Figure 14 Lateral deflection of building with OBT

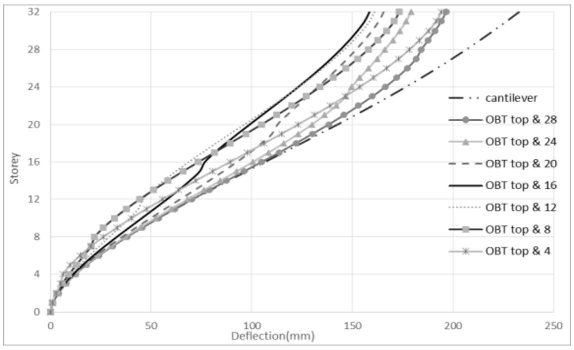

Figure 15 Lateral deflection of building with OBT cap truss and OBT

The maximum deflection at the top of the building is seen when there is no outrigger and belt truss systemin the building as seen from the above graphs. The structure without an outrigger and the belt truss system is referred to as a cantilever structure. In this structure, the maximum deflection at the top of the building is 232mm.

From Figure 12, when the outrigger is varied at various levels of the building it is noticed that the deflection is reduced where the outrigger is used. In each location where an outrigger is used, there is a reduction in building deflection. The deflection at the top is gradually reduced till it reaches the position of 16th storey. The model was again run by moving the outrigger to lower stories and it is noticed there is an increase in top deflection. Hence outrigger at 16th storey provided a minimum deflection of 180mm. So, it can be considered an optimum position. When the outrigger is used at the top it reduced the deflection at the top by 8%. The deflection produced when the outrigger is at storey 12, 16 and 20 is quite similar. When the outrigger is at the 12th storey it reduced the deflection by 20.7% and when the outrigger is at the 20th storey it reduced the deflection by 21.3%. Thus, it is observed that the 20th-storey position of the outrigger is more efficient than 12th storey outrigger. Similarly, the outrigger at 4th and 32nd storey also shows a similar type of result; the outrigger at 32nd storey is more efficient compared to the outrigger at 4th storey. At the optimum level of the outrigger, the deflection is reduced by 23%. The following list shows the percentage reduction in deflection, compared to the deflection in caltilever system, in decreasing order when the outrigger is used at various locations of the building.

a. Outrigger at storey 16 (22.6%) optimum position
b. Outrigger at storey 20 (21.3%)
c. Outrigger at storey 12 (20.7%)
d. Outrigger at storey 24 (17.9%)
e. Outrigger at storey 8 (15.5%)
f. Outrigger at storey 28 (13.1%)
g. Outrigger at storey 32 (8%)
h. Outrigger at storey 4 (7.2%)

Figure 13, shows the maximum deflection of the storey when one outrigger is fixed at the top and the next outrigger is varied at various storeys of the building. This is a two-outrigger system in which one is fixed at a position and the next is variable. The top position is used as a fixed outrigger position. Generally, an outrigger is used in place of a mechanical floor, plant floor, or refuse floor. The top floor is less used by the public and various plants of water supply, electricity, and lift mechanical floor are made in this part. So, the top part of the building is fixed. Also placing the outrigger at the top of the building eliminates the differential movement between the exterior columns by providing a compressive restraint of the exterior column in expansion and a tension restraint when the columns are in tension (Taranath, 1988). The minimum deflection is obtained at 16^{th} storey and hence considered as the optimum position of the outrigger having one fixed at the top. The outrigger at 16^{th} storey reduced the deflection from 232mm (cantilever) to a value of 168.571mm at the top. The top deflection is reduced by almost 28%. Again, the top deflection produced by the outrigger being at storey 4 and 28 is quite similar. The deflection produced by 12 is nearer to that of the optimum position i.e. (storey 16). One can also check if the optimum position lies between 20 to 16 or between 16 to 12, due to very less change in deflection for this system the optimum position is at the 16th storey of the building. As moving down or up from 16 the increase in deflection is observed. The following list shows the percentage reduction of deflection in decreasing order when one outrigger is fixed at the top and the second is used at various locations of the building.

a. Outrigger fixed at the top and at storey 16 (27.6%) optimum position
b. Outrigger fixed at the top and at storey 12 (26.8%)
c. Outrigger fixed at the top and at storey 20 (24.8%)
d. Outrigger fixed at the top and at storey 8 (22.5%)
e. Outrigger fixed at the top and at storey 24 (19.9%)
f. Outrigger fixed at the top and at storey 4 (14.9%)
g. Outrigger fixed at the top and at storey 28 (13.9%)

Figure 14, shows the maximum storey deflection when the OBT (outrigger with belt truss) system is used at various locations of the building. In this system, the exterior column is attached by means of the belt truss along the perimeter and the belt is indirectly connected to the core by means of outriggers running transversely from the central core. Again, varying the position of the outrigger with the belt truss system, the performance of the outrigger when placed at storey 32 and storey 4 are similar in nature regarding the reduction of deflection at the top of the building. In Figure 14, it is observed that on moving below the top it is found that the deflection decreases till the system moves to storey 16. On moving below storey 16 further downward it is observed that the deflection again increases. Thus, in this system also the optimum position of OBT is obtained at storey 16. The reduction in deflection is about 26%. But when the OBT is used at the top it reduced the deflection by about 9%. Also, when only the OBT is used at storey 4 it reduced the top deflection by 8%. It is because the exterior columns also take part in reducing the deflection of the central core as it is achieved by using the belt system at the exterior part of the building. The following list shows the percentage reduction of deflection in decreasing order when one OBT is used at various locations of the building.

a. OBT at storey 16 (26.2%) optimum position
b. OBT at storey 20 (24.9%)
c. OBT at storey 12 (23.8%)
d. OBT at storey 24 (21%)
e. OBT at storey 8 (17.6%)

f. OBT at storey 28 (15.2%)
g. OBT at storey 32 (8.7%)
h. OBT at storey 4 (8.1%)

Figure 15, shows the maximum storey deflection when one OBT is fixed at the top and the next OBT is varied at various locations of the building. It is a system where two OBT is put at the same time in the structure. The deflection at the top is less than that of the outrigger and belt truss. For this system, the minimum deflection is seen when the outrigger is at the level of storey 16. Hence from the graph where one OBT is fixed at the top the next optimum position of the outrigger is located at storey 16. Storey 16 reduced the deflection by 32 per cent. It is because both the OBT are resisting the lateral movement of the building and core and more columns are involved to resist the deflection. The following list shows the percentage reduction of deflection in decreasing order when one OBT is fixed at the top and the second is used at various locations of the building.

a. OBT fixed at the top and at storey 16 (32%) optimum position
b. OBT fixed at the top and at storey 12 (31%)
c. OBT fixed at the top and at storey 20 (29%)
d. OBT fixed at the top and at storey 8 (25.5%)
e. OBT fixed at the top and at storey 24 (23.1%)
f. OBT fixed at the top and at storey 4 (16.6%)
g. OBT fixed at the top and at storey 28 (15.6%)

The analysis of the modeling results, as shown in Figures 12 to 15, shows that there is a curvature change at the levels where the outrigger and outrigger with belt truss are used. It is due to the fact that at the level of

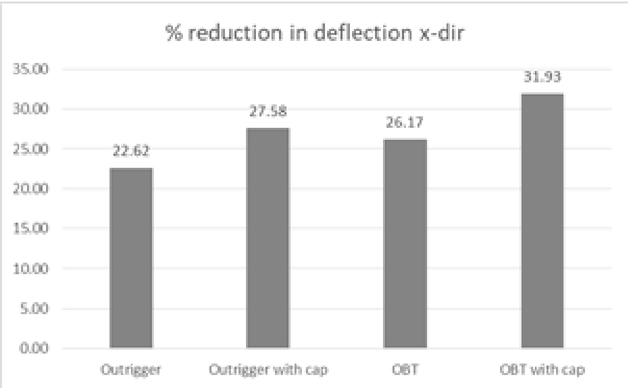

Figure 16 Comparison system in reducing deflection when they are at their optimum location

the outrigger and outrigger with the belt truss, the rotation of the core is restricted at those points by column outrigger interaction. Comparing the four systems when the outrigger and OBT are placed at their optimum position the following bar diagram shows the percentage reduction in top deflection of these systems.

Figure 16 shows which system of outrigger is more efficient in reducing the maximum storey deflection when they are at their optimum position. The system with the outrigger only can reduce the storey deflection but is less efficient than the rest of the three systems. If one outrigger is fixed at the top and the next is at its optimum position it can perform better than the case first. It is because two systems of outrigger are used and the top is fixed. The top fixed outrigger reduces the deflection at the top which is further reduced by the outrigger at storey 16 i.e. optimum location. It can be observed that this two-outrigger system is better at reducing the deflection than the deflection produced at the top by a single OBT system though exterior columns are also involved in reducing deflection. It is also because the deflection is reduced at the two places when one is fixed at the top and the next is at the optimum position. Apart from these when one OBT is fixed at the top and the next is at the optimum position, it proved to be more efficient than other systems in terms of reducing the top deflection. This system utilized more the number of columns to reduce the deflection than the rest of the three systems. Also, this system is increasing the lateral stiffness at two places. So more lateral stiffness of the overall building is increased by two outrigger systems than single outrigger and OBT systems. Thus, the efficiency of the building in terms of reducing the top deflection is in the order of:

Only outrigger <OBT only < one outrigger fixed at the top and next at other < One OBT fixed at the top and next at other position.

From Figure 12 to 15, it can be observed that the least deflection occurs at a distance of 0.5H. It is found, on moving down, the top deflection deceased till storey 16 and again increased on moving downward from it. Though it is observed that the difference in deflection between 20, 16 and 12 is very less, there may also exist the minimum deflection when the outrigger is placed between storey 20 to storey 16 or storey 12 to storey 16. Following graphs shows the changes in deflection when the outrigger is placed up and down from storey 16 at a step of 1 storey.

System Optimization

The figures 17 to 20 show that there is very less reduction in top deflection when the outrigger is at position storey 18 to storey 13. So, the before-obtained position of the outrigger to be considered at an optimum is fine. In the 1st and 3rd figures, the minimum deflection is obtained at storey 16. But in the 2nd and 4th figure minimum deflection is at the 14th storey though the change in deflection is very small. Hence, it can be said that the optimum position is at a distance of 0.5H when a single outrigger and single OBT system are used. But when the top is fixed the next optimum position of the outrigger is at a distance of 0.44 times the height of the building. Thus, in summary, it can be concluded that the optimum position of these systems varies from 0.44 to 0.5H.

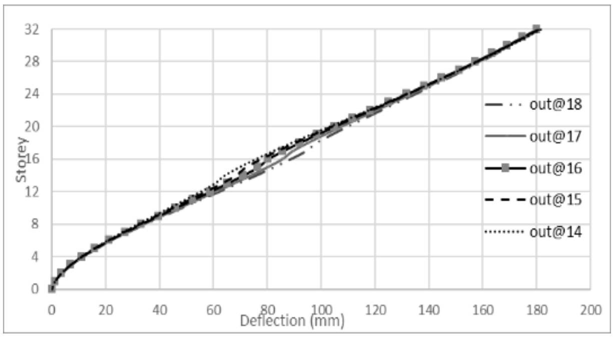

Figure 17 Storey Vs lateral deflection to find final outrigger position

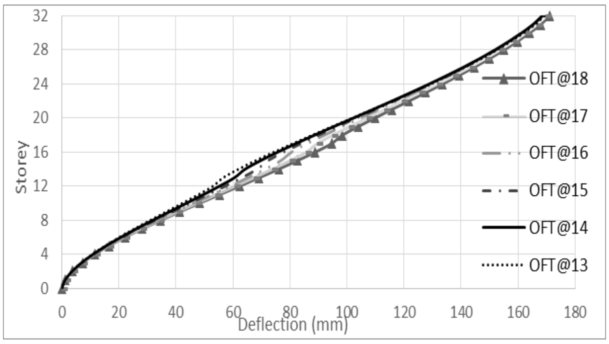

Figure 18 Storey Vs lateral deflection to find final outrigger optimum position with cap

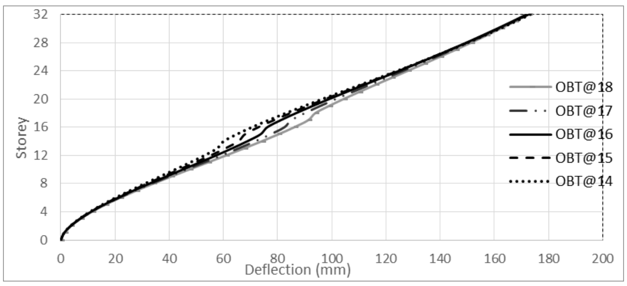

Figure 19 Storey Vs lateral deflection to find final OBT optimum position

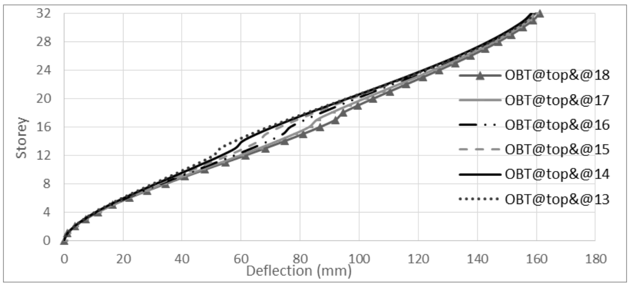

Figure 20 Storey Vs lateral deflection to find final OBT optimum position with cap OBT

Storey Drift

Story drift is the lateral displacement of one level relative to the level above or below. The story drift ratio is the story drift divided by the story height.

The **Error! Reference source not found.**Figure 21 to 24 show the effect of providing outriggers and OBT in reducing the inter-storey drifts of a building. It is known from the figures that for all the cases, there is a maximum reduction in drift where the outriggers and OBT systems are introduced. The higher the position of the outrigger lower the storey drift ratio at the top. Also providing the outrigger at the top reduces the top-storey drift for any position of the outrigger and OBT system. The top curve tries to converge at a single point in this system.

In all, maximum storey drift is observed in the cantilever structure. When the outrigger is used at any position the inter-storey drift is decreased. This outrigger reduced the drift at the top and at the level of the outrigger. The inter-storey drift at the base of the structure is zero. The inter-storey drift is reduced by 49.24% when the outrigger is used at the top as seen from Figure 21. But it is not able to reduce the deflection at the lower levels of the building by a large amount. It almost follows the cantilever drift index curve below the middle height of the building. The overall inter-storey drift of the building is reduced when the outrigger is used at the position of 16. It is capable to reduce the overall drift of the building below and above the outrigger position in a uniform manner. For other positions of outrigger, there is no such uniformity seen in reducing the inter-

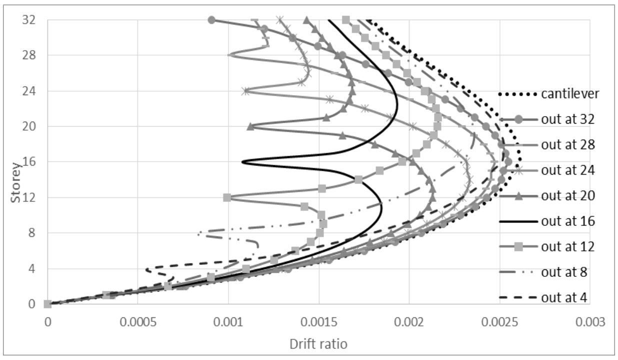

Figure 21 Storey drift index with outrigger

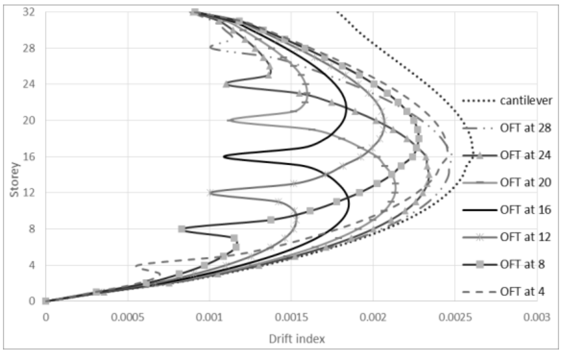

Figure 22   Storey drift index with outrigger and cap truss

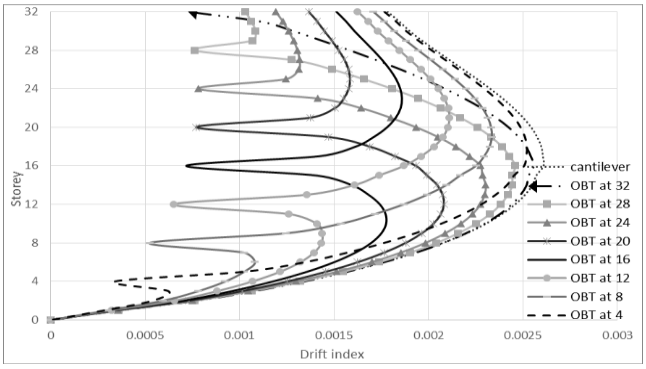

Figure 23 Storey drift index with OBT

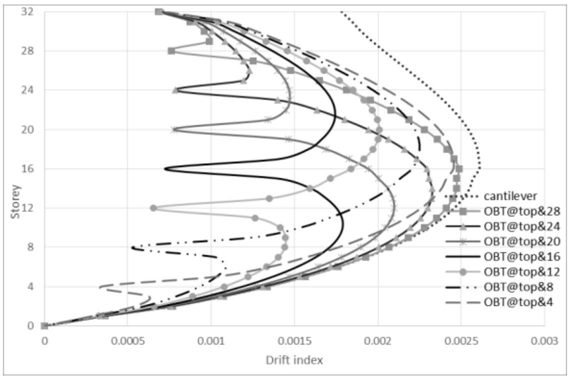

Figure 24 Storey drift index with OBT and Cap OBT

storey drift.

So, storey 16 can be taken as an optimum position to reduce the storey drift of the structure. At storey 16 the reduction in building drift at this level is 59%. Storey 16 also reduced the top storey drift by 13%.

The storey drift of One outrigger fixed at the top and the next variable at various positions of the building is shown in Figure 22. When the top is fixed, the storey drifts at the top was reduced and almost converge to a single point for any position of the next outrigger. The top drift was reduced by more than 50% when the outrigger was used at any position of the building. There is a uniform reduction in the drift when the outrigger was a storey 16. At the level of storey 16, the reduction in storey drift is 59% at that level when compared to the cantilever structure.

Figure 23 shows that the plot of storey versus storey drift index when only the OBT system is kept at various levels of the building. Similar to the outrigger system when only OBT is kept at various levels of the building there can be seen diverged inter-storey drift curve at the top of the building. There is more reduction in the inter-storey drift at each level of OBT than shown in Figure because it utilized the peripheral columns to reduce the drift of the storey. The reduction in the drift at the top when the outrigger is at a storey level of 16 is found to be 60%. It reduced the storey drift at storey 16 by an amount of 72.32% when compared with the cantilever structure. The reduction in inter-storey drift is more than 60% at any level of OBT.

Figure 24, shows the plot of storey vs maximum drift index after one OBT is fixed at the top and the next OBT is variable at various storeys of the building. When one OBT is fixed at the top then it helped in reducing the top drift and all the OBT system drift was reduced to almost a single point. It reduced the top-storey drift by more than 62%. At the level of 16, the drift was reduced by 72.5%.

From the above figures, it can be interpreted that the system with a top fixed can reduce the inter-storey drift more than without the system having a top fixed. The other position where the outrigger is variable except at the top is similar in reducing the drift. Similar is the result with OBT fixed and not fixed at the top. Hence from the figures, we can conclude that the OBT system is far better than the outrigger system for reducing the inter-storey drift of the building. The top fixed system reduces the storey drift at any level by a small amount than the top, not fixed condition. Hence from the figure, it can be confirmed that the lateral stiffness of the building and lateral stiffness of the storey is increased which has ultimately reduced the storey drift by a large amount.

System optimization

On further varying the position of the outrigger and OBT above and below storey 16, the obtained storey drift results are as follows (Figure 25 to 28); the results are given in Table 4.

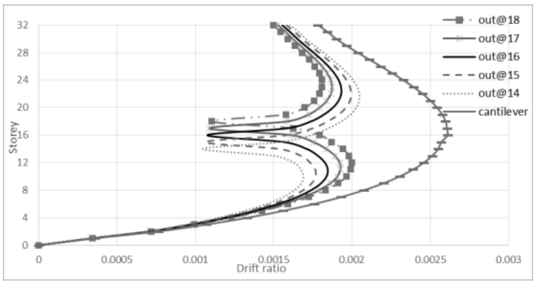

Figure 25 Storey drift index with outrigger for optimization

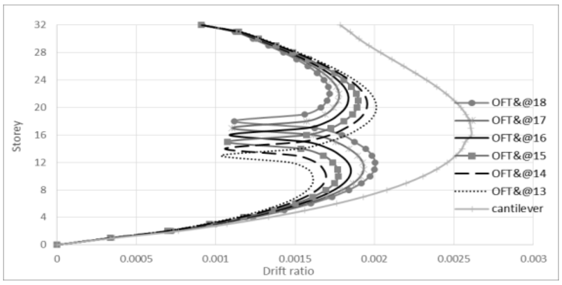

Figure 26 Storey drift index of outrigger with cap truss for optimization

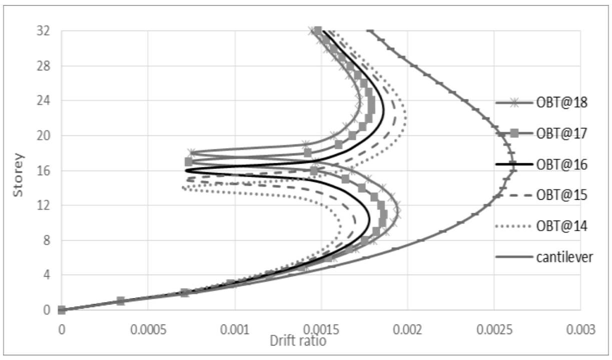

Figure 27 Storey drift index with OBT for Optimization

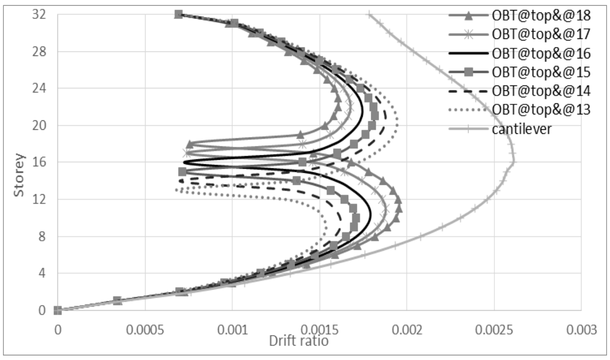

Figure 28 Storey drift index with cap OBT and OBT for optimization

Table 4 Storey drift with various systems for optimization

Storey	Drift ratio		difference	% reduction
	cantilever	Outrigger		
story18	0.002597	0.001106	0.001491	
story17	0.002605	0.001091	0.001514	
story16	0.002609	0.001087	0.001522	58.34
story15	0.00257	0.001062	0.001508	
story14	0.00255	0.001048	0.001502	

Storey	Drift ratio		difference	% reduction
	cantilever	Outrigger with cap truss		
story18	0.002597	0.001116	0.001481	
story17	0.002605	0.001102	0.001503	
story16	0.002609	0.001077	0.001532	58.72
story15	0.00257	0.001072	0.001498	
story14	0.00255	0.001058	0.001492	

Storey	Drift ratio		difference	% reduction
	cantilever	OBT		
story18	0.002597	0.000748	0.001849	
story17	0.002605	0.000732	0.001873	
story16	0.002609	0.000722	0.001887	72.32
story15	0.00257	0.000706	0.001864	
story14	0.00255	0.000692	0.001858	

Storey	Drift ratio		difference	% reduction
	cantilever	OBT with cap truss		
story18	0.002597	0.000753	0.001844	
story17	0.002605	0.000738	0.001867	
story16	0.002609	0.000717	0.001892	72.52
story15	0.00257	0.000711	0.001859	
story14	0.00255	0.000697	0.001853	

Fluctuating the Outrigger and OBT system with and without top fixed condition as seen from the optimization graphs there is a uniform reduction in storey drift at storey 16. Hence from these data storey, 16 can be considered as an optimum storey to reduce the storey drift of a building. Storey 15 and storey 17 also tried to show a similar result but their uniformity is less than that of storey 16.

The optimum position by deflection criteria, when the outrigger and OBT system was variable, was found to be at storey 16. Also, when their top is fixed the optimum position is found to be at storey 14. From inter-storey drift criteria, the optimum position of all the systems was found to be at storey 16. But if both the deflection and drift are considered then storey 16 can be considered as the optimum position which can show efficient performance for all the systems. Therefore, the optimum position lies at a distance of 0.5 times the building's height

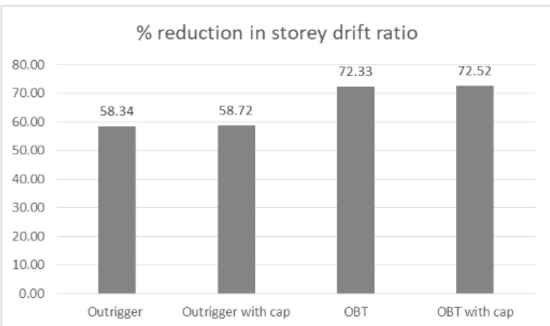

Figure 29 Comparing the systems for reducing storey drift ratio

Comparing the system in terms of reducing the storey drift ratio it can be concluded that the belt truss systems are far better than the outrigger system. Cap truss systems are suitable for reducing the upper-level drift ratio but at the same level, they show the same reduction in an inter-storey drift that is obtained with an outrigger only.

Time Period

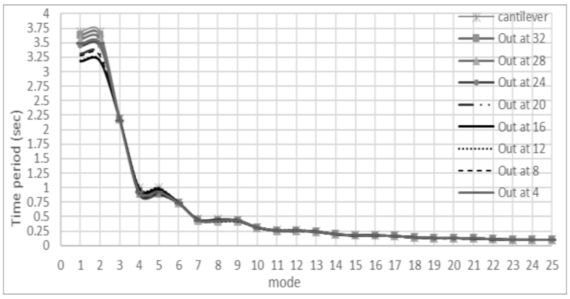

Figure 30 Modal time period with Outrigger

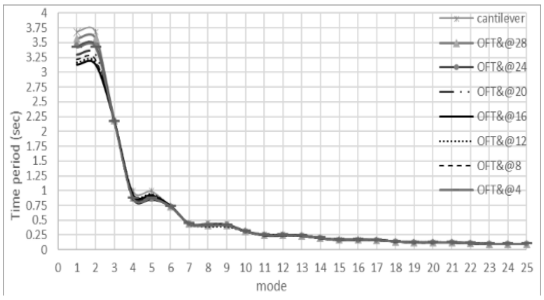

Figure 31 Modal time period Outrigger with Cap

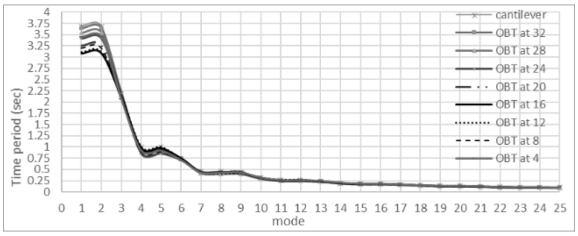

Figure 32 Modal time period with OBT

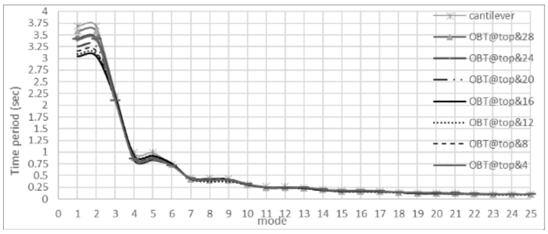

Figure 33 Modal time period of OBT with Cap

As the number of modes increases the time period of oscillation of a building decreases. Altogether 25 numbers of modes have been considered during the analysis of the structure. From the plot of the modal time period, it is observed that the maximum time period of the building has occurred under mode 1 of the building. Further, the time period of the building is reduced when the outrigger is at various locations of it. The maximum modal time period is found for the cantilever structure. It is found to be 3.688 seconds. As a symmetric structure, the modal time period in both directions is the same. So, mode 1 and mode 2 have the same time period. A slight variation might be found in the time period of mode 4 and mode 5. The rest of the remaining mode exhibits similar behaviour..

Figure 30 shows the variation in the modal time period of the building when the outrigger is kept at various stories of it. The minimum time period is found when the outrigger is located at storey 16. The time period reduced by the outrigger at the level of storey 16 and storey 12 is nearly the same. The maximum reduction in the time period is by 0.515 seconds when the outrigger is used at storey 16. The reduction in the time period when the outrigger is at storey 12 is by 0.492 seconds. Therefore, the outrigger at 12 reduced the time period by 13.34% while the outrigger at 16 reduced it by 13.96% than that of the cantilever.

Figure 31 shows the variation in the modal time period when an outrigger is fixed at the top and another is variable. Under the first and second mode outrigger at 12 reduced the time period by 14.1% while the outrigger at storey 16 reduced the time period by 15.05%. Storey 16 and storey 12 show the maximum reduction in the modal time period. When the outrigger is at other storeys the modal time period increases.

Figure 32 shows the variation in the modal time period when OBT is present at various locations of the building. Providing the outrigger at storey 12 reduced the modal time period (mode 1 and mode 2) by 15.32%. Outrigger at 16 reduced the time period by an amount of 15.46%. The maximum time reduction is by outrigger at storey 16 and then it is reduced next by storey 12 by the maximum amount. The outrigger at storey 32 shows the minimum variation in the modal time period.

Figure 33 shows the variation in the modal time period when the building has one OBT fixed at the top and the next is variable at various positions of the building. This system reduced the time period more than the other systems. When the next OBT is at storey 12 it reduced the maximum modal time period by 17.22% and when the OBT is at storey 16 it reduced the time period by 17.32%.

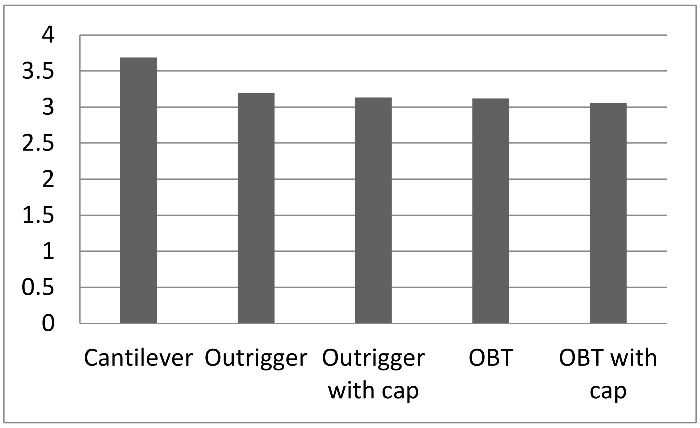

Figure 34 Comparison of the modal time period

There is very less reduction in the time period when the outrigger is at the top of the building. Providing the outrigger and OBT near the middle position reduces the modal time period by a significant amount. Among storey 16 and storey 12, the storey 16 outrigger and OBT system can be considered more beneficial in reducing the modal time period by a maximum amount. Among the systems OBT fixed at the top is considered the most efficient in reducing the time period of the building. The OBT system is better at reducing the modal time period than the outrigger system.

The following shows the system in decreasing order which provides better performance in reducing the modal time period.

OBT fixed at top system > OBT system > outrigger fixed at top system > outrigger system

Base Shear

The value of the base shear of a building is largely affected by the weight. The more the weight of the structure the more the base shear generated. Also, stiffness of the structure also affects the base shear generated. The higher the period of the structure means the more flexible the structure inhibits. A flexible assembly experience lesser acceleration compared with a stiff structure. The flexible structure is difficult to excite, it will have lower base shear compared with a stiff building.

Table 5 Base shear

System	Base Shear(kN)
cantilever	3887.277
Outrigger	3906.0191
outrigger with cap truss	3920.6908
OBT	3925.4195
OBT with cap truss	3971.5684

The weight of the structure is added when the outrigger and OBT system are added to it. So, the base shear is more in the OBT system. Cap truss systems generate high base shear because their weight is also more. From a stiffness point of view, the system without an outrigger and OBT is more flexible than the structure with an outrigger and OBT. The base shear of the OBT system is more than that of the outrigger system. The largest base shear is obtained when the same structure has the highest stiffness. The systems with cap truss show more increase in base shear than without cap truss system (Table 5). It is because the system is being used in two places.

Conclusion

From the above analysis and their result intepretation it can be seen that the lateral stiffness of the building can increased by placing the outrigger at various places. Also, OBT systems are more efficient in increasing the lateral stiffness of the building than the outrigger system. The belt and cap truss system is proven to be better than the outrigger system in reducing deflection. The optimum position of a single outrigger and single OBT is at the mid-height of the building when the criterion for selection is deflection. In the system with a cap truss, lower stories needed to be stiffer and the optimum position is not at the mid-height of the building. It is some distance below the mid-height of the building. The optimum position of the outrigger and OBT with cap truss is at 0.44H of the building when the selection criterion is deflection. Also, two outrigger systems are are more suitable than a single outrigger system. The cap truss helps in reducing the top deflection at the upper level and the next outrigger further helps in reducing the deflection at the places where they are used.

When various outrigger and OBT systems are introduced, they can reduce inter-storey drift by a large amount. In places where outrigger and OBT systems are introduced, inter-storey drift is reduced at the place by a maximum value and it also reduces the inter-storey drift of the whole building. Cap truss systems help in reducing the upper stories drift ratio by a large amount but quite less reduction is seen in lower stories. The optimum position of the Outrigger and belt truss with and without cap truss is at 0.5H of the building when the selection criteria are inter-storey drift.

Outrigger and OBT systems are very useful in reducing the period of a slender structure. The minimum time period occurs at the place of the optimum position of the outrigger and OBT.

With the introduction of the outrigger and OBT the base shear of the building is increased. Increased base shear shows the increment in the stiffness and weight of the structure when the outrigger and belt truss is used.

Recommendation

The construction of taller buildings is the most to eradicate the problem of housing in the core city areas. And it is important to introduce a lateral load-resisting system like an outrigger in such a building. The effect of the earthquake can be minimized using outrigger-type systems at various locations of the building.

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ISSN NO. 2091-1742

SCITECH NEPAL

Journal of Scientific and Technical Studies
Nepal Engineering College, Pokhara University

Research Article

DOI:10.3126/scitech.v17i1.60466

How Effective Is Inter-Basin Transfer to Manage Temporal Variation Of "Too Much" And "Too Little" Water Conditions for Irrigation in a Himalayan Basin?

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Received: April 25, 2023
Accepted: June 2, 2023

Abstract

Better irrigation facilities leading to "more crop per drop" are today's needs. This study examines how the overall water balance of Sunkoshi, Marin, and Bagmati Basins will be altered by implementing the Sunkoshi-Marin Diversion Project (SMDP) to fulfill the unmet demands of the Bagmati Irrigation Project (BIP) in the Bagmati Basin via the Marin Basin in Nepal. The specific objectives are to: i) quantify "too much" and "too little" water peculiar to the study basin based on historical data; ii) evaluate water availability, irrigation water requirement, and deficits with and without SMDP; and iii) provide evidence-based recommendations on the effectiveness of the SMDP considering hydropower generation, irrigation and low- and high-flow conditions. Thirty years of historical daily flow data (two gauging stations) and precipitation data (15 stations) were obtained from the Department of Hydrology and Meteorology. Other spatial input data were acquired from relevant authorized sources. Water availability has been estimated using flow at the diversion sites while the irrigation requirements have been calculated based on secondary information. Results show that additional water is not at all required for Marin and Bagmati Basins in the monsoon season. Rather, the diverted water increases the flood hazard. Moreover, the contribution of hydropower from SMDP to the national energy demand is insignificant in the monsoon. However, the SMDP was found to play an important role in meeting the irrigation deficits during the dry season. Its contribution to hydropower production in the lean period is also commendable. However, the proposed irrigation requirement of the BIP cannot be met even after the implementation of the SMDP. More importantly, there is a high probability of the intended diversion flow not being available in the Sunkoshi River (donor) which could have severe consequences downstream. Therefore, additional options for conjunctive use need to be explored.

Keywords: Irrigation; water management; inter-basin transfer; Nepal Himalaya; Sunkoshi-Marin Diversion Project

Introduction

Water is different from other natural resources because of its need for sustaining life, primarily for drinking and agriculture. With increasing population and urbanization, water is sure to be highly stressed in the future (ben Fraj et al., 2019; de Andrade et al., 2011; Veena et al., 2021). Water scarcity is a critical constraint to food production and a major cause of poverty and hunger globally. Climate change is projected to add to this global problem (Essenfelder & Giupponi, 2020; Ma et al., 2021). Thus, "more crop per drop" has become today's need. The developed world is relatively better off because of available technologies and resources in coping with the possible future impacts of water scarcity (de Andrade et al., 2011; Dickson & Dzombak, 2017). However, the developing world generally lacks the technology, expertise, and financial capabilities to withstand such impacts (Devkota et al., 2020; Devkota et al., 2017; Jalilov, 2021).

Some regions of the world face high temporal variability of water. For example, the annual average precipitation of Nepal is about 1800 mm (DHM/GoN, 2017). However, nearly 80% of this occurs in the four monsoon months (June-September) whereas the remaining 20% is spread out over the other eight months. This peculiar seasonal variation is also reflected in the flow of Nepalese river basins (Devkota & Gyawali, 2015; Devkota et al., 2020; Marahatta et al., 2021). As a result, problems of floods, landslides, and other water-induced disasters are common in Nepal during the monsoon months. This indicates "too much" water. On the contrary, water available during the dry months is insufficient to meet the various competing demands (Amjath-Babu et al., 2019; Bastakoti et al., 2017). This is a condition of "too little" water. Regulation of the surplus water from the monsoon to manage the water uses in the dry period in an economic way can be effectively achieved through storage projects within a basin (Bharati et al., 2016; Chinnasamy et al., 2015; Liu et al., 2019; Marahatta et al., 2022).

On the other hand, when there is spatial variation in the water availability and usage across river basins, inter-basin transfer has proven to be an effective water management technique, especially for arid regions. For example, de Andrade et al. (2011) discuss the Sao Francisco River trans-basin diversion in Brazil. Essenfelder & Giupponi (2020) used hydrological modelling and machine learning to examine how the water balance of the Dese-Zero River Basin in Italy is altered by inter-basin water transfer. ben Fraj et al. (2019) studied the politics of inter-basin water transfers focusing on the socio-environment considering the diversions from the north (Medjerda and Ichkeul basins) to the southern region and from the center to the coast in Tunisia. Smith & Shah (2020) and Woo et al. (2021) examined the potential impacts of inter-basin water transfer on water quality in the USA and South Korea respectively. However, due to the limited availability of resources and other constraints, inter-basin transfer in Nepal is in its infancy. The

Kulekhani hydropower Project (commissioned in the early 90s) diverting water from Bagmati to Narayani Basin, the Melamchi inter-basin transfer project (under construction) for augmenting drinking water supply to Kathmandu (the capital city) and Bheri-Babai diversion (under construction) for irrigation purposes are some notable examples. However, Madi-Dang diversion, Sunkoshi-Kamala diversion, Naumure-Kapilvastu diversion, and Sunkoshi-Marin diversion are some projects that have been planned for the future but are still in the study phases.

Interestingly, Veena et al. (2021) point out that the annual volume of global inter-basin water transfer of 2005 is expected to nearly double by 2025. Similarly, a study in the USA reported more than 2000 inter-basin water transfer schemes of varying magnitudes in the USA in 2017 (Dickson & Dzombak, 2017). Although the world witnessed the development of a large number of inter-basin water transfer projects, concerns have been raised over pressing issues such as water resource imbalances, water quality, socio-environmental impacts, and large construction and maintenance costs.

Among the various planned water resources development projects in Nepal, the Sunkoshi-Marin Diversion Project (SMDP) is an inter-basin transfer project that has been prioritized by the Government of Nepal (GoN). The project is past its detailed design stage and its construction has been initialized. This project diverts water from an adjoining donor (Sunkoshi) basin for irrigating the Bagmati Irrigation Project (BIP), one of the largest irrigation schemes in Nepal with a proposed command area of 122,000 ha (DOI/GoN, 2016). The GoN has planned to divert 77 m^3/s year-round from the Sunkoshi Basin to the Bagmati Basin (where the BIP is located) via the Marin Basin (Figure 1). This study aims at analyzing the viability of the SMDP with regard to its ability to manage the “too much” and “too little” water conditions of the areas under consideration.

The specific objectives of the study are:

i) To quantify “too much” and “too little” water peculiar to the studied basins in the Nepal Himalayas considering historical data;

ii) To evaluate water availability, irrigation water requirement, and deficits for the current and future conditions with and without SMDP; and

iii) To provide evidence-based recommendations on the effectiveness of the SMDP considering irrigation, hydropower generation, and low and high flow conditions.

Materials and Methods

Study Area

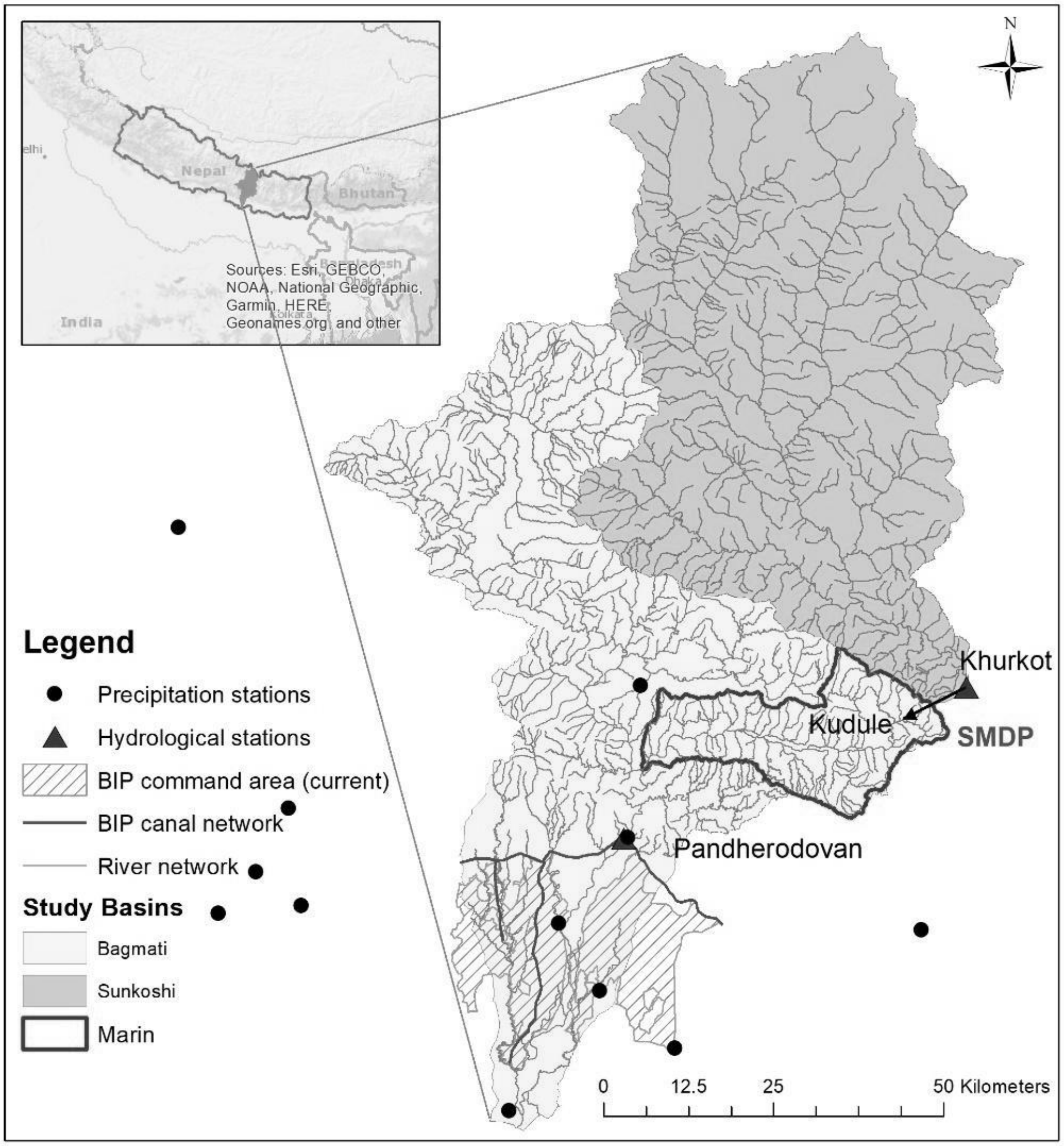


Figure 1: Location map of the Bagmati Basin, Sunkoshi Basin, and Marin Basin. BIP: Bagmati Irrigation Project; SMDP: Sunkoshi-Marin Diversion Project

The Bagmati Basin, Marin Basin, and Sunkoshi Basin are located in the central and eastern parts of Nepal in the central Himalayan region (Figure 1). The catchment areas of Bagmati Basin at Pandherodovan, Marin Basin at its confluence with the Bagmati River, and Sunkoshi Basin at Khurkot are 2700, 544, and 10209 km^2 respectively (DOI/GoN, 2016). The Bagmati Basin can be divided into three distinct regions, namely, upper (high hills including densely populated urban areas), middle (very sparsely populated forested areas in the lower hills), and lower (flat agricultural land extending up to the Indo-Gangetic plains) (ADB, 2015). The Bagmati Irrigation Project (BIP) is located on the lower part of the Bagmati Basin. It has been designed to currently irrigate 42,000 ha of cultivable land in the plain areas of Nepal with the intakes located near the Pandherodovan gauging station. The Marin River is a tributary of the Bagmati River and is situated in the lower hills of Nepal. It lies in a high precipitation zone with annual values over 2500 mm (DWIDP/GoN, 2009). The annual discharge of the Marin River just before the confluence with the Bagmati River is about 22 m^3/s (DWIDP/GoN, 2009). The SMDP is designed to divert water from the Sunkoshi River (at Khurkot) to the Marin River (at Kudule) through a 13 km-long tunnel to meet the irrigation demands of the BIP.

Methodology

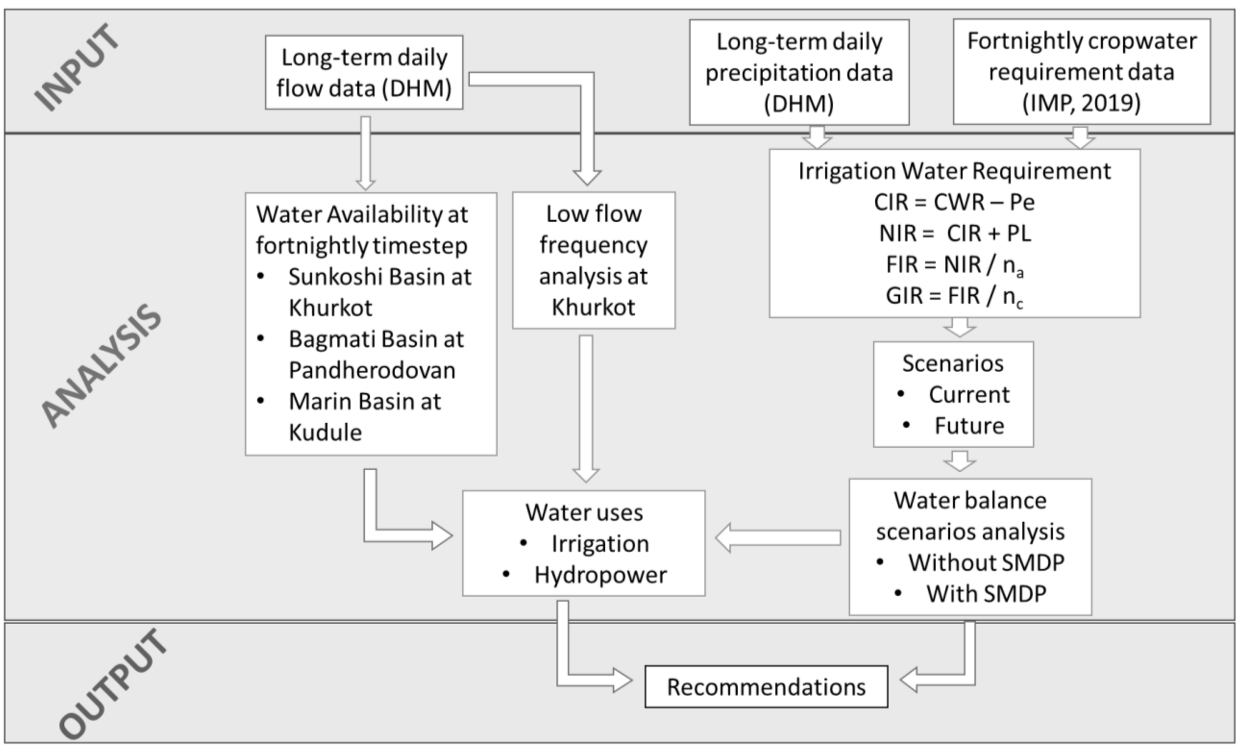


Figure 2: Flowchart of the overall methodology. DHM: Department of Hydrology and Meteorology; IMP: Irrigation Master Plan; Pe: Effective precipitation; CWR: crop water requirement; CIR: consumptive irrigation requirement; NIR: net irrigation requirement; FIR: field irrigation requirement; na: application efficiency; GIR: gross irrigation requirement; nc: conveyance efficiency; SMDP: Sunkoshi-Marin Diversion Project

This study analyses how effective the SMDP shall be considering the water availability and demands of the study basins. The overall research methodology is presented in Figure 2. Historical daily flow data of Khurkot (in the Sunkoshi Basin) and Pandherodovan (in the Bagmati Basin) stations of 30 years (1986-2015) was collected from the Department of Hydrology and Meteorology (DHM), GoN. There is no gauging station along the Marin River. The catchment area of the Bagmati River at Phadheredovan and at the powerhouse site (Kudule) of the SMDP are respectively 2700 and 129 km^2. Flow in the Marin River at the confluence with Bagmati River was transposed using the catchment area ratio method considering Pandherodovan as the base station. Water availability was assessed at Khurkot, Marin at its confluence with Bagmati River and at Pandherodovan at fortnightly timesteps. Additionally, low flow frequency analysis was carried out by fitting Gumbel distribution to monthly flow at the Sunkoshi-Marin diversion site for each month. Monthly low flows were estimated for 5-, 10- and 20-year return periods.

Water uses, namely, irrigation and hydropower, for the considered basins, were evaluated for the current as well as future scenarios. Long-term observed daily precipitation data from 13 stations for the lower Bagmati Basin and five stations of the Marin Basin was used to calculate effective precipitation. Crop water requirements for the Marin, as well as the Bagmati basins, were estimated considering the cropping pattern and intensity based on the recommendations of the Irrigation Master Plan by GoN (DoWRI/GoN, 2019). Percolation loss was taken as 10% of the consumptive irrigation requirement, conveyance efficiency as 70% and application efficiency 70% for the dry season and 85% for the monsoon season (Punmia et al., 2009), and the gross irrigation water requirement (GIR) was calculated. The design discharge, effective head, and overall efficiency for the hydropower project were taken from DOI/GoN (2016). Environmental flow for downstream release has been considered as 10% of the minimum of the monthly flows (MoEWRI/GoN, 2001). The ratio of the irrigable to agricultural land for the Marin basin was assumed 0.4 which has been prescribed by the DOI/GoN (2007) for the hills of Nepal. The current scenario refers to the case of the existing irrigated areas of the BIP while the future scenario deals with the planned expansion of its irrigated command area with and without SMDP. Recommendations were made regarding the applicability of the SMDP based on the results of the analysis.

3. Results and Discussion

3.1. Low-flow Analysis of Sunkoshi River

Average long-term monthly flows, estimated low-flows of 5-, 10- and 20-year return periods, and SMDP diversion at Khurkot are shown in Figure 3. It can be seen that there is a probability of failing to meet the proposed diversion flow even once in five years for February, March, and April. Further, there is a high probability of failing to meet this requirement for all the months of the dry period (December-May) once in 20 years. This is exactly what Marak et al. (2020) and Rollason et al. (2021) have warned pointing out that although inter-basin water transfer has been seen to be temporarily effective, its sustainability is not assured because of the dynamic hydrology. Additionally, Du et al. (2020) and Liu et al. (2019) question the downstream impacts on the river flow and its environment which will be largely altered by the water diversion. This will have a long-term impact on the overall hydrology as well as the biotic and abiotic components of the environment. Thus, it is evident that when environmental flow releases and existing downstream water uses are additionally considered, the year-round diversion of 77 m^3/s from the Sunkoshi River at Khurkot is to be revisited.

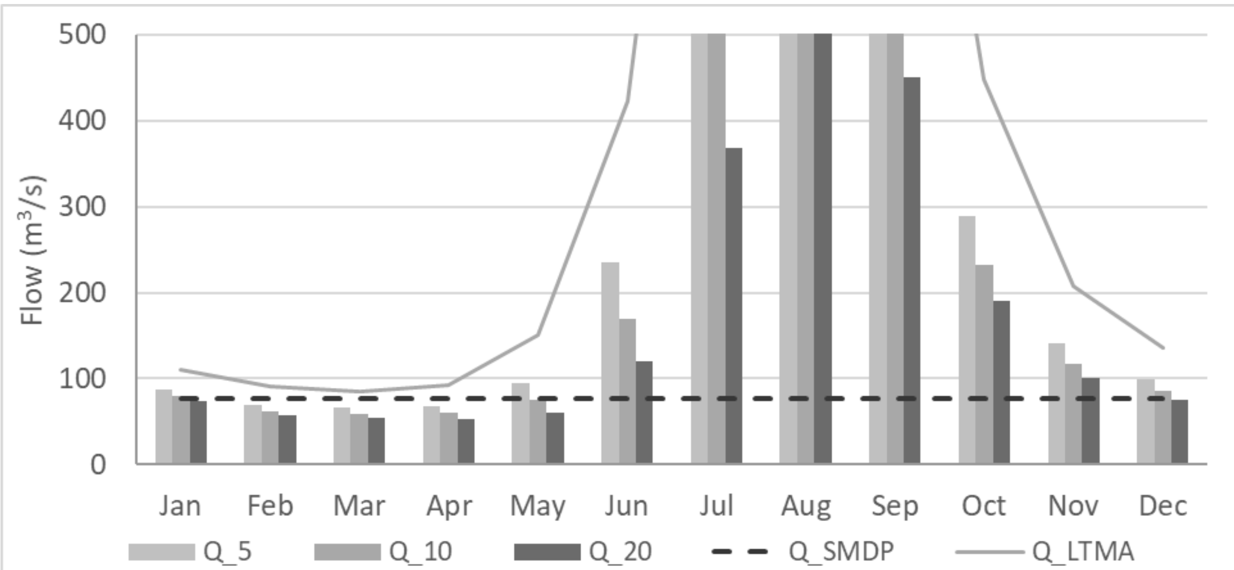


Figure 3: Monthly low flow analysis of Khurkot (SMDP diversion site) in the Sunkoshi River. Q_5, Q_10 and Q_20 refer to the flows of 5-, 10- and 20- years return periods respectively; Q_SMDP is the proposed year-round diversion flow (77 m3/s); SMDP: Sunkoshi-Marin Diversion Project; Q_LTMA is the long-term average monthly flows; high flows have been truncated to zoom in on low-flows.

3.2 Power Generation

Although the major reason for implementing the SMDP is augmenting irrigation, the GoN has also envisioned generating 40 MW of hydropower by constructing a run-of-the-river (ROR) project from a net head of 61 m and design discharge equivalent to the diversion discharge of 77 m^3/s including flushing discharge (DOI/GoN, 2016). Our analysis found that generation of 40MW of power is possible from May to October, that is during the monsoon assuming that the design discharge and other physical conditions remain the same. However, the targeted power generation cannot be met by the hydropower project in almost 40% of the time in March and about one-third of the time during February and April. In some months, the possible power generation is as low as 18 MW (Figure 4). It is interesting to note that power generation is maximum in the case of January and November almost throughout the analyzed period with only a very few incidents generating less than 35 MW. This uncertainty due to the variable hydrology is to be duly considered while fixing the power generation capacity of this project. Furthermore, Nepal is a ROR hydropower-dominated country with a current total installed capacity of about 1396 MW out of which ROR installed capacity is 1304 MW (~93%) (NEA/GoN, 2021). Generating hydropower from the diverted water contributes to meeting the national energy demand during the dry period of the year to some extent. However, it has very little significance from the power generation point of view during the monsoon and post-monsoon seasons in which almost all the ROR projects throughout the country are operating at their full capacities (Devkota et al., 2022; Marahatta et al., 2022). Furthermore, the operation of the hydropower project during the monsoon amplifies the flood risk in the downstream areas with the additional discharge and increases the likelihood of damage to the turbine blades. Developing countries have not been able to construct such inter-basin transfers in large numbers mainly because of financial and technical resource limitations (Annys et al., 2019; Jalilov, 2021). Therefore, investing a huge capital in the hydropower project (about USD 4500/kW) (Best, 2017) to be operated for dry season benefit only also needs to be a serious point of consideration before finalization of the project in the best interest of the nation.

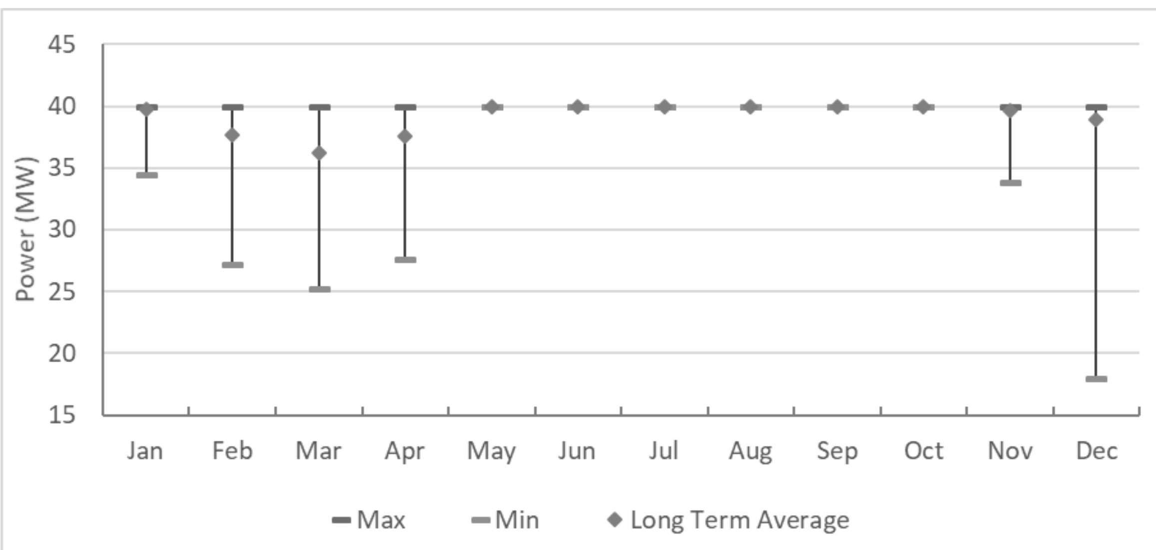


Figure 4: Variation in power generation from the proposed Sunkoshi-Marin Diversion Project

3.3 Impact of Floods on Marin Basin

The historical one-day maximum flood peak at Padherodovan is 7,550 m^3/s. Transposing this to the proposed hydropower project site (Kudule) in the Marin River using the catchment area method, it comes out to be 360 m^3/s. It is witnessed that the frequently occurring floods are creating problems of inundation to adjacent agricultural land. It is to be noted here that Marin Basin lies in a rain-pocket area, and it is located in the Siwalik range. As a result, erosion and sediment issues are already prominent in this basin, particularly during the monsoon. GoN has been desperately carrying out a lot of river training works to mitigate the associated flood impacts. With an addition of another 77 m^3/s (which is more than 20% of the maximum value) from Sunkoshi in the monsoon, the flooding situation will be aggravated. Moreover, riverbed scouring and riverbank erosion will also increase as an impact of the added runoff in the river. Hence, these issues need careful attention. Thus, diversion of water from the Sunkoshi River during the monsoon season is detrimental to the Marin Basin from floods, erosion and sedimentation points of view.

3.4 Water Balance

Water Availability

The long-term annual average flow of the Marin River at Kudule and Bagmati River at the BIP intake site are respectively 6 and 127 m^3/s. Similar to the condition of most Nepalese rivers, in the Marin and Bagmati too, about 80 percent of the flow occurs during the four months of monsoon (June – September) and only about 20 percent is available for the remaining eight months (Figure 5). The critical dry period, that is from December to May, has about 8% of the flow with the minimum flow occurring in March.

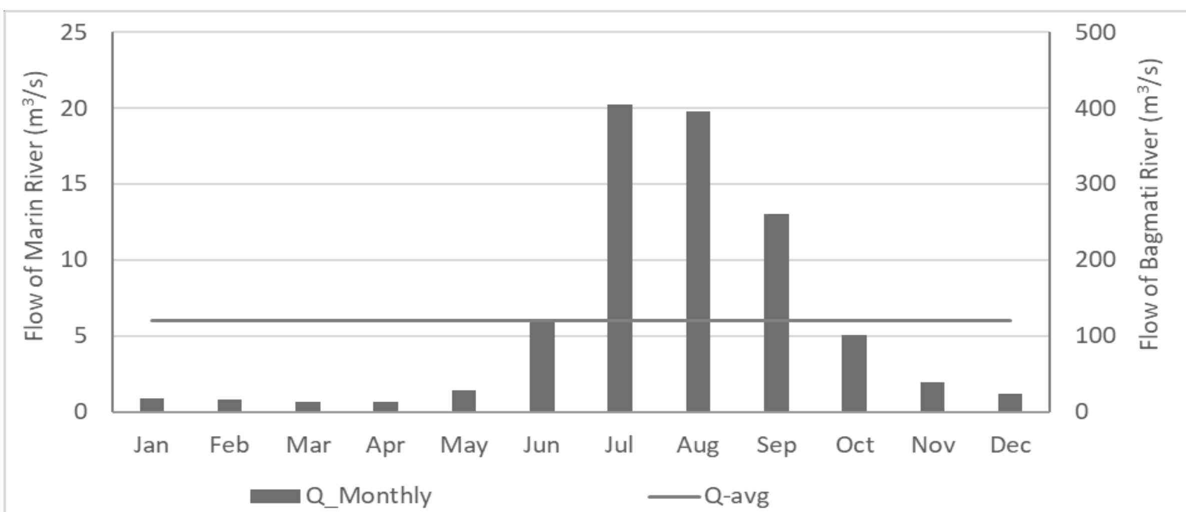


Figure 5: Long-term flow variation of Marin and Bagmati Rivers. Q_monthly: average monthly flow; Q-avg: average annual flow

Irrigation Water Requirement and Deficit

a) Marin Basin

The Gross Irrigation Requirement (GIR) for 2146 ha of irrigable land of the Marin basin and the estimated flow available in the Marin River at fortnightly intervals is shown in Figure 6. Water deficit period has been marked as the time in which the GIR exceeds the availability of river flow. It can be seen from the plot that the deficit period lasts from the second half of October to the first half of May.

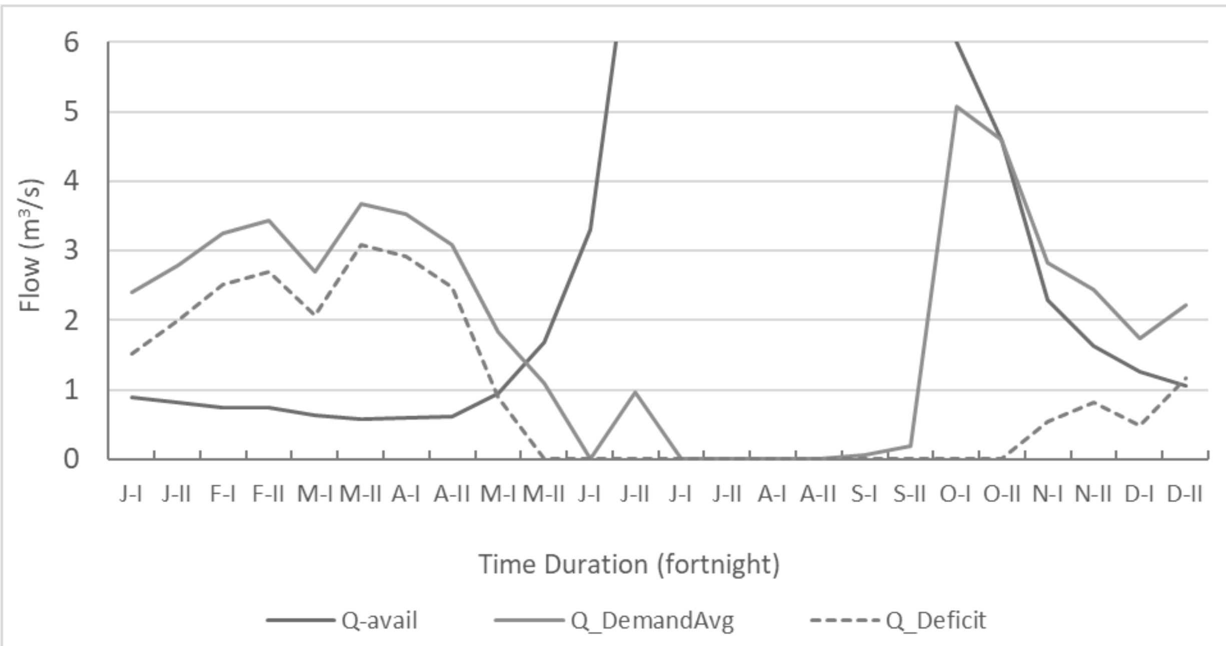


Figure 6: Average fortnightly flow availability required for year-round irrigation and deficit in Marin Basin. Q_avail: available long-term average flows; Q_DemandAvg: average gross irrigation requirement; Q_Deficit: irrigation water deficit; high flows have been truncated to zoom in on low-flows.

Analysis of the 30 years' data shows that deficits in irrigation water vary among the months of a year and also inter-annually. The variation is maximum in the second half of October. However, maximum deficit of 3.67 m^3/s is seen in the first half of April. The monsoon months do not witness any such deficit except a very small amount in the second half of June.

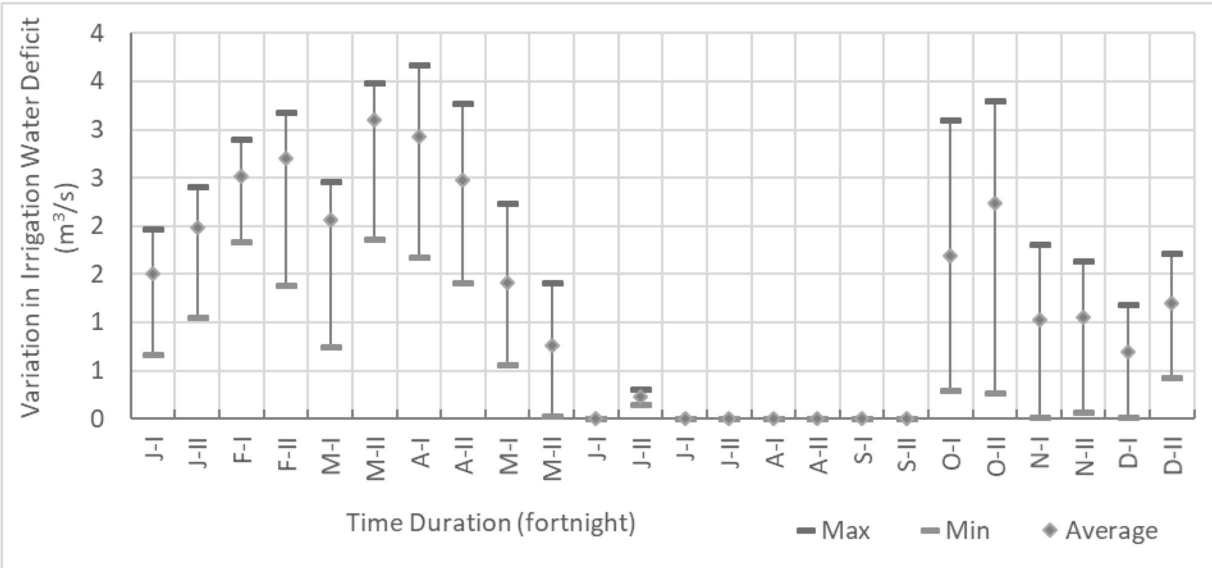
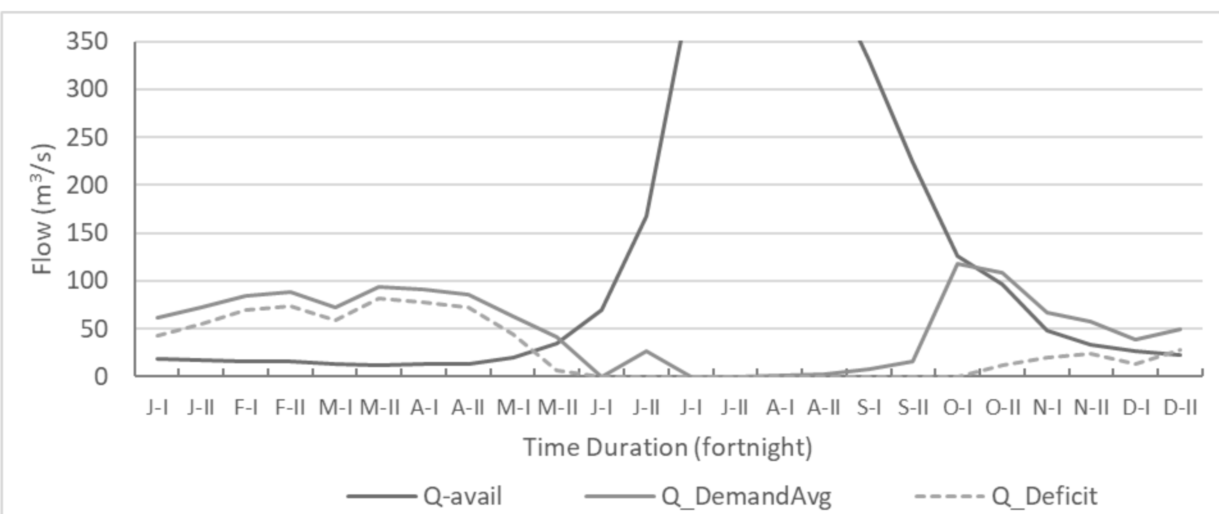


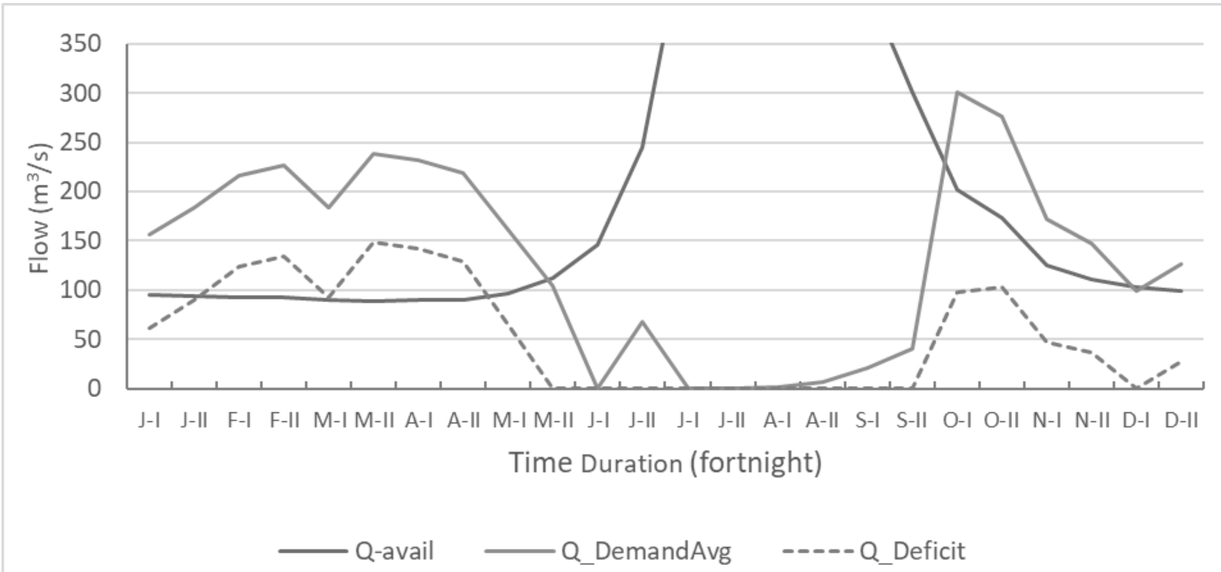
Figure 7: Average fortnightly irrigation water deficit and its variability in the Marin Basin

b) Bagmati Basin

The current irrigable area of the BIP is 47,700 ha while the proposed area to be irrigated after Sunkoshi-Marin Diversion is 122,000 (DOI/GoN, 2016). GIR was computed for these two phases ("Without SMDP" and "With SMDP") based on crop water requirement for BIP command area from (DoWRI/GoN, 2019). Long-term average of the water available for irrigation, GIR and water deficit is shown in Figure 8.



a) “Without SMDP” scenario (current irrigable area of BIP: 47,700 ha)

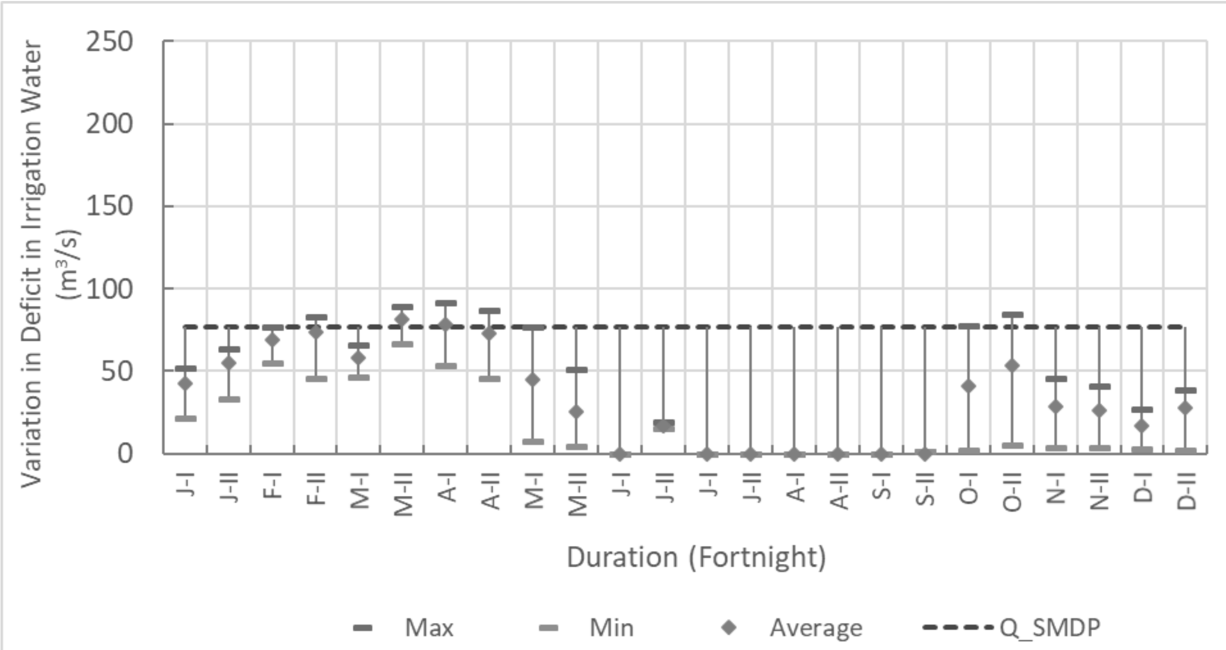


b) “With SMDP” scenario (propose irrigated area of BIP after SMDP: 122,000 ha)

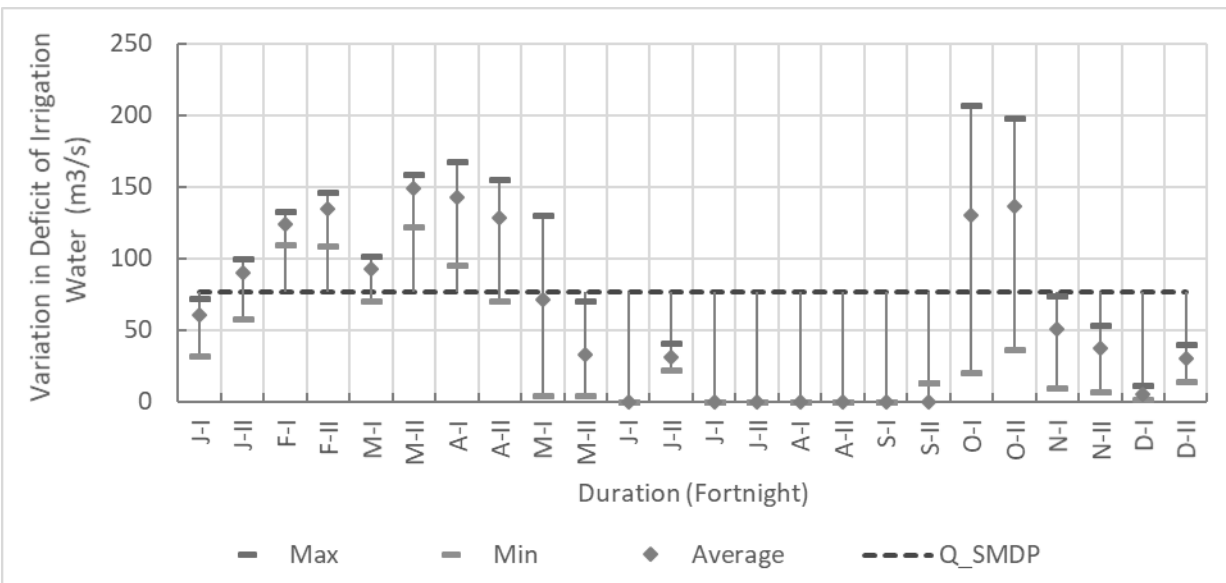
Figure 8: Average fortnightly flow availability required for year-round irrigation and deficit in Bagmati Basin a) “Without SMDP” scenario and b) “With SMDP” scenario. BIP: Bagmati Irrigation Project; SMDP: Sunkoshi-Marin Diversion Project; Q-avail: average available flow; Q_DemandAvg: average irrigation demand; Q_Deficit: average unmet demand. High flows have been truncated to zoom in on low flows.

Figure 8a shows that irrigation water deficit of the “Without SMDP” scenario which begins from the second half of October until May, with the highest deficit of up to 81 m^3/s, occurring in March's second half. However, it begins from the first half of October up to May first half in case of “With SMDP” scenario (Figure 6b). The maximum deficit in this scenario also occurs in the second half of March (149 m^3/s), similar to the “without SMDP” case.

The variation in water deficits for “Without SMDP” and “with SMDP” are shown in Figures 9a and 9b respectively. The water deficit for “Without SMDP” ranges (difference between maximum to minimum in a given period) from zero during the monsoon period to 80 m^3/s in the second half of October. The maximum deficit is more than 90 m^3/s (second half of April 1992). In case of “With SMDP”, the maximum range is 186 m^3/s occurring in the first half of October and the maximum deficit of 206 m^3/s also in the first half of October (in 2000).



a) "Without SMDP" scenario



b) "With SMDP" scenario

Figure 9: Average fortnightly irrigation water deficit and its variability in the Bagmati Irrigation Project command area. Q_SMDP: proposed year-round diversion from the Sunkoshi-Marin Diversion Project

Further from Figure 9a, we can see that five fortnights (February II, March II, April I and II, and October II) out of the 24 have a maximum deficit greater than 77 m^3/s. Almost 10% of the 720 fortnightly periods of the 30-year analysis duration (30*24=720) have water deficit more than the amount of flow diverted to the Marin Basin from Sunkoshi River. The diverted water cannot meet the water deficit for 10% of the time, even in the "Without SMDP" scenario. The condition is more severe for the "With SMDP" scenario. The deficit exceeds 77 m^3/s for more than one-third (35%) of the considered time horizon. This can be observed from the second half of January to the first half of May and the first and second halves of October (10 out of 24 fortnights). These values indicate that it is not sufficient for the BIP to solely rely on the SMDP to fulfill its current and future unmet demands. Additional options for conjunctive use such as with groundwater in the Terai areas of Nepal need to be explored. Conjunctive use of water in addition to inter-basin transfers has been seen to be successful in other parts of the world, for example in China (Ma et al., 2021). Furthermore, as rightly pointed out by Akron et al. (2017), there is doubt over such transfer projects being economically feasible in the long run. Moreover, the active involvement of multiple stakeholders to minimize the associated socioeconomic impacts due to such large-scale diversion projects is of utmost importance (Veena et al., 2021). Therefore, there are still mixed reactions in favor of and against the implementation of the SMDP at the community, national and implementation levels.

4. Conclusion and Recommendations

This study analyzed how the overall water balance of the Sunkoshi Basin, Marin Basin and the Bagmati Basin will be altered because of the Sunkoshi-Marin Diversion Project (SMDP) which is on the priority list of the Government of Nepal. Seasonal assessment of water availability in these river basins were carried out using historical flow data. Irrigation water requirement was calculated using historical precipitation data and other spatial secondary information. The impacts of the inter-basin water transfer on irrigation deficit and hydropower were evaluated at fortnightly timestep.

It was seen that additional water is not at all required for Marin and Bagmati Basins in the monsoon season because "too much" is already available during this time. Rather, the diverted water is likely to increase the flood hazard of the Marin River. Moreover, this diversion has an insignificant contribution to the national energy demand during the monsoon through hydropower generation which is a by-product of this project. On the other hand, the SMDP has been found to be of great value in meeting the irrigation deficits in the command areas of both the Marin and Bagmati basins during the dry season because of "too little" water during this time. Its contribution to hydropower production in the lean period is also commendable. However, the proposed irrigation requirement of the BIP cannot be met even after implementation of the SMDP. And more importantly, there is a high probability of not even having the intended diversion flow available in the Sunkoshi River which could have severe consequences downstream. Therefore, firstly, the magnitude of the diversion flow needs to be re-assessed. Secondly, additional options of conjunctive use such as with groundwater in the Terai areas of Nepal need to be explored by GoN in order to fulfill the unmet irrigation demand of the BIP during the dry period.

Furthermore, diverting water in the dry season only and shutting down or partially operating the project in the monsoon season could be a management option for dry season unmet demand minimization, increasing the project life of the SMDP and flood risk reduction in the study basins.

Thus, designing the SMDP project relying only on the historical observed data is seen to be very risky. Development and application of a robust decision support system with a strong model-base to optimize the available water amongst the competing uses by minimizing the unmet demand is highly recommended in this context. Contrary to the project-by-project approach, an integrated basin management approach is more effective in terms of evaluating the upstream-downstream impacts of this inter-basin diversion project. Finally, incorporating the impacts of climate change on the hydrology as well as crop modelling of the study basins could be potential areas of future research.

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ISSN NO. 2091-1742

SCITECH NEPAL

Journal of Scientific and Technical Studies
Nepal Engineering College, Pokhara University

Review paper

DOI:10.3126/scitech.v17i1.60467

Critical Success Factors of Agile Software Development - A Systematic Literature Review

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Received: April 20, 2023
Accepted: October 10, 2023

Abstract

Agile software development has gained more popularity due to its capacity to manage constantly changing needs and generate high-quality software in less time. However, several success factors are required for an agile project to succeed. Agile development technique, delivery strategy, project team training, customer and staff involvement, management commitment, organizational culture, communication, and project management process are critical success factors (CSF) discovered in this study. This study's goal is to locate and evaluate these crucial elements of the agile software development methodology's success. A systematic literature review was conducted to study and analyze the previous studies to identify the CSFs in agile development. The findings of the literature review indicate that technical, people, organizational, and process factors are crucial for the success of agile projects. Each CSF falls into any one of these factors. Overall, this study's findings emphasize the significance of CSFs in the agile software development process. Organizations and software development teams can enhance their agile processes and raise the likelihood of project success by being aware of these aspects. Teams may create high-quality software in less time while simultaneously fulfilling the goals and expectations of the customer by concentrating on different success factors.

Keywords: agile; critical success factors; project management; project success; software; software development

Introduction

Software has currently become one of the most important and necessary aspects in this contemporary world due to the growing demand for information technology. In a time when augmented reality, the Internet of Things, and other cutting-edge technologies are being used all over the globe, software development enterprises are striving for optimized tools and methods. The rapid development of software development tools and methods has benefited all kinds of software development enterprises; worldwide software development businesses are still looking for specialized answers to their problems so they can respond to changes rapidly and, at the same time, maximize return on investment. The success of the project depends on meeting its deliverables within a certain budget while maintaining its quality, scope, and deadline. The most crucial tool for achieving project deliverables in any company is project management. Applying knowledge, abilities, tools, and strategies improves control over material and human resources (Dyba & Dingsoyr 2009). By boosting productivity, and dependability, and offering customers higher-quality products, it helps to strengthen customer relations. Agile, a project management style, has recently been adopted by the majority of software-based businesses for effective and efficient project development (Dyba & Dingsoyr 2009). The core concepts of Agile include quick deployment of solutions, early and frequent delivery of customer-valued products, resource utilization, quick problem detection, focusing on clients, effective communication and collaboration, adapting to changes, and adaptability. The primary goal of this study is to review the critical success factors of the agile software development process.

To conduct the study, a systematic literature review (SLR) technique was used. The SLR is a research technique used to thoroughly discover, assess, and summarize the body of literature that is currently accessible on a specific subject or research question. The procedure entails a thorough screening of the identified articles for relevance and quality after a systematic search of appropriate databases and other sources. According to Kitchenham (2004), the objective of a systematic literature review is to provide a rigorous, transparent, and replicable summary of the current state of knowledge on a particular topic or research question. It can be used to identify gaps in the existing literature and guide further research in a particular field.

The agile development approaches, delivery strategy, project team training, customer and staff involvement, organizational culture, project management process, management commitment, and communication are the success criteria found by this process. In addition, this study introduces a taxonomy that classifies all these critical success factors (CSF) into technical factors, people factors, organizational factors, and process factors.

In this study following research questions are answered:

RQ1: What are the success factors in agile software development (ASD)?

RQ2: What are the most critical success factors that need to be taken care of during the implementation of ASD?

RQ3: How the identified critical success factors can be mapped into a robust framework?

The answers to these questions will be useful in determining the importance of CSFs for a successful software development process improvement and may help software companies that use agile methodologies to focus on addressing them to get a higher return on investment and customer satisfaction in less time.

Agile software development methodologies

Agile software development emphasizes adaptability, customer interaction, and continual improvement. It is a collaborative, iterative approach to software development. It is built on the Agile Manifesto, a set of guidelines that puts people and interactions ahead of processes and working software, customer collaboration, and adapting to change. Several characteristics of agile software development have been found in the literature. According to Dyba and Dingsoyr (2009), the fundamental characteristics of agile development include communication and collaboration, accepting conflicts, and supporting creativity and innovation. Managers serve only as facilitators, and the design and execution processes are iterative and inseparable. According to a survey conducted by Vijayasarathy and Turk (2008), using agile development will make it possible to meet customer expectations and produce high-quality software. Other advantages of implementing agile development include higher levels of flexibility, reduced expenses for development, more frequent delivery of functional software, and more reusable code. Agile development might be considered a method to deal with the complexity of the various parts of software development, which exists in a relatively complicated area (Pelrine 2011).

Agile principles state that value addition should take precedence over plan adherence. The value that consumers receive from receiving functional software frequently and quickly can be increased (Dingsøyr et al. 2012). With agile development, the software development team is expected to deliver early and then get feedback quickly, allowing for easier modifications, higher quality, and ongoing testing. According to Highsmith and Cockburn (2001), two of the most difficult issues facing business and technology today are addressed by agile practices: first, the need for an inventive approach to software development and, second, the requirement for a work environment that is dynamic and responsive to frequent changes. According to Cockburn and Highsmith (2001), the agile philosophy prioritizes the importance of people over traditional software development methods. Since a skilled team is essential, the value of each team member increases as the development process becomes more agile.

Critical Success Factors

The Critical Success Factor (CSF) approach to identifying and evaluating an organization's performance was first designed in 1979 and it was later improved and gained widespread acceptance (Bullen & Rockart 1981, Rockart & Crescenzi 1984). Bullen & Rockart (1981) define the CSF as the small number of areas where strong competitive performance will ensure the individual, department, or organization. CSFs are a select few crucial areas where "things must go right" for the business to succeed and for the manager to reach their objectives. Critical success factors are areas of importance where everything needs to be done correctly through the company process to thrive the accomplishment and to meet the objectives of the manager (Nasehi 2013). According to different studies by Reel (1999) and Bytheway (1999), CSFs in software projects are related to basic project management approaches or the marriage of software engineering and business strategy. According to a different case study, CSFs in software projects include a variety of elements, including the estimating and validation phase of the development life cycle, executive management, project management, resource management, and strategic-level planning (Boghossian 2002).

When Walid and Oya proposed a new framework to determine crucial success and failure elements in 1996, the hunt for the success and failure criteria in the adoption of agile methodology began. They have proposed a new framework for fundamental variables and their impact on their effective and efficient contributions to project success. They used empirical research to gauge the viability of applying the suggested design. The survey's findings show that although the importance of these factors varies by industry, project managers' managerial abilities, team members' commitment and technical expertise, project attributes, and environmental factors can be just as important as organizational factors (Belassi and Tukel 1996). Pikkarainen et al. (2012) studied the case of successful implementation of agile software development projects in three different Finnish software companies. The study highlighted the significance of management's belief in and support for agile. The study also discovered that firms implementing agile methodologies needed to strengthen the development team and modify agile practices to meet organizational requirements.

It is required to look at the relationships among the different agile success criteria before conducting a factor analysis. We reviewed the studies on agile software development's CSFs (Aldahmash et al. 2017). As a result, the CSFs for agile software projects were narrowed down to eight success factors - delivery strategy, team capability and training, customer involvement, agile development approaches, communication, organizational culture, project management process, and top management support (Aldahmash et al. 2017).

Methodology

Systematic Literature Review

In this study, we have selected the systematic literature review technique to investigate the critical success factors in agile software development methodology. The literature shows that numerous studies have looked at the success elements of implementing agile methods in an organization. A systematic literature review (SLR) is a kind of secondary research study used to evaluate existing primary literature and studies relevant to the research question in a systematic and organized manner. This SLR is done for the evaluation of all the relevant data containing the success factors of agile software development. The research questions concerned with the study are listed in the introduction section. According to Kitchenham (2004), planning the review, carrying out the review, and reporting the review are the three primary stages of SLR.

Planning of Mapping

In the planning phase, the authors must first identify and clarify the various components of the study objective to ensure that research questions have not already been addressed in earlier reviews. Therefore, defining the research questions mentioned in the introduction section was an important phase in this procedure. The search is done by using academic databases such as IEEE Explorer, ACM digital library, Science Direct, Research Gate, Springer, Google Scholar, and other sources.

Search String

The search query used for the extraction of relevant literature was:

{Critical success factors} AND ({Agile} OR {ASD} OR {Agile Software Development})

Primary study selection

The papers have been selected by exploring their title, abstracts, and conclusion. The research papers having unclear objectives and ambiguity were not selected.

Inclusion criteria

To include any research paper in the study, it should satisfy the following criteria:

i. It must be published in a Journal or at a Conference.

ii. The paper must be written in the English language and available as a full-text article.

iii. The primary study must focus on critical success factors in agile software development.

Exclusion criteria

The research articles are excluded if they fall into any of the following categories:

i. Articles that do not describe success factors in agile software development.

ii. The articles are written in any other language than English.

iii. All the studies are not available electronically.

iv. Non-peer-reviewed articles.

v. Unpublished research papers and thesis.

Database

The search is done by using academic databases such as IEEE Explorer, ACM digital library, Science Direct, Research Gate, Springer, Google Scholar, and other sources. The papers published after 2000 are considered in this study. Past research papers (Aldahmash 2017), (Van Kelle et al. 2015), (Livermore 2007), (Iqbal et al. 2019), (Wan et al. 2011), (Kalenda 2018), (Chow and Cao 2008), (Mishra et al. 2009), (Sheffield and Lemétayer 2013), (Stankovic 2013), (Hoda et al. 2017), (Stelzmann 2010), (Wan and Wang 2010), and (da Silva and dos Santos 2015) were selected for the review purpose in this study. These studies have demonstrated several agile development success factors. Details of the selected papers and the filtration of these papers are shown in Table 1.

Table 1: Filtration of Papers

Database Name	**Number of papers**	**Title filtration**	**Abstract Filtration**	**Selected papers**	**Reference**
IEEE Explorer	844	9	6	4	[17][18][19][20]
ACM Digital Library	141	12	5	1	[21]
Science Direct	238	5	2	4	[22][23][24][25]
Research Gate	136	23	10	2	[16][26]
Springer	132	14	6	1	[27]
Google Scholar	981	22	7	2	[28][29]
Total	**2472**	**85**	**36**	**14**	

Findings

Even in situations with high levels of process maturity, the agile software development practice has a detrimental effect on project performance. In this study, the CSFs are selected if such factors are validated in multiple studies. Different agile software development critical success factors discovered in different previous studies are presented in Table 2.

Table 2: Agile software development CSFs

Dimensions	Success Factor	Articles
Technical Factor	Agile development technique	[16][22][27][29]
	Delivery strategy	[16][18][22][23][24][28]
People Factor	Project team training	[20][29][23][27][28]
	Customer and staff involvement	[22][23][26][27] [29]
	Management commitment	[17][18][19][21]
Organizational Factor	Organizational Culture	[20][23][24][28][29]
	Communication	[20][17][27][29]
Process Factor	Project management process	[22][24][25][29]

The conceptual framework for the category-wise distribution of CSFs in ASD found from existing studies is explained below and demonstrated in Figure 1.

Technical Factors

From the study and analysis of previous studies related to critical success factors in agile software development methodologies, it is found that agile development technique and delivery strategy were found as major CSFs under technical factors.

Agile development technique

The project members must be conversant with the chosen method or technique before using an agile method or technique. All members of the agile development project team must understand the concepts, ideas, and terminology utilized by the chosen agile technique or practice (Chow and Cao 2008) and (Stelzmann et al. 2010).

Delivery Strategy

Two things are crucial for the successful delivery of an agile development project Chow and Cao (2008). First and foremost, you must frequently produce functional software. Second, you ought to present the most crucial characteristics first. Each member of the team should be aware of their role in the delivery strategy and how to carry it out.

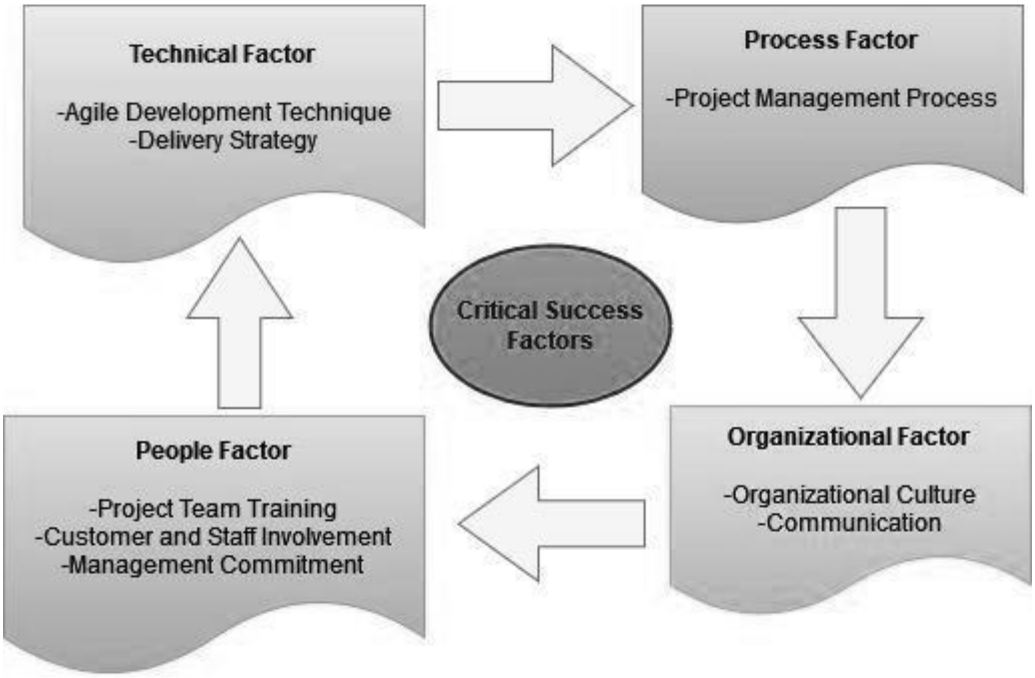

Figure 1: Category-wise distribution of CSFs in Agile software development

People Factor

People are the most important success factor in any project. Proper utilization of human resources leads the project toward success. In the case of agile methodology, people are the major factor for the successful completion of the project. From the study and analysis of different studies, project team training, customer and staff involvement, and management commitments were found as CSFs under the people factor.

Project team training

Motivated individuals should be the foundation of agile development. Any project needs the appropriate people to succeed, but agile projects require more of them since they rely so heavily on the competence of their team members. Regular training programs for the project team are crucial CSF for agile software development since they educate team members about new regulations, trends, tools, and methodologies. It has consistently benefited the organization and process improvement productivity. Training agile team members can raise the company's profile, enhance team dynamics and creative problem-solving skills, and provide them with the ability to manage agile projects. During the agile development project, a focus on training and ongoing learning should be made (Misha et al. 2009). According to Livermore Livermore (2007), obtaining training on the adopted agile methods or practices is significantly correlated with successful agile adoption.

Customer and Staff Involvement

In an agile development strategy, the active involvement of staff and customers is necessary for the successful completion of the project. It is an important CSF because it measures how much the employees trust, acquire, use, believe in, own, and adhere to the project. The involvement of customers is crucial for producing frequent releases of functional software and accepting changes in requirements. Customers will be happier with agile development if they are more involved (Misha et al. 2009). It is thought that customer cooperation and dedication affect how successfully agile software is implemented (Hoda et al. 2017).

Management Commitment

It is the most critical success element for the implementation of process improvement. Management commitment in a company refers to the degree of backing, funding, realization, and involvement of higher and lower-level management in the software process improvement initiative. A study conducted by Livermore (2007) found that the success of agile projects is strongly linked to the level of support from top management. Therefore, the involvement and support of management play a critical role in the success of agile projects.

Organizational Factor

Organizational factors play a vital role in the successful implementation of agile methodology. Organizational culture and communication are considered the CSFs for agile under organizational factors.

Organizational culture

Organizational culture is considered one of the important success factors. Agile software development can be impacted by a variety of organizational aspects or elements, which are referred to as organizational culture. A dynamic culture is required to react to the changes that occur during the agile development process, and it is a crucial component of the shift to agility (Misha et al. 2009). Three organizational culture facets that can affect agile development have been identified by Wan and Wang (2010): the culture of working overtime, the culture of mistrust inside the organization, and the absence of a collaborative culture.

Communication

Communication is important in every part of life and is equally important in software development. It is even more important in agile software development as agile need frequent communication with customer and co-workers. In agile projects, there is a lot of involvement from customers, frequent feedback, dynamic changes, and self-organizing teams (Aldahmash 2017). This means that effective communication is necessary between project members and customers. A study conducted by Stelzmann et al. (2010) emphasized the importance of direct communication in agile development. They suggested that direct communication can help to improve the communication process in agile projects.

Process Factor

It is important to identify a clear process for software development and train the staff for the introduced process. From different studies, it is found that the project management process is CSF for the agile methodology that falls under the process factor.

Project management process

The project management process is one of the critical success factors for the successful implementation of agile methodology. It's crucial to have a well-thought-out and size-appropriate project strategy when starting an agile development project. The success of the project and the standard of the software can be enhanced by selecting the appropriate project management methodology Chow and Cao (2008). The project factor is a reliable gauge of software development agility (Sheffield & Lemétayer 2013). The project management procedure should give the project team more control and maximize the abilities of the development team. Due to the numerous adjustments and iterations involved with agile projects, a flexible approach to project management is required.

Conclusion

Agile software development is a flexible, cooperative, and iterative methodology that enables teams to swiftly adapt to changing needs, enhance customer communication, find and fix issues early on, and promote a culture of continuous improvement. The objective of this study was to review the previous research works and to identify the critical success factors for agile software development methodology. After reviewing the previous studies, four different factors namely technical, people, organizational, and process factors with eight critical success factors for successful implementation of agile software development were introduced. Such eight CSFs are agile development technique, delivery strategy, project team training, customer and staff involvement, management commitment, organizational culture, communication, and project management process. By taking into account the crucial success factors in ASD, software companies can work regarding an approach that will highlight those significant process areas within the company that need to be enhanced to provide more value, which will ultimately lead to an increased return on investment and profitability. The result of this study might help software companies' successful implementation of agile methodology which might help the organization advance and succeed.

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ISSN NO. 2091-1742

SCITECH NEPAL Journal of Scientific and Technical Studies
Nepal Engineering College, Pokhara University

Research Article DOI:10.3126/scitech.v17i1.60469

A Case Study on the Effect of Geometric Design Consistency on Road Crashes on Narayanghat-Muglin Road Section

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DOI
Received: May 8, 2023
Accepted: October 5, 2023

Abstract

Design consistency is overlooked while designing roads, resulting in unsafe road facilities. The safety performance of a highway can be greatly enhanced by detecting and addressing any inconsistencies present on the road. Over time, the application of geometric standards shifted from new road construction to upgrading, which could result in limited design options. Due to the emerging importance of design consistency in geometric design, this research has been initiated to evaluate horizontal curve consistency based on an established operating speed prediction model.

Horizontal curve data of the Narayanghat–Mugling Road section has been collected from the Division Road Office, Bharatpur, and accident data has been obtained from the District Traffic Police, Chitwan. Out of 242 horizontal curves in the Narayanghat-Muglin road section, the design consistency of 223 horizontal curves was evaluated, while 19 horizontal curves with posted speed limits were not considered because these curves are not within the range of design criteria set out in Asian Highways Design Standards (1993).

The average, maximum, and minimum 85th percentile speed was found to be 78, 101, and 32 kmph respectively. Out of 223 horizontal curves evaluated for individual consistency based on operating speed, 75% of the curves were categorized as “poor”, 16% as “fair”, and 9% as “good”. It was found that under successive element consistency evaluation based on operating speed, 22% of horizontal curves were categorized as “poor”, 23% as “fair”, and 55% as “good”. When studied under vehicle stability consistency evaluation criteria, 88% of the curves were classified as “fair” and 12% as “good”. It was found that the predicted accidents caused by geometric design inconsistency and vehicle stability are 5.12% of total accidents per year.

From the safety standpoint, if the condition $|V_{85}-V_d|>20$ is met, critical discrepancies between the design speed and operating speed arise, resulting in unsafe operations. Therefore, it is generally advisable to consider redesigning those road sections.

Keywords: Design Consistency, Safety, Operating Speed, Speed Prediction Model, Accident Prediction.

INTRODUCTION

Significant growth in motorization and highway construction over the past decades has led to increased mobility and economy nationwide. However, this increased mobility has also resulted in hundreds of thousands of deaths and millions of injuries annually, worldwide, due to traffic collisions.

Road accidents are typically influenced by four main factors: the road itself, human error, the vehicle, and the environment. While all of these factors can contribute to accidents, only the road factor can be readily improved by traffic and transportation engineers in order to reduce the frequency and severity of accidents (Shakya 2020). If a driver encounters an inconsistency on the road that deviates from their expectations, they may respond by adopting an unsuitable speed or maneuver, which could result in accidents (Ng and Sayed 2004). Poor consistency means bad fitting, surprising events, and high-speed variability along different road segments and among different drivers, increasing the likelihood of crashes (Weber & Matena 2005). When the design is consistent with what the driver expects to find, the highway is also consistent thus reducing the possibility of driving errors and unsafe maneuvering (Castro et al. 2015). The use of operating speed as a consistency tool requires the ability to accurately predict speeds as a function of the roadway geometry (Fitzpatrick et al. 2000). An alignment that demands drivers to negotiate high-speed gradients and does not satisfy their expectations, on the other hand, is regarded inconsistent and results in a greater crash frequency (Galante et al. 2021). Geometric design standards, which are formulated on the basis of the design speed concept, constitute one of the primary causes of design inconsistency and have been practiced since the 1930s. The concept's foundation lies in the principles of a vehicle's dynamics as it traverses a horizontal curve of circular shape at a steady speed, as negotiated by a driver (Galante et al. 2021). Previously, in Nepal, road agencies' top goals were connectivity rather than safety. This, together with the country's rugged terrain, became one of the contributing causes of the country's rising number of road crashes. As infrastructure and urbanization progressed, traffic density increased drastically, reducing the effectiveness of the road network and increasing the number of road crashes at an alarming rate. In an effort to enhance the efficiency of road networks, responsible organizations have sought to upgrade existing roads to multilane roads. Despite this, there have been reports of several crashes occurring in newly constructed multilane road sections.

When selecting a route or mode of transportation, speed is a crucial consideration. Road users evaluate the appeal of different highways based on factors such as time, convenience, and cost. The actual speed at which the vehicles travel, known as the operating speed, is typically determined under free-flow conditions and is represented by the 85th percentile speed. To predict operating speed, several factors must be taken into account, including the radius and length of horizontal curves, sight distance, superelevation rate, side friction factor, and pavement conditions. This study explores various methods of predicting operating speed and evaluates consistency across individual geometric elements and successive elements.

RESEARCH OBJECTIVES

The general objective of this study is to evaluate the effect of geometric design consistency on the road crashes of the Narayanghat-Muglin road section in the Gorkha-Narayanghat Highway in Nepal.

MATERIALS AND METHODS

To achieve the objective of the study, the secondary data was extracted from as-built drawings provided by the Department of Roads. The data includes all geometric parameters required to evaluate the geometric consistency. Historical accident data was obtained from the District Traffic Police, Chitwan. The Narayanghat-Muglin road comes under class II as per Asian Highway Classification with 2 lanes and a design speed of 50 kmph (“Annex I Asian Highway Classification and Design Standards,” n.d.). Through a review of relevant literature, it has been found that a plethora of models have been created for predicting operating speed. These models can differ significantly in terms of their form and the number of variables incorporated in each one. It is noteworthy that the majority of these models are designed to calculate operating speeds on horizontal curves as shown in Table 1.

Table 1: Speed Prediction Models (Memon et al. 2008)

S.N.	Model	Model Equation for V85	R2
1	Lamm et al. 1990	94.398-3188.656/R	0.79
2	Lamm and Choueiri 1987	95.6-0.0438CCRs	0.82
3	Lamm et al. 1999	Exp (4.561-0.000527CCRs)	0.63
4	Merrall and Talarico 1994	Exp (4.561-0.0058D), D=5729.58/R	0.631
5	TAC 1999	102.45+0.0037LC-(8995+5.73LC)/R	unknown
6	Ottesen and Krammes 2000 (Model 1)	103.66-1.95DC	0.8
7	Ottesen and Krammes 2000 (Model 2)	102.44-1.57DC+0.012LC-0.01DCx LC	0.81
8	Voigt 1996	99.61-2951.37/R+0.014LC-0.131I+71.82e	0.84
9	Kanellaidis et al. 1990	129.88-623.10/R ½	0.78
10	Fitzpatrick (2000)	for -9%<G<-4%, V_{85} = 102.10 -3077.13/R	0.58
		for -4%<G<0%, V_{85} = 105.98-3709.90/R	0.76
		for 0%<G<4%, V_{85} = 104.82-3574.51/R	0.76
		for 4%<G<9%, V_{85} = 96.61-2752.19/R	0.76

where,

CCRs = curve change rate in gons per kilometer (1 gon = 0.90) = [63700(Lc11/2R + Lcr/R + Lc12/2R)]/L

DC=Degree of Curve = 1746.38/R

e = Super elevation rate in m/m

I = deflection angle of horizontal curve in degrees

L = Lc11 + Lcr + Lc12 in m

Lc11 = Length of the spiral curve in m

Lc12 = Length of the spiral curve out in m

Lcr = Length of the circular curve in m

LC = Length of the horizontal curve in m

R = Radius of the horizontal curve in m

The model developed by Fitzpatrick has been used in this research since the methodology has been validated in multiple research projects and has been accepted by FHWA as the basis for examining design consistency on two-lane rural roadways in the IHSDM.

A statistically significant road safety model was used to predict the number of road traffic accidents (Ng & Sayed 2004). The model relies on horizontal curve data only with three design consistency measures that are statistically significant ($|V_{85}-V_d|$, ΔV_{85}, and Δf_R). This model simplified the safety evaluation of highway alignment based on design consistency:

$$\text{Accidents per 5 years} = \exp(-3.369) \times L^{0.8859} \times V^{0.5841} \times \exp[0.0049(V_{85}-V_d) + 0.0253\Delta V_{85} - 1.177\Delta f_R]$$

where,
L=Section length in km
V=Annual average daily traffic in vehicles per day
$V_{85}-V_d$ =Difference between operating and design speed in km/hr
$\Delta V_{85} = |V_{85i}-V_{85i+1}|$, where V_{85i} and V_{85i+1} are operating speeds on elements i and i+1 respectively
$\Delta f_R = f_R - f_{RD}$, where f_R is side friction assumed and f_{RD} is side friction demanded on the element.

RESULTS and DISCUSSIONS

The information related to the geometric alignment of the study road was collected from the Road Division Office, Bharatpur. The details of the horizontal curve are presented in Table 2. Out of 242 curves 19 curves with radius less than 50m are not considered for consistency evaluation because these curves are not within the range of design criteria set out in Asian Highways Design Standards (1993) and the speed limit has been posted at these sections.

Table 2: Horizontal curve summary

Total no. of Horizontal Curves	242
Minimum Radius of Curve in alignment	15 m
Maximum Radius of Curve in alignment	1000 m
No. of Curve with Radius Greater than or equal to 50 m	223
No. of Curve with Radius less than 50 m	19

85^{th} percentile speed of 223 number of curves are calculated based on the model developed by Fitzpatrick (Fitzpatrick et al. 2000). The summary of 85^{th} percentile speed calculation is presented in Table 3.

Table 3: 85^{th} Percentile Speed Summary based on Fitzpatrick

Design Speed	50 km/hr
Maximum 85^{th} percentile Speed	101 km/hr
Minimum 85^{th} percentile Speed	32 km/hr
Average Operating Speed	78 km/hr

The average 85th percentile speed of the study road was 78 kmph which indicated that average speed of the free-flowing passenger car on the study road is 78kmph. The maximum 85th percentile speed of the study road was 101 kmph which exists at three horizontal curves with a radius of 1000m. The minimum 85th percentile speed of the study road was 32 kmph which exists at four horizontal curves with a radius of 50m.

The prevailing method for assessing the consistency of highway design typically relies on operating speed as the primary criterion. For a single geometric element, with reference to threshold values of Lamm et al. (1999) (Fitzpatrick et al. 2000), the horizontal curves with $|V85\text{-}Vd|<=10$ were under the "good" category and there are 21 horizontal curves in this road. The curves with $10<|V85\text{-}Vd|<=20$ were under the "fair" category; there are 35 horizontal curves under this category in this road. The curves with $|V85\text{-}Vd|>20$ were under a "poor" category; there are 167 horizontal curves under this category in this road as shown in Figure 1.

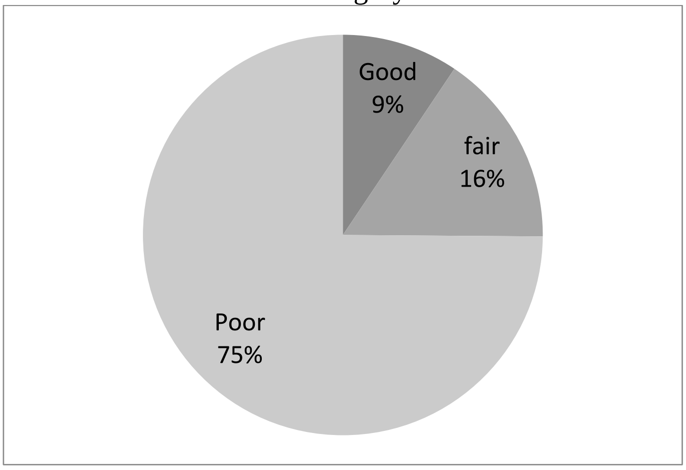

Figure 1: Individual horizontal curve consistency

Similarly for consistency evaluation of successive horizontal curves in the Narayanghat-Muglin road, a comparison of the operating speed of successive curves was carried out. For ith and i+1th successive curves, curves with $|V_{85i}\text{-}V_{85i+1}|<=10$ were under the "good" category (123 curves). Similarly, curves with $10<|V_{85i}\text{-}V_{85i+1}|<=20$ were under the "fair" category (51 curves), and the curves with $|V_{85i}\text{-}V_{85i+1}|>20$ were under the "poor" category (49 curves), as presented in Figure 2.

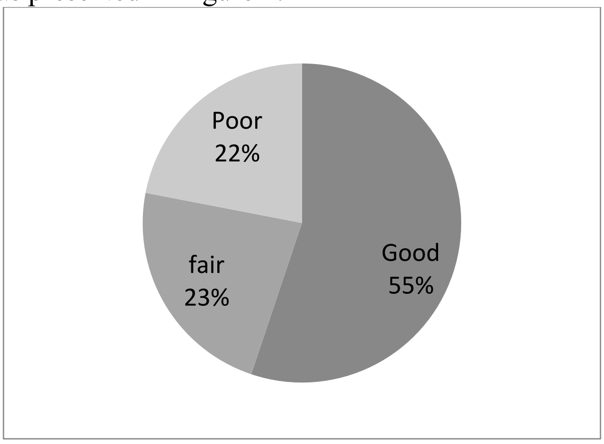

Figure 2: Successive horizontal curve consistency

For consistency evaluation of horizontal curves based on vehicle stability the discrepancy in the side friction assumed vs. demanded at each horizontal curve was calculated. Curves with $\Delta f_r>=0.01$ were under the "good" category and there are 27 curves with the "good" category in the study road. Similarly curves with $0.01>\Delta f_r>=-0.04$ were under "fair" category and there were 196 curves with fair category in the study road. The curves with $\Delta f_r<-0.04$ were under the "poor" category and there was no curve under the "poor" category in this road as shown in Figure 3.

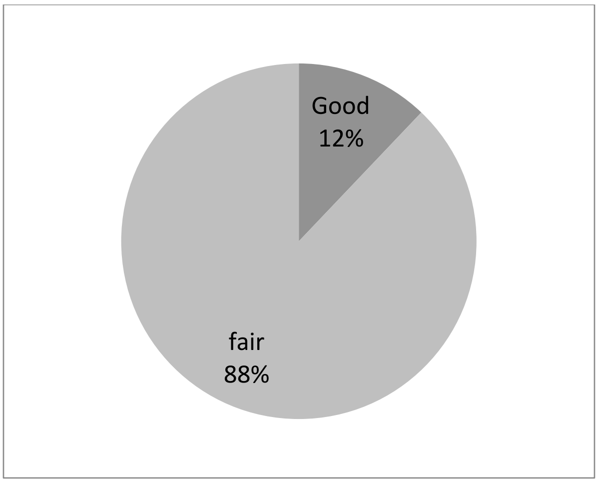

Figure 3: Consistency evaluation based on vehicle stability

The graph has been plotted with Cumulative distance on the horizontal axis and operating speed on the vertical axis to generate a speed profile along the road length. The speed profile is presented in Figure 4. The speed profile shows that there are 18 curves (8%) have an operating speed less than the design speed and the remaining 205 curves (92%) have an operating speed greater than the design speed.
The statistically significant model based on curve data and consistency measure (Ng & Sayed 2004) was used to predict the accidents per 5 years and the result is presented in Table 4. For the prediction of accidents, Average Annual Daily Traffic (AADT) has been taken for the year 2018 (Ojha & Ojha 2018).

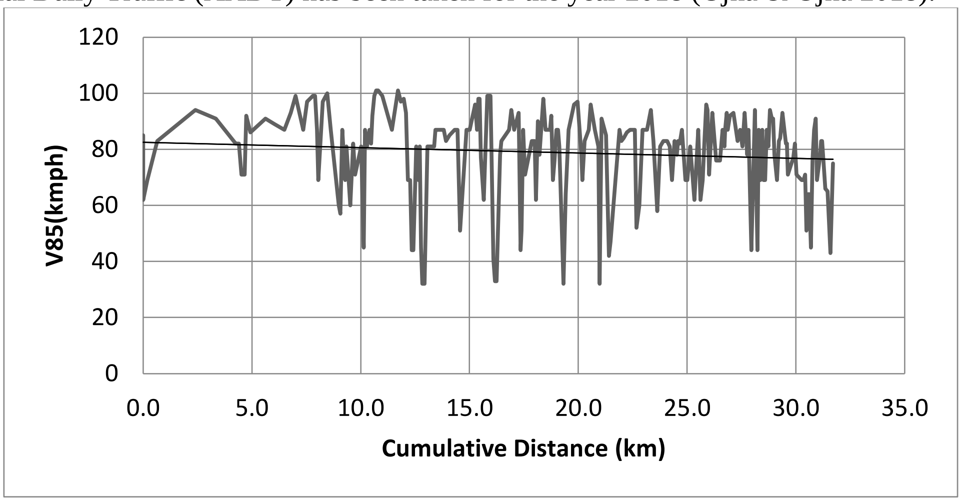

Figure 4: Operating Speed Profile

Table 4: Accident prediction summary

No. of accidents predicted per 5 years	66
No. of accidents predicted per year	13
Total Accident recorded by Traffic Police (from May 2021 to May 2022)	254

It has been observed from the traffic police accident record; at the period of 1 year (from May 2021 to May 2022) the total number of accidents in the study area is 254. There may be several causes of accidents among which this study shows that 5.12% of the accidents are attributed to the geometric inconsistency and vehicle stability. The predicted accident percentage of 5.12 in this study area is in compliance with the study performed by Reddy & Shashidher (2018) which shows the total no. of accidents in curve sections is 4.54%.

CONCLUSIONS

This study was aimed to find the effect of geometric design consistency on road accidents. From the results and discussion, it can be concluded that:On average, the 85^{th} percentile speed was 28 kmph greater than the design speed. The speed profile shows there are 18 curves that have an operating speed less than the design speed and the remaining 205 curves have an operating speed greater than the design speed.

Among the 223 horizontal curves, there are no curves that satisfy all 3 consistency criteria under the "good" category; 11 (5%) curves that satisfy all 3 consistency criteria under the "fair" category. There were no curves that satisfied all 3 consistency criteria under the "poor" category. There were 22 (10%) curves that satisfied 2 consistency criteria under the "good" category, 53 (24%) curves satisfy 2 consistency criteria under the "fair" category, and 25 (11%) curves satisfy 2 consistency criteria under the "poor" category.

Based on the accident prediction model on the basis of geometric design consistency, the total number of accidents predicted per year is 13, which is 5.12% of the total accidents that occurred from May 2021 to May 2022.

ACKNOWLEDGEMENT

The authors are thankful to the Division Road Office, Bharatpur, and the District Traffic Police, Chitwan for providing the data.

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ISSN NO. 2091-1742

SCITECH NEPAL

Journal of Scientific and Technical Studies
Nepal Engineering College, Pokhara University

Research Article

DOI:10.3126/scitech.v17i1.60491

Cost Comparison of Flexible Pavement on Weak Sub-Grade Soil Modified with Lime and SD

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Received: May 31, 2023
Accepted: October 5, 2023

Abstract

The effectiveness of flexible pavement is affected by the subgrade quality. The subgrade refers to a compacted layer of soil that provides sideways support to the pavement. When constructed on a weak subgrade, it negatively impacts the pavement's performance, leading to a shorter lifespan. Traditionally, the common method to stabilize a soft subgrade involves removing the weak soil and replacing it with stronger soil. However, due to the high expenses associated with soil replacement, highway agencies are exploring alternative approaches to constructing highways on soft subgrades. Soil stabilization is a commonly employed alternative in pavement construction, serving as an effective method to enhance the engineering characteristics of soil, including its strength and stability. This paper focuses on the utilization of lime and stone dust (SD) as admixtures for an efficient ground improvement technique over weak subgrade soil deposits. The California Bearing Ratio (CBR) test is conducted by making the specimens of weak subgrade by adding the variable percentages of a mixture of lime and SD. First, the soil was mixed up with lime to 12% by weight with an increment of 3% again the soil was mixed with SD with increments of 10% up to 50% by weight of soil. The study determined an optimal lime content of 3% based on the geotechnical properties of the mixture and the cost considerations of lime and the weak subgrade. Following this, SD was added to the optimized lime-weak subgrade mixture in varying increments of 10% by weight, up to a maximum of 40%. The modified mixes were then evaluated for their CBR and maximum dry density values. The CBR is increased to 15% and the total pavement thickness decreased to 725 mm for 50% SD addition with 4.89 % in cost reduction.

Keywords: *Plastic Limit; Liquid Limit; Plastic Index; California Bearing Ratio; Unconfined Compressive Strength; Pavement.*

INTRODUCTION

There is more than 2000 km of road network in Kathmandu Valley, Nepal, of which more than 500 km constitutes strategic road network. These major routes transverse the soft soil of Kathmandu Valley at various places. Some of the roads built over these deposits are affected by subgrade rutting due to the presence of soft soil deposits in these areas (Paneru, 2020). The major problem associated with soft soil subgrade is that road built over this soil requires frequent maintenance and overlay; the Department of Roads (DoR) makes huge investment annually to make the roads serviceable. Presently the roads are built based on past experience and practices. The method of replacement is employed in soft subgrade conditions. The practice in other countries has suggested chemical stabilization are more reliable in soft subgrade condition than the replacement by capping layer (Harris *et al.*, 2006). The soil in the Kathmandu Valley, specifically the black clay referred to as *Kalomato*, consists mainly of heavy clay with clay-to-loam variations. It was formed by the deposition of fine sediments from rivers and streams into a lake, containing a significant amount of organic matter (Sakai, 2001). It is generally light to dark grey in color with a soft and compressive nature (Dahal and Zheng, 2018). The compressive nature of soft subgrade poses a challenge to highway engineers. The minimum soaked CBR value of subgrade for pavement construction must be greater than 5%, limiting the expansion below 1%. If pavement needs to be constructed over subgrade with a CBR value of less than 5%, lime or mechanical stabilization should be carried out (DoR, 2016). The soil is stabilized with various chemicals with lime being the most commonly used stabilizers in the road (Bell, 1996). Currently in Kathmandu Valley, either a capping layer of stronger material or lime stabilization (DoR, 2016) is used to overcome the problem associated with soft soil. The problem with the conventional method of replacement is that it requires the acquisition of suitable material away from the site which can increase the construction cost. Furthermore, the soil excavated to be replaced gets wasted and needs to be dumped away. At present, lime stabilization is considered an expensive solution to treat soft soil subgrade. To overcome the above problems the relatively less costly SD was mixed with lime. Certain subgrade soils, particularly clayey soils, exhibit high strength when their moisture content is low. However, as the water content surpasses the optimal value, these soils become weak and less manageable. In such cases, it is recommended to either replace the soil with high-quality fill material or employ appropriate treatment methods to improve its properties (Prusinski and Bhattacharja, 1999). The objective of chemical soil stabilization is to improve the stability of soils by increasing the size of soil particles, reducing the plasticity index, minimizing swelling-shrinking potential, and enhancing cementation. This is achieved by introducing specific chemical compounds into the soil as part of the stabilization process (Fondjo *et al.*, 2021). Apart from strength and stability soil stabilization prevents erosion and dust formation (Sen and Kashyap, 2012). A comparative study has been conducted on soil stabilization using lime and cement up to 15% conducting tests like liquid limit, plastic limit, CBR and UCS tests. The research reflected a maximum 10% substitution as beyond 10% the test values show a decreasing trend (Rai, Singh and Tiwari, 2020). The experimental study including lime and cement shows that the compressive strength at 28 days increased 2 to 6 times compared to untreated specimens. Furthermore cement relatively demonstrated higher influence on mechanical behavior as compared to lime (Sharma *et al.*, 2018). Soil modified with lime improves workability and compatibility. Soils classified according to the USCS as CH, CL, MH, ML, OH, OL, SC, SM, GC, GM, SW-SC, SP-SC, SM-SC, GW-GC, GP-GC, ML-CL, and GM-GC should be considered as potentially capable of being stabilized with lime (Firoozi *et al.*, 2017). Experimental research on subgrade modified with 2%, 4 % and 6 % of lime found that the engineering properties of soil significantly improved by the addition of lime (Singh and Res, 2015). SD in the range of 0 – 60% is used as a modifier and its effect on liquid limit (LL), plastic limit (PL), plasticity index (PI), maximum dry density (MDD), optimum moisture content (OMC), and CBR is analyzed (Dixit and Patil, 2016). The result demonstrated that 20% SD as a modifier in expansive soil improved MDD and CBR by 5% and 35% respectively, whereas OMC and Atterberg limit values were diminished which made the soil suitable for the subgrade (Bilal and Talib, 2016). In a study conducted in the Bundelkhand region of India, the stabilization of soft soil was investigated using crusher dust, a waste product. The study determined that an optimal percentage of 40% crusher dust (quarry dust) resulted in notable changes in various soil properties. Specifically, there was a decrease in the liquid limit from 54.10% to 24.2%, a reduction in swelling pressure from 103.6 KN/m^2 to 9.4 KN/m^2, an increase in shrinkage limit from 12.05% to 18.7%, an improvement in CBR value from 1.91% to 8.06%, and a slight increase in UCS value from 28.1 kN/m^2 to 30.2 kN/m^2 (Parhi and Das, 2014).

The general objective of this study is to perform a comparative study of strength enhancement and cost analysis of flexible pavement on weak soil modified with lime and SD in combination.

MATERIALS AND METHODS

To achieve the objective of the study, the study area is selected in Madhyapur Thimi-5 Paachagaal, Bhaktapur Nepal. The sampling point starts from Thimi police station located in Purano Bato to a distance of 1 km length. The soil sample, lime and SD stabilizers were collected using standard methods of sampling conforming IS 2720 part one. The soft soil sample at a depth of 0.5 to 0.6m was collected in the wet state. Table 1 shows the tests that are carried out on the soil sample.

Table 1: Tests on soil sample

SN	Name of Test	Test Procedure
1	Specific Gravity	IS 2720 (Part 3)
2	Liquid Limit	IS 2720 (Part 5)
3	Plastic Limit	IS 2720 (Part 5)
4	Free Swell Index	IS 2720 (Part 40)
5	Wet Sieve Analysis	IS 2720 (Part 4)
6	Standard Proctor Compaction	IS 2720 (Part 7)-1980
7	California Bearing Ratio	IS 2720 (Part 16)-1987

Lime is one of the additives used in this study that is commercially known as hydrated lime ($Ca(OH)_2$). The required lime in this study was purchased from the local market. The product specification of the lime is shown in Table 2.

Table 2: Physical Properties of Lime

S.N.	Requirement	Physical Properties of Lime
1	No. 30 mesh (600 µm), max.%	0.05
2	No. 200 mesh (75 µm), max %	No Value Assigned
3	Pits or Pops	Not applicable unless No. 30 Mesh>0.5% then one
4	Plasticity	200 within 30 minutes
5	Water retention, min. %	85 within 30 minutes

The SD used in this study is procured from a local stone crusher plant. The gradation of SD was done in the laboratory; other physical characteristics of SD were not carried out in the laboratory.

CBR and UCS tests were performed on selected virgin soil, soil mixed with lime, soil mixed with SD and soil mixed with lime and SD. The modified Proctor tests were performed on soil samples alone as well as their mixes with an increasing percentage of lime by weight (3, 6, 9 and 12 percent) of soil, and SD with (20, 30, 40 and 50 percent). The MDD was plotted to obtain the optimum percentage of lime and SD and lime with SD mixed with the soil. In total, fifty-six samples were prepared to study the fluctuation in CBR values. Soaked CBR tests were carried out for the following combinations:

- Natural soft soil with no additives.
- Natural soft soil modified with lime (+3%, +6%, +9%, +12%)
- Natural soft soil modified with SD (+20%, +30%, +40%, +50%)
- Natural soft soil modified with optimum lime with SD (+20%, +30%, +40%)

For the CBR values more than 5% the composition of pavement course was evaluated for different lime and SD combinations. From the design table of the Guideline for the Design of Flexible Pavements (GFPD-2014 (2^{nd} Ed., 2021) the pavement composition for maximum design traffic of 250 million standard axles (msa) considering future upgrading for various values of CBR was taken to evaluate the overall required thickness of pavement. The variation of thickness was evaluated based on the required thickness of pavement for various combinations of lime and SD.

The quantity of materials and cost per unit area for pavement structure was analyzed based on norms of rate analysis for road and bridge work and Bhaktapur district rate. The rate analysis was carried out for the computed pavement composition and variation of cost per unit area was evaluated for different combinations of additives.

RESULTS and DISCUSSIONS

Sieve analysis and hydrometer tests were performed on the clay soil sample, and the results are presented in Figure 1. The figure indicates that the soil is classified as fine-grained since more than 30% of the soil fraction passes through sieve No. 200 (0.0075 mm).

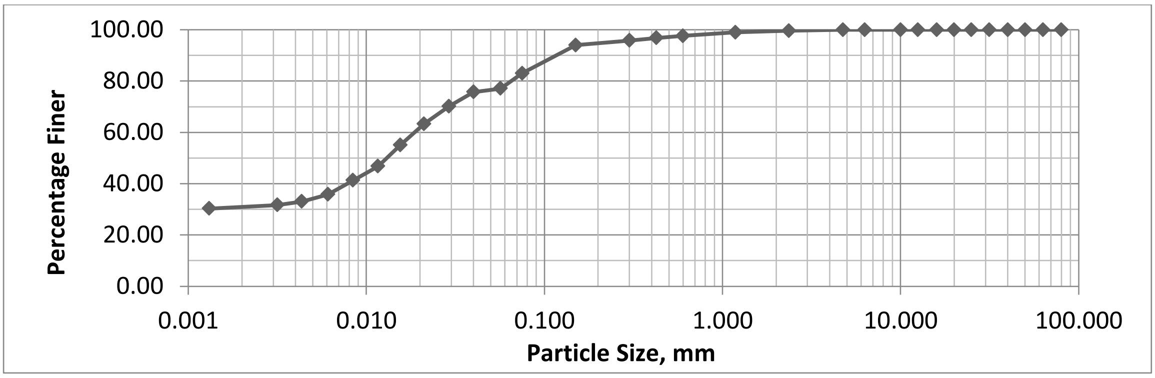

Figure 1: Soil Particle Gradation Curve

The elevated fine content suggests that the soil may consist of clay or silt. According to the AASHTO classification system, the soil falls within the range of A-4 to A-7 soils. Upon further analysis, it is determined to be an A-4 soil since the liquid limit and plastic index are both below 41 and 10, respectively, as indicated in Table 3. Soils in this group are classified as silty soil with a group index of 10, and they are generally considered fair subgrade material.

Table 3: Classification of soil sample

Sample Number	Passing ASTM Sieve # 200, %	LL, %	PL, %	PI, %	Classification	
					AASHTO	USC
S-1	83	34	26.41	7.59	A-4(10)	ML

The moisture density relationship was determined using modified Proctor compaction test for different compositions of soil with lime and SD.

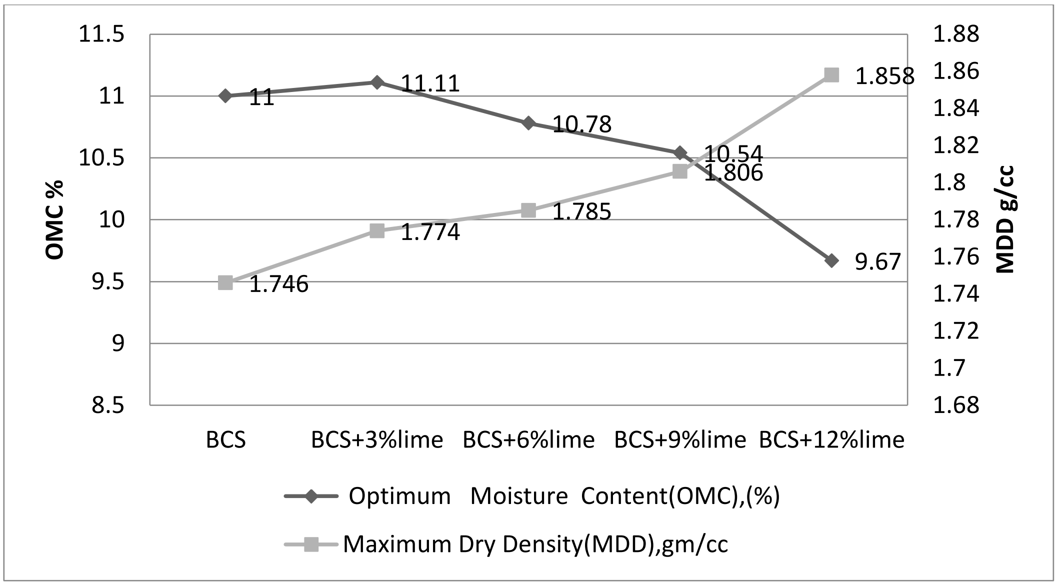

Figure 2: Variation of OMC and MDD with Lime

There was a decrease in OMC with the addition of lime. It is evident from Figure 2 that the OMC changes from 11% to 9.67% and shows a declining trend with the addition of lime from 0% to 12% with the peak value at 3%. The MDD varies from 1.746 to 1.858 and revealed an increasing trend with the peak value at 12%. Lime plays a role in coagulating, aggregating, or flocculating soil particles resulting in greater workability with enhanced strength and stiffness.

As shown in Figure 3, the reason for an increase in MDD of soil by the addition of SD is due to better rearrangement of soil particles with an increasing percentage of SD. Replacement of clay with higher specific gravity non-plastic SD improves the binding capacity. With increasing percentage of SD OMC was found to decrease because of reduction in clay content of soil which has less attraction for water.

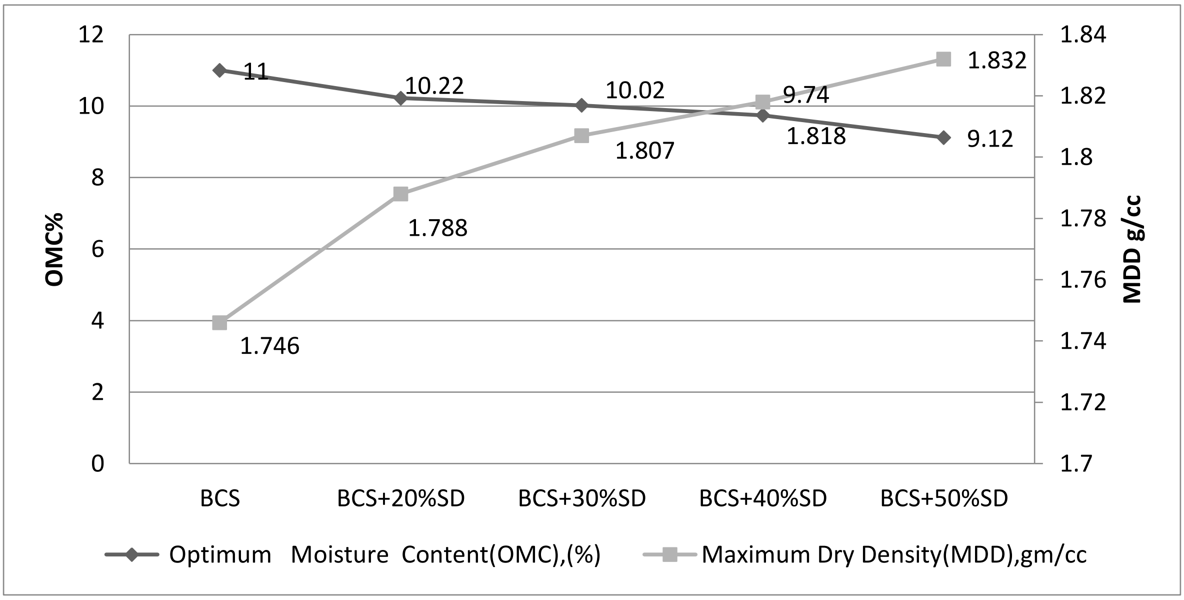

Figure 3: Variation of OMC and MDD with SD

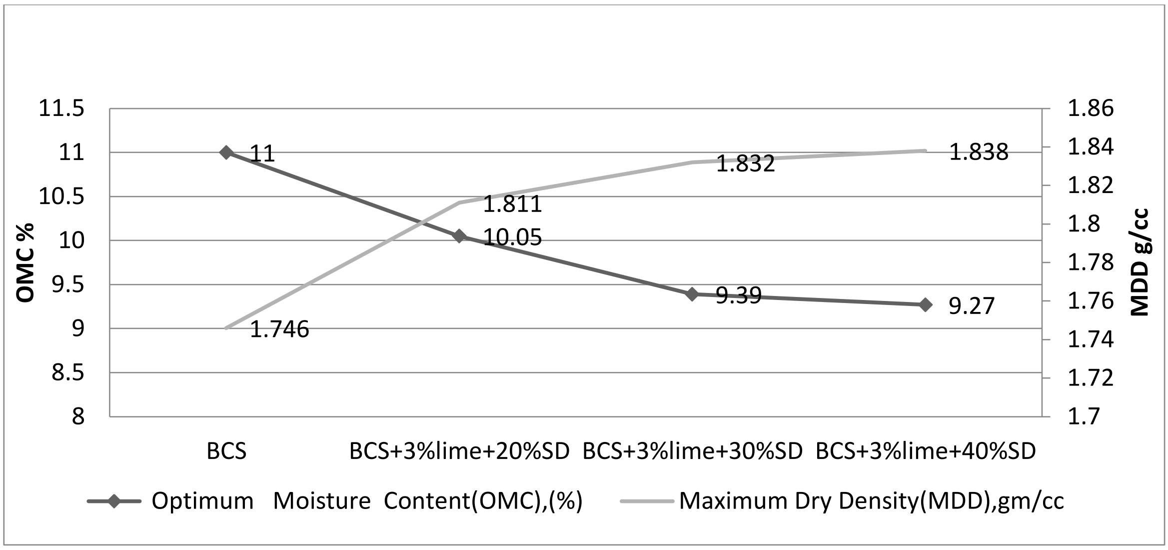

Figure 4: Variation of OMC and MDD with Lime and SD

However to study the combined effect of lime and SD on the soil samples laboratory tests were conducted with varying percentages of SD with 3% lime content. The rationale for fixing 3% lime is that lime is more expensive than SD. The graph in Figure 4 indicates that there is a rising trend of MDD and a declining trend of OMC with the increase in SD.

To understand the consequence of lime and SD on the strength of weak sub soil, CBR test has been performed on soil with 3%, 6%, 9% and 12% lime, soil with 20%, 30%, 40% and 50% SD and soil with 3% lime and 20%, 30% and 40% SD. As represented in Figure 5, the CBR values of the soil samples without additive is only 4% which do not meet the requirement of a minimum of 5% as mentioned in the SSRBW whereas CBR values is in increasing trend with the addition of additives and meet the specifications.

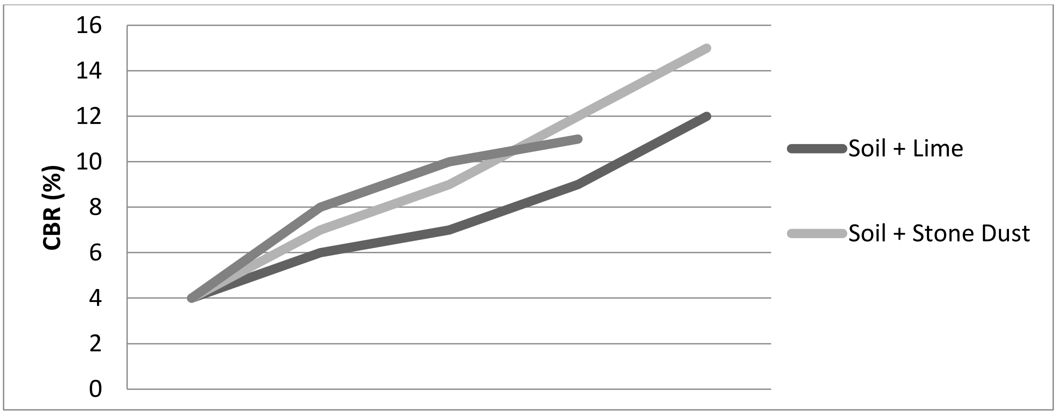

Figure 5: Variation of CBR with Different Composition of Additives

In order to find the variation of pavement cost based on the CBR values obtained for different compositions of additives cost analysis was done based on the district rate of Bhaktapur. The thickness of corresponding pavement layers was evaluated on the basis of the design of flexible pavement guidelines with a maximum traffic of 250 msa. The maximum pavement thickness of 845 mm was observed for soil modified with 3% lime whereas the minimum pavement thickness of 740 mm was obtained for three compositions viz soil modified with 12% lime, soil modified with 40% SD and soil modified with 3% lime and 40% SD.

The minimum cost is NRs. 5726.81 for soil + 50% SD and the maximum cost is NRs. 7106.78 for soil + 3% lime. As explained above the pavement with 50% SD addition was selected because it exhibited more CBR 15% value as compared to lesser values of CBR of other categories. Figure 6 shows the graphical variation of cost per square meter of flexible pavement modified with lime and SD.

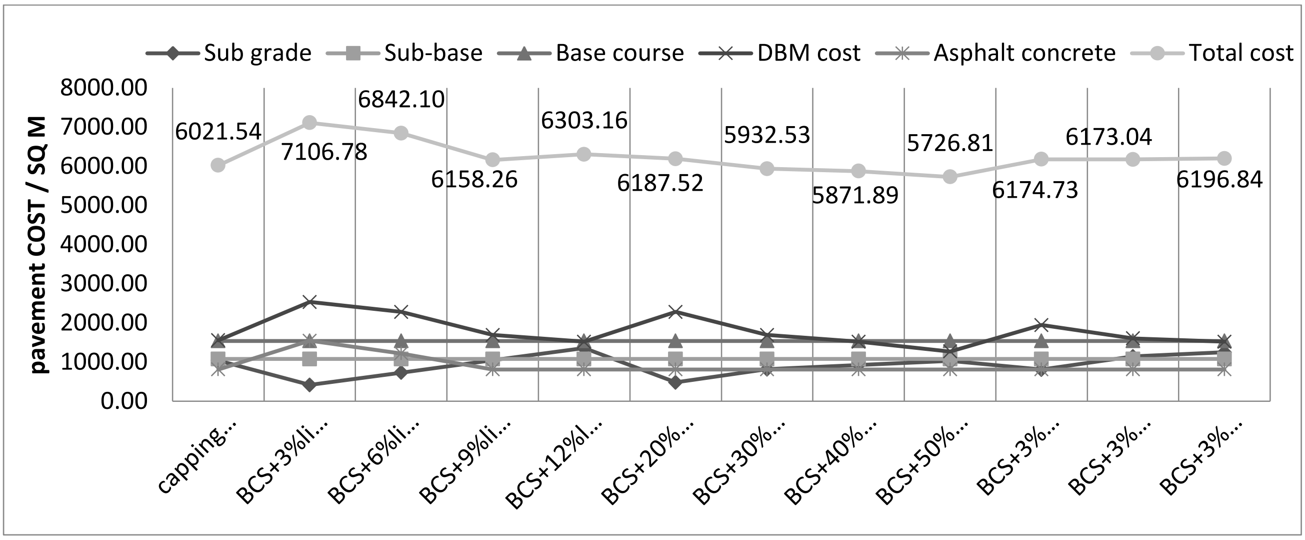

Figure 6: Variation of Pavement Cost with Pavement Components

CONCLUSIONS

This study aimed to find the variation in the cost of pavement in which weak subgrade soil was modified with lime and SD. From the results and discussion, it can be concluded that:

I. The weak subgrade is identified as ML soil (Inorganic silts with none to low plasticity) with LL, PL, PI, OMC and MDD as 34, 26.41, 7.59, 11.15% and 1.76 g/cc respectively. The dry density varied from 1.788 to 1.832 with a maximum value at 50% SD addition.

II. The experimentally obtained soaked CBR values showed continuous rising trend with maximum value as 12 for 12% lime addition which is 3 times greater compared with 4% value for soil whereas maximum value as 15% for 50% addition of SD which was 275% more compared with 0% addition of SD.

III. The maximum and minimum pavement cost was RS 77106.78 and RS 5726.81 for 3% lime and 50% SD addition respectively.

IV. The local weak soil can be improvised for highway construction as the geotechnical properties were improved for 250 msa design traffic.

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ISSN NO. 2091-1742

SCITECH NEPAL

Journal of Scientific and Technical Studies
Nepal Engineering College, Pokhara University

Research Article

DOI:10.3126/scitech.v17i1.60492

Machine-Learning Based Prediction of Lung Cancer

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Received: April 20, 2023
Accepted: October 10, 2023

Abstract

The incidence of lung cancer has now exceeded all other types of cancer globally, making it the leading cause of cancer-related deaths. Compared to other types of cancer, lung cancer has a poor prognosis and high mortality rate, making it challenging for humans to accurately predict its incidence rates. The goal of the study is to implement machine learning techniques for the early detection of lung cancer, which can increase patient survival rates. To find the most important factors and predict the possibility of lung cancer, a variety of data mining approaches, including logistic regression, k-means, and apriori algorithms are used in this study. Age, gender, smoking habit, and medical history are a few of the factors included in the dataset used for the study. The logistic regression classifier shows an accuracy of 95% for the classification of lung cancer in patients. The simulation results obtained from the k-means clustering algorithm shows that the main causes for the possible occurrence of lung cancer are chronic diseases, fatigue, allergy, wheezing, alcohol consumption habit, and breath problem. Similarly, according to the association rule's findings, there is no chance of lung cancer developing in a non-drinker who is free of peer pressure, allergies, and wheezing issues.

Keywords: Apriori; classification; data mining; k-means; logistic regression; lung cancer; machine learning; prediction

Introduction

Lung cancer is considered a leading cause of cancer-related deaths globally; with many people succumbing to the disease every year. This is largely due to increased smoking habits and air pollution; which have made lung cancer a serious and ongoing global issue. People who have had previous lung diseases are at a higher risk of developing lung cancer. Smoking and tobacco consumption are considered the primary factors responsible for lung cancer. Detecting lung cancer early can greatly improve the chances of successful treatment and save lives.

As one of the major causes of death worldwide; cancer begins when a few cells in a body start to grow in an uncontrolled manner. Every type of tumor arises through "hereditary adjustments" and "epigenetic changes" to the DNA genome; even though various tumor types differ in how their cells proliferate and spread. Recent studies have strengthened the argument that epigenetic changes are important to the emergence of human malignancies (Kumar & Rao; 2021). According to Singh & Gupta (2019); an estimated 1.7 million people die due to lung cancer. In approximately 80% of lung cancer cases worldwide; smoking is considered a primary cause. Including smoking; many other factors are also responsible for causing lung cancer.

Different types of machine learning algorithms can predict the relationship between risk factors and lung cancer. They provide precise analysis and predictions. In the last twenty years; artificial intelligence and machine learning algorithms have become increasingly essential in analyzing complex data and reaching reliable conclusions. Machine learning algorithms have been created to classify; forecast; or reduce the amount of raw data. In this study; we have used different machine learning algorithms to predict the possibility of the occurrence of lung cancer based on the participant's medical history and statistical data. The different machine learning algorithms used in this study are Logistic Regression; K-Means; and Apriori algorithms for classification; clustering; and association respectively.

The Kaggle repository was used to collect the dataset for this study (Kaggle; 2022). The dataset was pre-processed so that machine learning algorithms could use it. Using the data balancing technique; the unequal distribution of data across cancer and non-cancer classes was addressed. To determine the most accurate prediction model; the accuracy of each machine learning model is calculated and compared.

Related Works

Lung cancer is the major cause of cancer-related deaths globally; which is a serious and common disease. For patients to receive better care and experience better results; early detection and correct prognosis of lung cancer are crucial. Machine learning techniques have been used in recent years to categorize and predict lung cancer. Many machine-learning approaches are based on neural networks. Using labels from the original training data; this method entails categorizing the data into different groups. Several machine learning techniques; which may be roughly categorized as supervised or unsupervised methods; can be used to categorize data.

A unique multi-layered approach is proposed to construct a cancer risk prediction system that combines decision tree and clustering approaches by Ramachandran et al. (2014). The authors built a model that incorporates a decision tree as a classification algorithm and k-means as a clustering algorithm to detect cancer. A study conducted by Abdullah et al. (2021) examines the precision ratios of three classifiers; including support vector machine (SVM); k-nearest neighbor (k-NN); and convolutional neural network (CNN); in data taken from the UCI repository to find lung cancer at an early stage and possibly save many lives. The results of the experiment indicate that the SVM; which has an accuracy of 95.56%; obtains the best result; followed by CNN (92.11%) and KNN (88.40%).

In a study by Zhou et al. (2021); lung nodules on computed tomography (CT) images were accurately classified using deep learning approaches. High sensitivity and specificity were attained for their classification model; demonstrating the promise of machine learning techniques to assist in the diagnosis of lung cancer.

A study conducted by Tuncal et al. (2020) used support vector regression; a back-propagation learning algorithm; and a long-term memory network to analyze lung cancer data for eleven European countries with records going back to 1970. The findings show that all algorithms are capable of scoring highly when estimating incidence rates; although Support Vector Regression did better than the other approaches that were taken into account.

Danjuma (2015) conducted a study to identify and evaluate the performance of machine-learning algorithms in patients with lung cancer. On datasets for thoracic surgery adopted from the UCI repository; multilayer perceptron; J48; and the Naïve Bayes algorithms were utilized to train and evaluate models. To evaluate the performance of the classifier; a 10-fold cross-validation technique was used. With an accuracy of 82.3%; the comparative analysis reveals that the multilayer perceptron shows the best performance.

Kourou et al. (2015) examined several machine learning algorithms to assess the efficacy of ML techniques in cancer prognosis and prediction. They concluded that supervised models should be the primary subject of research while developing prediction algorithms. While Malvezzi et al. (2014) used a linear regression model to anticipate cancer mortality rates across the European Union; Ribes et al. (2014) employed Bayesian models to forecast both incidence and mortality rates in Catalonia. Random forest and Rule Induction Algorithms were used by Alhaj and Maghari (2017) to identify the cancer survival rates in the Gaza Strip.

Radhika et al. (2019) conducted a study to predict and categorize medical imaging data as a primary area of study. Comparative studies utilizing various machine learning methods revealed that the support vector machines had greater accuracy (99.2%). Naive Bayes offers 87.87% accuracy; Decision Tree offers 90%; and Logistic Regression offers 66.7%. The data set for the study was adopted from the UCI repository.

Another study by Sujitha and Seenivasagam (2021) proposed a machine learning-based model for predicting the survival rate of lung cancer patients. They used data from the Surveillance; Epidemiology; and End Results (SEER) program and found that their model outperformed traditional statistical models in predicting survival rates.

The categorization and prediction of lung cancer have shown considerable potential for data mining approaches. These methods can increase the precision and efficiency of diagnosis; which will benefit patients. However; more investigation is required to confirm the reliability and accuracy of these models as well as their application in clinical practice.

Materials and Methods

This section describes the methodology used in this study and it is divided into three sub-sections namely data description and preprocessing; algorithm description; and implementation procedure.

Data description and pre-processing

The dataset used for the study purpose is adopted from the Kaggle repository. There were 309 entries in total; including 162 male and 147 female. One target class and 15 attributes make up the data set. The attributes of the data set are listed in Table 1.

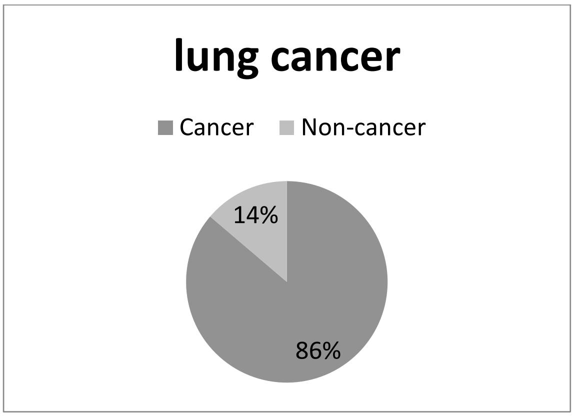
Table 1: Data set description

Attribute Name	Variable Type	Possible Value
Gender	Predictor Variable	Male; Female
Age	Predictor Variable	21 to 87
Smoking	Predictor Variable	Yes; No
Yellow_finger	Predictor Variable	Yes; No
Anxiety	Predictor Variable	Yes; No
Peer_pressure	Predictor Variable	Yes; No
Chronic diseases	Predictor Variable	Yes; No
Fatigue	Predictor Variable	Yes; No
Allergy	Predictor Variable	Yes; No
Wheezing	Predictor Variable	Yes; No
Alcohol consuming	Predictor Variable	Yes; No
Coughing	Predictor Variable	Yes; No
Shortness of breath	Predictor Variable	Yes; No
Swallowing difficulty	Predictor Variable	Yes; No
Chest pain	Predictor Variable	Yes; No
Lung_cancer	Response Variable	YES; NO

The data set available in the data repository might not be balanced or complete. The missing values and noise in data may affect negatively in final prediction. The data preprocessing technique is implemented to balance the dataset to achieve better accuracy. At this point; the null values are verified; and corrected. The preprocessing processes for the dataset include feature selection; value reduction; and normalization.

The first step in data preprocessing is checking for null values and if occurs it was filled by using the supervised filter in WEKA. In the next step; the numeric values were converted to categorical values as most of the values are in numeric form in the original data set. In original data set '2' was used to represent 'YES' and '1' was used for 'NO'. For this; we have replaced the value '2' with 'Yes' and '1' with 'No'. To make it more understandable; the values of age attribute 'M' was replaced by 'male'; and 'F' was replaced with 'female'.

The target variable (lung cancer) column in the study's dataset had a value of "YES" in 270 rows whereas "NO" was present in just 39 rows; indicating a substantial amount of imbalance. If such uneven data is not regulated; predictions and outcomes are useless. 33 duplicate entries in the data set were also deleted. The dataset now contains 276 entries; 238 entries with cancer; and 38 entries without cancer after the duplicate items have been removed. To balance the uneven distribution of cancer and non-cancer classes in the data set; SMOTE technique was applied in this study to oversample the minority class "non-cancer". The distribution of the data set based on the response variable before and after sampling is shown in Figure 1.



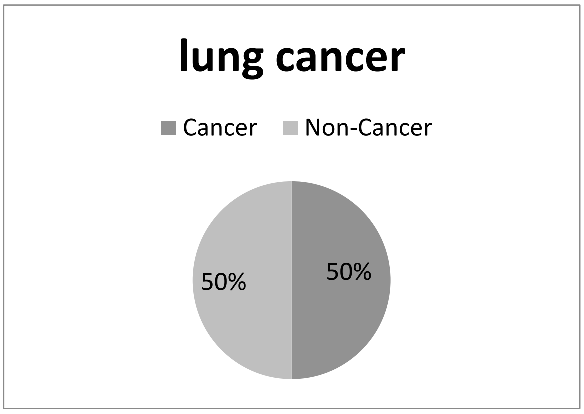


Figure 1 (a): Data before sampling **Figure 1 (b):** Data after sampling

After balancing the data set; the next step is to develop the model. A test set and training set is created from the preprocessed data. A 10-fold cross-validation approach is used to find the performance of the machine learning algorithm. 90% of the total dataset is randomly chosen as the training set for the 10-fold cross-validation approach; while the remaining 10% is chosen as the test set. After dividing the dataset; we utilized classification; clustering; and association methods to train the model.

Algorithm description

Logistic Regression

Regression methodology known as logistic regression foresees a categorical dependent variable. To assess the statistical significance of the variables; the logistic regression equation includes the maximum likelihood ratio (Hosmer et al. 2013). The main objective of logistic regression is to estimate the probability of the response variable based on the values of one or more predictor variables or features.

Based on the values of a collection of predictor variables; logistic regression is effective at predicting the existence or absence of a characteristic or outcome. It is useful for models when the dependent variable is categorical even though it resembles a linear regression model (Kurt et al. 2008). Since there are only two possible values for the output attribute in the data set; logistic regression was selected in this instance.

The probability of the response variable is produced by the logistic regression model; which is a linear model that has been converted using a logistic or sigmoid function. Any real-valued input is translated by the logistic function; which is an S-shaped curve; into a probability between 0 and 1 (Hosmer et al. 2013). A maximum likelihood strategy is used to estimate the logistic regression model; to identify the parameter values that maximize the likelihood of the observed data.

K-means Algorithm

In unsupervised machine learning; the k-means algorithm is a common clustering algorithm. A set of data points is divided into k clusters using k-means; where k is the predetermined number of clusters. The goal of clustering is to find commonalities and designs in large data sets by dividing them into groups (Mohamad & Usman 2013). The k-means algorithm can decrease the cost function of clustering through the utilization of a distance function that matches categorical items; modes (rather than cluster means); and an intensity mechanism that enhances the modes during clustering. It is defined as a set X = X1;...; Xn of objects of n numeric values; a natural number k n; and a measured distance is given; the k-means algorithm seeks to divide X into m nonempty disjoint clusters Y1;...; Ym with Yi Yj = and m i=1 Yi = X so that the sum of the squared difference between data items and the data cluster centers is reduced (San et al. 2004).

Apriori Algorithm

The a priori algorithm is a group of steps for figuring out the much earlier forms set in a specific database. The data mining technique repeats the join and prune procedures until the most common item set is generated. The main goal of the apriori algorithm is to establish an association rule between different entities. The relationship between two or more variables is explained by the association rule.

In the first iteration; set X directly comprises the first selection item set Y1. If X = x1; x2... xn; then Y1=x1; x2;....; xn. First; the candidate item set Yk for the K-th iteration emerges from the common items Lk-1 found in the previous iteration. Then; for each item in the set; assign a counter with a starting value of zero and scan the data file Z in the correct sequential order. The counter for those sets will rise as long as each activity is present in each item set. After all; relationships have been scanned; the support level could be determined based on the real value of |Z| and the negligible support level of a particular Yk of the set of common items. Continue until there are no new items (Yabing 2013).

Implementation procedure

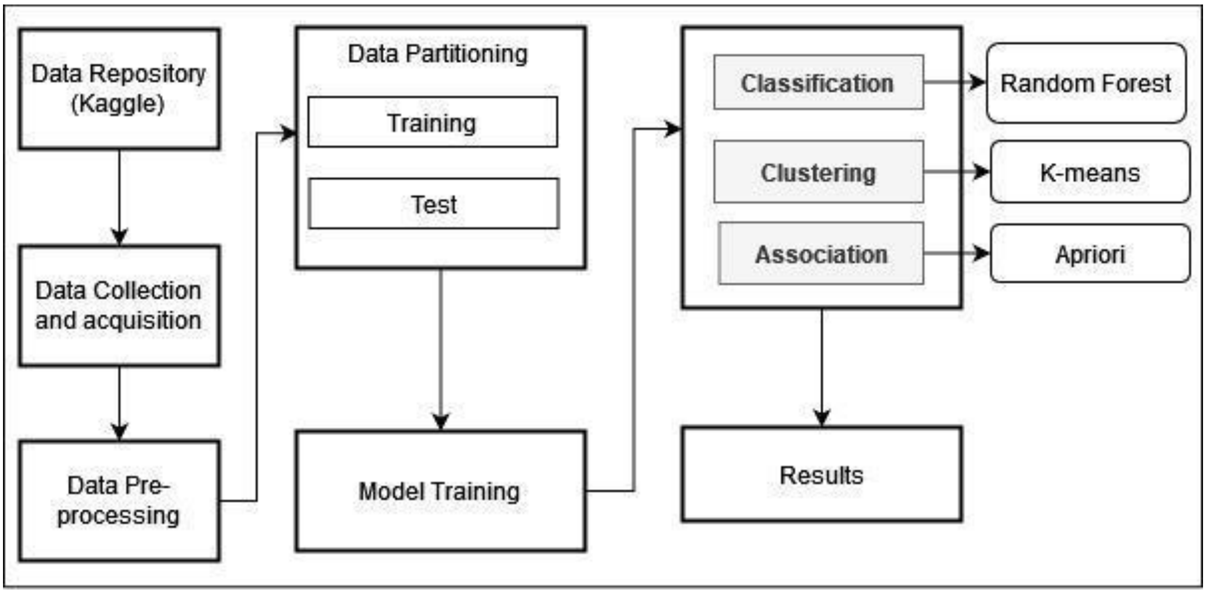


Figure 2: Working procedure

The proposed implementation procedure is illustrated in Figure 2. The implementation procedure involves different stages from data acquisition the result acquisition. The first step is data collection and acquisition following the preprocessing of data. Data partitioning is the next step. In data partitioning; we split data into training and test sets for model training. In model training; we have used classification; clustering; and association algorithms. For classification; the Logistic Regression algorithm is used; the k-means algorithm is used for clustering; and for association; apriori algorithm is used. After training the given model; we achieve the corresponding results; and the achieved result is represented according to the objective of the study.

Result and Discussion

The dataset adopted from the Kaggle repository was trained using WEKA 3.8.6 environment (WEKA 2022). A 10-fold cross-validation approach is used for training and testing the data set. A 90% of the total dataset is randomly chosen as the training set for the 10-fold cross-validation approach; while the remaining 10% is chosen as the test set. The details result of the 10-fold cross-validation for Logistic Regression is depicted in Figure 5 to Figure 8 in the supplementary section.

Classification Results

The process of classification involves developing a model that can categorize objects and predict their missing features. The outcome of the classification process can be described using different metrics; but for this paper; we have focused on measures such as accuracy; precision; recall; and f-measure. The result obtained by implementing logistic regression classifier is illustrated in Table 2.

Table 2: Performance measure of Logistic Regression Classifier

Classifier	Accuracy	Precision	Recall	F-Measure
Logistic Regression	0.950	0.954	0.950	0.952

Table 3: Confusion Metrics for the Logistic Regression Classifier

	a	b
a	226	12
b	11	227

a = Yes (the participant has the possibility of occurring lung cancer)

b = No (the participant does not have the possibility of occurrence of lung cancer)

The result obtained after training the model shows that the logistic regression classifier performed well in the detection of lung cancer with an accuracy of 95%. Other measures such as precision; recall; and f-measure for the classifier are measured at 95.4%; 95%; and 95.2% respectively. The result indicates that 95% of data has been classified correctly for the prediction of lung cancer and only 5% of data has been classified incorrectly.

The confusion metrics shown in Table 3 indicate that 226 instances were correctly classified as possibility of occurring lung cancer and 12 instances were incorrectly classified as they do not have the possibility of occurrence of lung cancer. Similarly; 227 instances were correctly classified as they do not have the possibility of occurrence of lung cancer; and 11 instances were incorrectly classified as they have the possibility of occurrence of lung cancer. In this way; a total of 95% of instances were correctly classified and only 5% of instances are incorrectly classified.

A receiver operating characteristic (ROC) curve is used as the graphic depiction of the classifier's results. The ROC curve for the logistic regression classifier is shown in Figure 3.

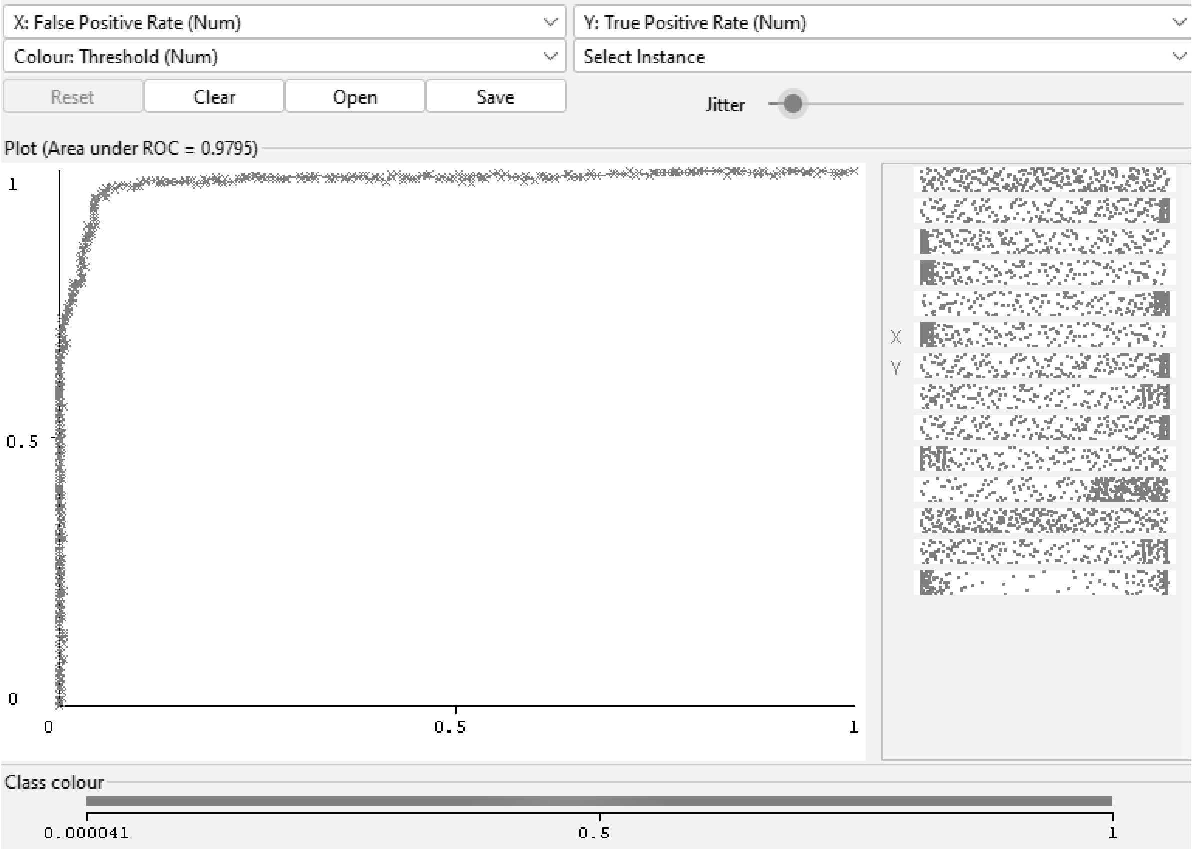


Figure 3: The ROC curve for the Logistic Regression classifier

The Receiver Operator Characteristic (ROC) curve is a measurement tool for binary classification problems. In essence; it distinguishes between "signal" and "noise" by comparing the true positive rate (TPR) against the false positive rate (FPR) at various threshold values. The area under the curve (AUC); used as a summary of the ROC curve; quantifies a classifier's ability to distinguish between classes. From the ROC curve for the logistic regression classifier; we can see that the value of AUC is 0.9795; this indicates that the classifier has performed in a better way to classify true positive and true negative cases.

Clustering Results

Clustering is the process of finding groups of things that are similar to one another yet distinct from other groups of objects (Prabha & Shanavas 2014). The k-means clustering algorithm was used in this study and the result obtained from the simulation is depicted in Table 4.

From the clustering result; we can conclude that the males with an average age of 64 having chronic diseases; fatigue; allergy; wheezing; alcohol consumption habit; and breath problem have the possibility of lung cancer. Similarly; females with an average age of 61 who does not have alcohol consumption habit; no chronic diseases; no peer pressure but have a smoking habit; yellow fingers; and fatigue does not have a chance of occurrence of lung cancer.

Table 4: Performance of k-means clustering algorithm

Attribute	**Full Data (476)**	**Cluster 0 (171)**	**Cluster 1 (305)**
Gender	Male	Male	Female
Age	62	64	61
Smoking	Yes	No	Yes
Yellow_fingers	Yes	No	Yes
Anxiety	No	No	No
Peer_pressure	No	No	No
Chronic diseases	No	Yes	No
Fatigue	Yes	Yes	Yes
Allergy	No	Yes	No
Wheezing	No	Yes	No
Alcohol Consuming	No	Yes	No
Coughing	No	Yes	No
Shortness of breath	Yes	Yes	Yes
Swallowing difficulties	No	No	No
Chest pain	No	Yes	No
Lung_cancer	***YES***	***YES***	***NO***

Association Results

The association data mining method can be applied to datasets to uncover intriguing correlations; recurrent patterns; interrelations; or causal structures between groups of elements. The association rule model was developed in WEKA using the apriori algorithm. The result obtained from the simulation is illustrated in Figure 4.

From the result obtained from the simulation; it is found that a non-alcoholic person without peer pressure and allergy; and not having a wheezing problem does not have any possibility of occurring lung cancer.

1. PEER_PRESSURE=No ALLERGY =No WHEEZING=No SWALLOWING DIFFICULTY=No 216 ==> ALCOHOL CONSUMING=No 216
2. PEER_PRESSURE=No ALLERGY =No SWALLOWING DIFFICULTY=No LUNG_CANCER=NO 218 ==> ALCOHOL CONSUMING=No 217
3. PEER_PRESSURE=No WHEEZING=No LUNG_CANCER=NO 217 ==> ALCOHOL CONSUMING=No 216
4. PEER_PRESSURE=No ALLERGY =No LUNG_CANCER=NO 223 ==> ALCOHOL CONSUMING=No 221
5. ALCOHOL CONSUMING=No LUNG_CANCER=NO 231 ==> ALLERGY =No 228

Figure 4: Performance of Apriori algorithm.

Conclusion

Data mining algorithms analyze a variety of variables; including patient medical history; and statistical data; to find patterns and connections that may not be immediately obvious to human observers. Different data mining techniques were used in this study to classify and predict the possibility of occurrence of the lung cancer in participants. The logistic regression classifier; k-means clustering algorithm; and apriori algorithm are used for the prediction of lung cancer. The Logistic Regression classifier has predicted the possibility of lung cancer in participants in a better way with an accuracy of 95%. The result obtained from the data mining techniques shows that males having chronic diseases; fatigue; allergies; wheezing; alcohol consumption habits; and breathing problems have a high chance of occurrence of lung cancer even if the participant does not have a smoking habit. Similarly; females are found to be safe from lung cancer. The main parameters that promote the occurrence of lung cancer are found to be peer pressure; allergy; alcohol consumption; and chronic diseases. This study helps medical personnel to predict and protect individuals from lung cancer.

This study was conducted using secondary data acquired from an online data repository. In the future; the study can be extended by using primary data collected directly from hospitals and health organizations and implementing the self-developed algorithms.

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Supplementary Material

The details output of 10-fold cross-validation for the Logistic Regression classifier is shown in Figures 5 to 8. Basic run information for Logistic Regression is shown in Figure 5. Figure 6 depicts the training set description for 10-fold cross-validation for Logistic Regression. Odds ratios are shown in Figure 7 and the summary of the results is shown in Figure 8.

```
=== Run information ===

Scheme:       weka.classifiers.functions.Logistic -R 1.0E-8 -M -1 -num-decimal-places 4
Relation:     lung cancer_processed data
Instances:    476
Attributes:   16
              GENDER
              AGE
              SMOKING
              YELLOW_FINGERS
              ANXIETY
              PEER_PRESSURE
              CHRONIC DISEASE
              FATIGUE
              ALLERGY
              WHEEZING
              ALCOHOL CONSUMING
              COUGHING
              SHORTNESS OF BREATH
              SWALLOWING DIFFICULTY
              CHEST PAIN
              LUNG_CANCER
Test mode:    10-fold cross-validation
```

Figure 5: Basic run information for Logistic Regression

```
=== Classifier model (full training set) ===

Logistic Regression with ridge parameter of 1.0E-8
Coefficients...
                              Class
Variable                        YES
===================================
GENDER=Female                1.2365
AGE                          0.0226
SMOKING=Yes                   2.383
YELLOW_FINGERS=No           -1.9578
ANXIETY=No                  -0.2635
PEER_PRESSURE=Yes            2.6797
CHRONIC DISEASE=Yes          4.4871
FATIGUE =No                 -3.3509
ALLERGY =Yes                 1.9347
WHEEZING=No                 -1.1332
ALCOHOL CONSUMING=No        -2.4093
COUGHING=No                 -3.9458
SHORTNESS OF BREATH=No       1.0187
SWALLOWING DIFFICULTY=No    -4.4183
CHEST PAIN=No               -0.7539
Intercept                    5.2815
```

Figure 6: Training set description for 10-fold cross-validation for Logistic Regression

```
Odds Ratios...
                                   Class
Variable                             YES
===================================
GENDER=Female                     3.4434
AGE                               1.0229
SMOKING=Yes                      10.8371
YELLOW_FINGERS=No                 0.1412
ANXIETY=No                        0.7684
PEER_PRESSURE=Yes                  14.58
CHRONIC DISEASE=Yes              88.8635
FATIGUE =No                       0.0351
ALLERGY =Yes                      6.9216
WHEEZING=No                        0.322
ALCOHOL CONSUMING=No              0.0899
COUGHING=No                       0.0193
SHORTNESS OF BREATH=No            2.7696
SWALLOWING DIFFICULTY=No          0.0121
CHEST PAIN=No                     0.4705
```

Figure 7: Odds Ratios

```
Time taken to build model: 0.1 seconds

=== Stratified cross-validation ===
=== Summary ===

Correctly Classified Instances         453               95.1681 %
Incorrectly Classified Instances        23                4.8319 %
Kappa statistic                          0.9034
Mean absolute error                      0.0746
Root mean squared error                  0.2083
Relative absolute error                 14.9208 %
Root relative squared error             41.6558 %
Total Number of Instances              476

=== Detailed Accuracy By Class ===

                 TP Rate  FP Rate  Precision  Recall   F-Measure  MCC      ROC Area  PRC Area  Class
                 0.950    0.046    0.954      0.950    0.952      0.903    0.980     0.983     YES
                 0.954    0.050    0.950      0.954    0.952      0.903    0.980     0.974     NO
Weighted Avg.    0.952    0.048    0.952      0.952    0.952      0.903    0.980     0.979

=== Confusion Matrix ===

   a   b   <-- classified as
 226  12 |   a = YES
  11 227 |   b = NO
```

Figure 8: Summary of the result for Logistic Regression

ISSN NO. 2091-1742

SCITECH NEPAL

Journal of Scientific and Technical Studies
Nepal Engineering College, Pokhara University

Research Article

DOI:10.3126/scitech.v17i1.60493

Assessment of Rainfall-Induced Shallow Landslides in Kavre District, Nepal

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Received: May 7, 2023
Accepted: October 8, 2023

ABSTRACT

Steep slopes and fragile geology make Nepal a landslide-prone country. Kavre district experiences a large number of shallow landslides in the monsoon season. This research aims to establish rainfall intensity relation with rainfall duration along with rainfall threshold for the initiation of shallow landslides in the Kavre district, Nepal. The six rain gauge stations' rainfall data in the Kavre district from 1987-2016 and landslide data from 1987-2013 were used for establishing rainfall thresholds. The rainfall that risks the landslide event was sorted and the regression analysis of the rainfall and landslide yielded a relationship $I = 86.738 * D^{-1.066}$ having a coefficient of determination $R^2 = 0.1257$. The analysis also incorporates the drawing of the lower boundary which is the 48-h rainfall depth that indicates the rainfall threshold for the initiation of landslide in the Kavre district. The 48-hour rainfall intensity and rainfall depth at which the risk of landslide initiation is high in the Kavre district is 1.4 mm/h. and 67.18mm. Analysis of the antecedent rainfall and the landslide occurrence event indicated that the daily rainfall at failure conditions is better correlated with 3 days of cumulative rainfall at failure than with 5, 7, 10, 15, and 30 days. The study is significant for rainfall-induced landslide disaster management.

Keywords: Antecedent rainfall; Rainfall duration; Rainfall intensity; Rainfall thresholds; Shallow landslides

INTRODUCTION

Steep slopes and fragile geology make Nepal a landslide-prone country. There were 7295 disasters from 14 April 2022 to 12 September 2023 in Nepal, 657 people lost their lives with an estimated loss of NRs. 4,120,887,197. MoHA (2023) reported that 66 landslides from 15 April 2022 to 8 September 2023 in Kavre District resulted in the death of 9 persons and an estimated loss of NRs. 50,216,000 (MoHA, 2023). There were 302 landslide disasters in total from 14 April to 11 August 2019 in Nepal in which 57 people lost their lives and an estimated loss of NRs. 53,953,000 (MoHA, 2019). Kavre District experiences a large number of shallow landslides in the monsoon season. Six people lost their lives in a landslide on 23 July 2002 in Kavre District (DPA, 2002); about 2000 households in places like Pokharichaur, Devitar, Bhimkhori, Maadan Kundari, Kattike Deurali, Kaidabhanjyang, and Chunche Danda in this district are at high risk of landslides (Adhikari, 2015). The hydrologic characteristics of an area play an important role in landslide occurrences. Landslides affect human life and economic activities and also lead to sedimentation in rivers affecting the hydropower structure and degradation of water quality. It affects the biotic life leading to environmental degradation (Sanstha, 2016). Most of the landslide studies carried out in Nepal are on landslide susceptibility mapping and hazard mapping, and limited studies are found on rainfall thresholds. (Gautam et al., 2021) conducted landslide susceptibility mapping of the Indrawati Watershed, a high mountain area of central Nepal employing four approaches: frequency ratio, logistic regression, artificial neural network (ANN), and support vector machines, and found that Eutric cambisols soil type has a strong association with landslide occurrence; he further added that the ANN approach possessed the best predictive capability and yielded more reliable results. (Devkota et al., 2013) assessed landslide susceptibility mapping utilizing three models - index entropy, logistic regression, and certainty factor, in GIS applying to the Mugling-Narayanghat road section, Nepal, and found all three models showed reasonably good accuracy in predicting landslide susceptibility. (Kayastha et al., 2013) applied the analytical hierarchy process in the Tinau watershed, Nepal to prepare a landslide susceptibility map, and found that landslide susceptibility levels agree with past landslide occurrences.

Mandal & Sarkar (2021) estimated the rainfall thresholds of shallow landslides along National Highway-10 in the Darjeeling Himalayas. It identified 288 rainfall events that caused 681 landslides. The rainfall thresholds were calculated using a power law. The threshold rainfall intensity and duration threshold were calculated according to lithostratigraphy. Koley et al. (2019) assessed rainfall thresholds for landslide events in the Sikkim Himalaya, India. Using data from daily rainfall, they attempted to define the local facet of thresholds for landslides. The study examined 210 landslides, which were grouped into 155 landslides connected to rainfall information. The threshold relationship for landslide onset was determined by fitting the lower boundary limit. The short-term (24-hour) rainfall events that increased the risk of landslides along the road corridor in Sikkim and 10-day and 20-day antecedent rainfall needed for the onset of landslides were found. Dikshit et al. (2019) estimated the rainfall thresholds for the manifestation of landslides in the Bhutan Himalayas. The relationship was established for Chukha Dzongkhag using a power law fitted to the lower limit of rainfall conditions plotted in logarithmic scales. Moreover, the study includes antecedent rainfall of 3 to 30 days focusing on 10 days and 20 days. Dikshit & Satyam (2018) estimated rainfall thresholds for landslide occurrences in the Kalimpong area situated in the Darjeeling Himalayas, India. The rainfall data and landslide data were analyzed and rainfall thresholds were calculated using power law. The study analyzed daily rainfall before failure and rainfall over periods of 3, 7, 10, 15, 20, and 30 days. Lee (2016) conducted a correlation analysis between rainfall and landslides and made predictions based on climate change. The climate change scenarios were examined by applying the GCM model and geo-statistics method Co-kriging for interpolation. Larsen & Simon (1993) studied rainfall intensity-duration thresholds for landslides located in humid tropical environments, in Puerto Rico; analyzing 256 storms, 41 storms were extracted that resulted in landslides, and a lower boundary line was fitted to define rainfall thresholds. In the Indian Garhwal Himalayas, near the Rishikesh-Badrinath National Highway, Kanungo & Sharma (2014) studied rainfall thresholds for the prediction of shallow landslides in road segments in and near the Karnaprayag-Chamoli-Joshimath region; an empirical intensity duration thresholds were developed. They further studied the 10-day and 20-day antecedent rainfall before failure. Dahal & Hasegawa (2008) conducted research on rainfall thresholds establishing rainfall intensity-duration threshold and normalized rainfall threshold followed by a study of antecedent rainfall of 3,5,10,20 and 30 days. Shrestha et al. (2008) researched creeping landslide for effective use in planning and execution of slope stability enhancement measures in Otoyo Town, Shikoku, Western Japan, utilizing a three-dimensional model. Giannecchini (2006) developed the threshold for soil slip initiation in terms of mean intensity, duration, and mean annual precipitation (MAP) for the southern Apuan Alps, Italy.

Studies on rainfall-induced landslides and determining their threshold haven't been carried out in the Kavre District. Rainfall is critical in contributing to landslides, and the study of rainfall-induced landslides is significant in disaster management. In today's climate change setting, it has become critical to investigate climate change impact on rainfall-induced landslides. This study aims to determine the rainfall threshold for the initiation of shallow landslides in the Kavre District, Nepal.

MATERIALS AND METHODS

Study Area

Kavre District lies in the Bagmati Province, South-East of Kathmandu at a distance of 25 km. It is bounded on the East and East-South by Sindhuli, on the North by Sindhupalchowk, Kathmandu on the West, Lalitpur on the West-South, and Makwanpur in the South covering an area of 1396 km^2. Its elevation ranges from 280m to 3018m, climate ranges from sub-tropical to temperate but most regions have sub-tropical climates. The mean annual rainfall is 1121mm. Sunkoshi and Roshi are major rivers of the Kavre District. The Kavre District map with landslide area and no landslide areas are shown in Figure 1.

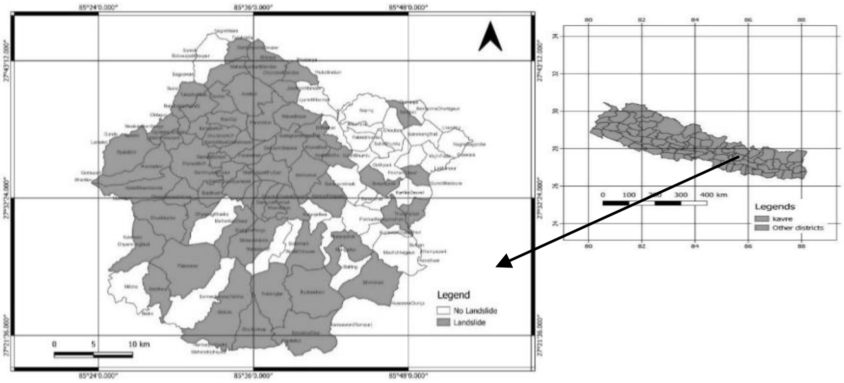

Figure 1 Kavre District Map with location of landslide areas

Methods

The shape file of the Kavre District was downloaded (www.diva-gis.org/gdata). The landslide locations were obtained from Desinventar, the disaster inventory management system. The landslide locations are depicted in color on the map using QGIS showing landslide and no landslide area.

The six rain gauge stations' rainfall data of the Kavre District from 1987-2016 was collected. Landslide data from 1987-2013 of the Kavre district were downloaded from Desinventar and used for establishing rainfall thresholds. The daily rainfall and antecedent rainfall corresponding to landslide occurrence events were analyzed taking Khopasi rain gauge station as the base station. The rainfall intensity (I) is calculated by dividing the accumulative rainfall by the total duration (D). A non-linear regression analysis was carried out and its line was drawn on a logarithmic scale. The relationship was developed concerning rainfall intensity I and duration D employing the power law (equation 1).

$$I = \alpha * D^{\beta} \qquad (1)$$

The analysis incorporates the drawing of the lower boundary that is the 48-h rainfall depth that indicates the rainfall threshold above which the initiation of landslide is high. The rain from the beginning to the day of the landslide event was taken as antecedent rainfall. The linear regression analysis was carried out for the antecedent rainfall study and plotted on an arithmetic scale.

RESULTS AND DISCUSSIONS

Rainfall Threshold

The non-linear regression analysis of the rainfall and landslide yielded rainfall thresholds with the creation of the best-suited regression line having a coefficient of determination R^2 = 0.1257. Equation 2 illustrates the relationship between rainfall duration (D) in hours and intensity (I) in mm/h. The rainfall threshold regression line graph is shown in Figure 2.

$I = 86.738 * D^{-1.066}$ (2)

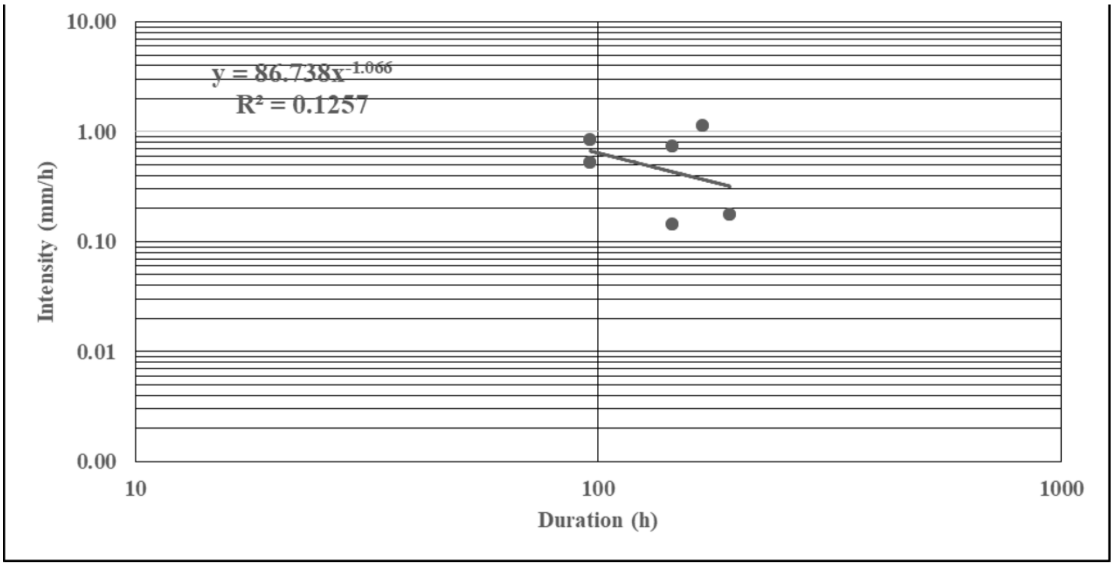

Figure 2 Rainfall intensity-Duration threshold for initiation of a landslide

On substitution of the duration value in the above-developed equation it was found that at 48-h all the data at which the landslide had occurred was observed to be above the 48-h boundary line which is said to be the threshold. The 48-h threshold boundary line is shown in Figure 3. Utilizing the developed relationship (equation 2) the rainfall intensity corresponding to the 48-h duration is 1.4 mm/h (67.18 mm in 48 hours). Thus the rainfall intensity at which the possibility of landslide initiation is high in the Kavre District is 1.4 mm/h.

Various researchers have studied rainfall thresholds at the global, regional, and local levels. The rainfall thresholds can be broadly classified into physically based and empirically based rainfall thresholds. The empirical-based rainfall threshold studies have been carried out in the Lesser Himalayan region. The 24-hour rainfall of 0.95 mm/h in the Darjeeling Himalayas has a high risk of landslide initiation (Dikshit & Satyam, 2018). The short-term rainfall of 24 hours of 1.82mm/h increases the risk of landslides along the Sikkim road corridor (Koley et al., 2019). The 48-hour rainfall of 36.7mm can lead to landslides in the Kalimpong region, Darjeeling Himalayas (Teja et al., 2019).

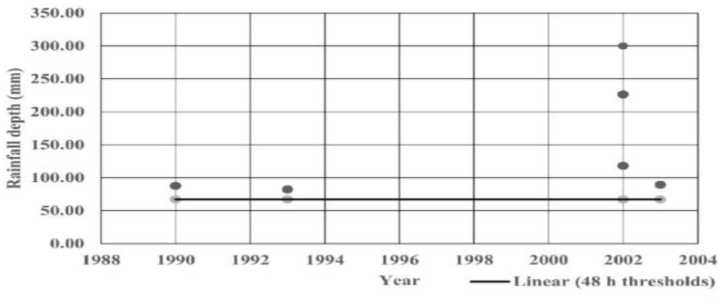

Figure 3 Rainfall threshold (mm)

The possibility of landslides by 24 hours of rain with a cumulative rainfall of 53 mm is high in Chukha Dzongkhag of Bhutan (Dikshit et al., 2019). The empirical intensity duration thresholds of 0.87 mm/h have a high likelihood of triggering landslides on the Rishikesh-Badrinath national highway (Kanungo & Sharma, 2014). The rainfall threshold exceeding 144mm of daily rainfall increases the risk of landslides in the Himalayan Mountains (Dahal & Hasegawa, 2008).

Antecedent Rainfall

The rainfall and cumulative rainfall on the day of failure were analyzed by linear regression. The coefficient of determination of a relationship between daily rainfall at failure and cumulative rainfall at failure R^2 is 0.3747. The relationship was identified for 5 days, 7 days, 10 days, 15 days, and 30 days but their coefficient of determination is lower than that of 3 days. This indicates that rainfall on the day of failure is better correlated with 3 days of antecedent rainfall. The daily rainfall at failure against cumulative rainfall at 3, 5, 7, 10, 15, and 30 days is shown in Figure 4.

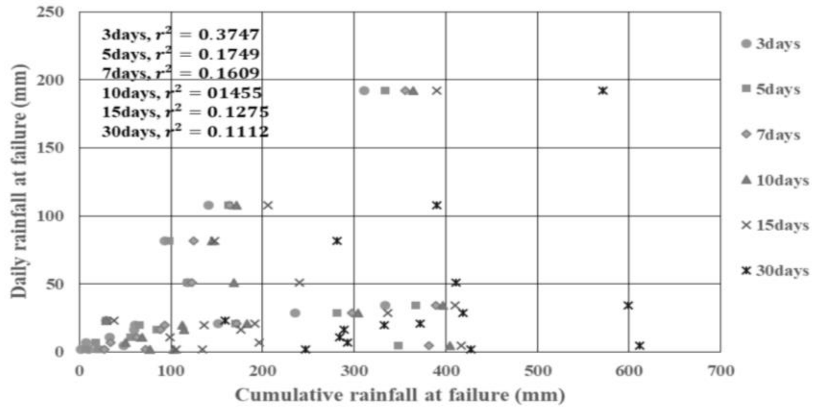

Figure 4 Daily rainfall versus Cumulative rainfall at failure

The antecedent rainfall effect and its contribution to triggering landslides have been studied in various regions of Lesser Himalaya and has been mentioned that its relationship is significant. The previous rainfall of three to five days is effective in causing landslides (Mandal & Sarkar, 2021). The 10-day and 20-day antecedent rainfall needed for the onset of landslides is 58mm and 139mm respectively (Koley et al., 2019). The antecedent rainfall study of 3 to 30 days was carried out in Bhutan and 10 days and 20 days rainfall initiating landslide was found to be 88mm and 142mm (Dikshit et al., 2019). (Dikshit & Satyam, 2018) mentioned the requisite of 88.37 and 133.5mm antecedent rainfall at 10-day and 20-day for landslide in Kalimpong region, India. (Kanungo & Sharma, 2014) discovered that 185 mm rainfall of in 20 days is necessary for the onset of landslides in the Garhwal Himalayas in India.

CONCLUSION

The 48-h rain intensity and rainfall depth at which the risk of landslide initiation is high in the Kavre District are 1.4mm/h and 67.18 mm respectively. The study found that the daily rainfall at failure and 3 days of antecedent rainfall at failure have a better correlation. The effect of cumulative rainfall is found to be lesser in 5, 7, 10, 15, and 30 days. The study of rainfall threshold helps in installing a landslide warning system. The study is significant for rainfall-induced landslide disaster management. Further research on landslides, using additional factors, is required in the Kavre District.

Acknowledgments

The author expresses his acknowledgment to Energize Nepal at Kathmandu University for providing academic support for pursuing a Ph.D., the author thanks the Department of Hydrology and Meteorology in Kathmandu, Nepal for providing the meteorological data. I would like to express my thankfulness to the reviewers, with their help this publication has become possible.

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ISSN NO. 2091-1742

SCITECH NEPAL

Journal of Scientific and Technical Studies
Nepal Engineering College, Pokhara University

Research Article

DOI:10.3126/scitech.v17i1.60494

Barriers to Implementing Safety Measures During COVID-19 Pandemic on Building Construction Projects in Nepal

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Received: May 9, 2023
Accepted: October 8, 2023

Abstract

The COVID-19 pandemic caused disruptions in building construction projects, with safety measures being a major concern for workers and the public. This study aims to assess the barriers to safety measures during the COVID-19 pandemic on building construction projects in Nepal. A total of 330 responses were collected from construction professionals in Nepal using a Likert scale. To ensure the data's suitability for factor analysis using Principal Component Analysis, Kaiser-Meyer-Olkin, Bartlett's Sphericity test, inter-component correlations, and Cronbach alpha scores for internal consistency were checked, and principal components were extracted. A 25-item safety barrier to safety measures in building construction projects during the COVID-19 pandemic was identified through an extensive review of the literature; six components were retained using Principal Component Analysis which represented the model of choice and explained 62.86 % of the data variance. The components were; inappropriate safety guidelines, psychological working pressure, inadequate hygiene monitoring and control, lack of safety awareness, improper working culture, and insufficient planning and scheduling. The internal consistency for the retained components was high; Cronbach α scores ranged from 0.72 to 0.796. “Inappropriate Safety Guidelines” was the most critical barrier to implementing safety measures during the COVID-19 pandemic in building construction projects, according to the rankings of the six identified components. It is recommended that construction professionals and regulatory bodies prioritize the development and adherence to robust safety protocols tailored to pandemic conditions. Regularly updating and reinforcing these guidelines will be crucial in safeguarding the health and well-being of workers while ensuring project continuity. Additionally, investing in thorough training and awareness programs can significantly mitigate this barrier's impact.

Keywords: Building construction projects; COVID-19 pandemic; Principal component analysis; Safety barriers; Safety measures

Introduction

The COVID-19 pandemic has had a remarkable impact on the safety sectors worldwide, and the construction industry has been greatly affected. Barriers to safety measures, in building construction projects due to COVID-19 have been considered important topics that plague stakeholders in building construction projects.

Neither the government nor the construction professionals in Nepal explored barriers to safety measures and barriers toward a possible pandemic unmanageable against which construction professionals must first identify the fundamental cause and its effect, after which they could prioritize prevention. However, many researchers have focused on the study of the effects or impact of COVID-19 on the construction industry but, limited insights have been provided for the major critical factors affected due to COVID-19, and barriers to safety measures, in building construction projects.

(Amoah and Simpeh, 2021) highlights challenges of COVID-19 safety measures on building construction projects. These challenges encompass a wide array of issues, including a pervasive ignorance regarding the pandemic's implications, the subpar quality of Personal Protective Equipment (PPE) provided by contractors, a concerning lack of adherence to health protocols, obstacles in sharing tools and equipment among workers, challenges related to public transportation due to restrictions, deeply ingrained superstitions, and noteworthy offsite behaviors. To overcome the situation created by the pandemic first the barriers are essential to be identified. This research aims to highlight the major barriers to implementing safety measures to reduce COVID-19 or similar pandemic situations in building construction projects in Nepal.

Literature Review

As the COVID-19 epidemic spread over the world, it caused enormous fear, tension, and stress, affecting practically everyone. It has an impact not just on people's physical health, but also on their mental health and sense of well-being even though employees were worried about job security, and were forced to work despite heightened health risks (Grensing-Pophal, 2020). The lack of control was another hazard, as much of the control that an employee has traditionally had over how they perform their job was been withheld by COVID-19 restrictions (Letitia, 2020).

(Pamidimukkala et al., 2021) highlighted major safety and health concerns that the construction workforce may face during the COVID-19 pandemic, mainly concerns about the risk of being exposed to the virus at work, family pressure, managing workloads, isolation, lack of access to equipment, low self-esteem, uncertainty about the future of the workforce, adapting to different workplaces and new schedules, and learning new communication tools and dealing with technical difficulties.

Major challenges to implementing safety measures in building construction projects from COVID-19 pandemic

Table 1: Barriers to implementing safety measures in building construction project due to COVID-19 pandemic

S. N	Major Safety Barriers Challenges	Sources
1	Ignorance of COVID-19	(Amoah and Simpeh, 2021)
2	Supply of poor PPEs by contractors	(Amoah and Simpeh, 2021)
3	Difficulty in sharing tools and equipment	(Amoah and Simpeh, 2021)
4	Lack of funds to implement COVID-19 measures	(Amoah and Simpeh, 2021)
5	Poor safety culture	(Maqbool and Khan, 2020)
6	Lack of strict enforcement of WHO regulations	(Maqbool and Khan, 2020)
7	Supply of wrong information by the workers	(Amoah and Simpeh, 2021)

8	Site access and egress (one-way systems; minimize congestion; hygiene; site inductions)	(Stiles et al., 2021)
9	Lack of resources for implementing public health and social measures	(Maqbool and Khan, 2020)
10	Sanitizing all materials	(Maqbool and Khan, 2020)
11	Lack of government policies	(Maqbool and Khan, 2020)
12	Personal protective equipment (PPE) shortages	(Alsharef et al., 2021)
13	New procedures to provide health and safety on-site	(Sierra, 2022)
14	Lack of safety leadership across the sector	(Stiles et al., 2021)
15	Lack of safety measures compliance	(Amoah and Simpeh, 2021)
16	Incorrect use of face mask	(Amoah and Simpeh, 2021)
17	Inadequate work planning to avoid close contact	(Stiles et al., 2021)
18	Inappropriate hygiene at the workplace (Hand washing, promoting hygiene, guidance for cleaning of hygiene areas)	(Stiles et al., 2021)
19	Learning new communication tools and dealing with technical difficulties.	(Bou Hatoum et al., 2021)
20	Thinking of personal and family while working	(Bou Hatoum et al., 2021)
21	Major concerns about the risk of being exposed to the virus at work	(Bou Hatoum et al., 2021)
22	Uncertainty about the future of the workplace	(O'Connor et al., 2021)
23	Taking responsibility for personal and family needs while working	(Bavel et al., 2020)
24	The feeling of not contributing enough to work	(CDC, 2022)
25	Adjusting to a different workplace and work schedule	(CDC, 2022)

Methodology

This study aimed to identify the primary barriers to implementing safety measures in building construction projects during the COVID-19 pandemic period in Nepal, utilizing quantitative research methods and a cross-sectional design. The targeted study population comprised project managers, contractors, consultancies, site engineers, suppliers, and procurement officers who were actively involved in various commercial and government building construction projects in Nepal. A total of 330 individuals were surveyed using a questionnaire that was prepared by reviewing previous research articles and included a Likert scale of five ordinal measures from one (1) to five (5) (1=Strongly Agree; 2=Agree; 3=Neutral; 4=Disagree; 5=Strongly Disagree). The respondents were asked to rank the barriers to implementing safety measures in building construction projects based on frequency of occurrence according to their judgment and experience. After data collection, the data was processed, cleaned, and prepared for analysis. Principal Component Analysis (PCA) was used to extract the major components underlying the dimensions of barriers to implementing safety measures, with the help of SPSS version 25.

Result and Discussion

Demographic and professional information of respondents:

Table 2: Demographic and professional information of respondents

Variable	Frequency	Percent	Variable	Frequency	Percentage
Age (in years)			*Education*		
20-25	159	48.18	Higher Secondary	74	22.42

26-35	135	40.91	Undergraduate	89	26.97
36-45	27	8.18	Graduate	98	29.70
46 or above	9	2.73	Postgraduate	69	20.91
Work experience (in year)			*Professionals*		
1-4	116	35.15	Contractor	122	36.97
5-8	117	35.45	Consultancy	95	28.79
9-12	58	17.58	Suppliers	46	13.94
13 or more	39	11.82	Site Engineers	67	20.30

Table 3 provides a comprehensive overview of the demographic and professional information of the respondents. In terms of age distribution, the majority fall within the 20-25 and 26-35, accounting for 48.18% and 40.91% respectively. The older age groups, 36-45 and 46 or more represent smaller segments, making up 8.18% and 2.73% respectively. Regarding educational attainment, the largest group has completed their graduate studies, comprising 29.70% of the respondents. This is closely followed by undergraduates at 26.97%, while those with higher secondary education make up 22.42%. Post-graduate education is the least common, constituting 20.91% of the sample.

A majority of respondents have accumulated 1-8 years of professional experience. Specifically, those with 1-4 years and 5-8 years of experience represent 35.15% and 35.45% respectively. Participants with 9-12 years of experience make up 17.58% of the group, while those with 13 or more years of experience constitute 11.82%.

In terms of professions, the largest group is comprised of Contractors at 36.97%, followed by Consultancy professionals at 28.79%. Site Engineers make up a substantial portion at 20.30%, while Suppliers represent the smallest category, accounting for 13.94%. This data paints a vivid picture of a diverse and dynamic respondent population, showcasing a broad range of ages, educational backgrounds, work experiences, and professional roles within the sample group.

Reliability Analysis:

Cronbach's alpha (α) was employed to assess the internal consistency of the factors related to barriers to implementing safety measures. The obtained alpha values indicated a high level of reliability 0.802, which exceeded the recommended threshold of 0.70 proposed by (Nunnally, 1978).

Kaiser–Meyer–Olkin (KMO) and Bartlett's tests:

Kaiser–Meyer–Olkin (KMO) and Bartlett's tests were performed to examine the suitability of these data for PCA. The KMO measure of sampling adequacy of items was performed and found 0.829, in the meritorious range according to Kaiser (1974). Additionally, Bartlett's test was significant ($\chi2$ = 1449.595, df = 300, Sig. = 0.000), indicating a significant correlation among the variables and thus making it suitable for factor analysis (Shrestha et al., 2021).

Factor extraction for safety measures barriers:

The Scree test and eigenvalue were used to identify six components through Varimax rotation. Based on the results shown in Figure 1, it was found that there are six factors with eigenvalues greater than one that contribute significantly to the total variability observed in the data. On the other hand, the remaining factors only account for a minor proportion of the variability and are therefore considered less important (Shrestha et al., 2021).

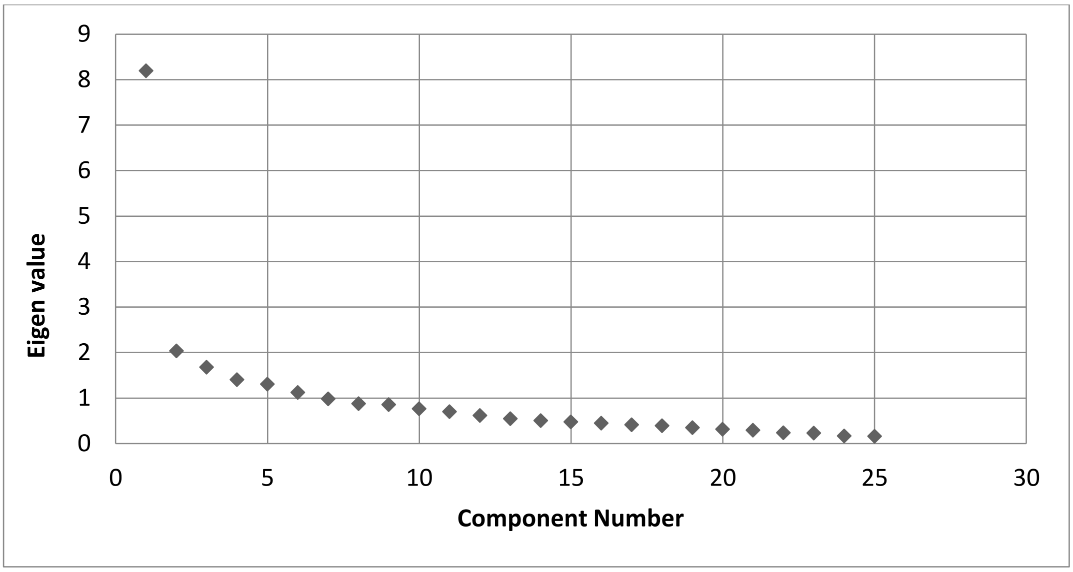

Figure 1: Scree Plot

In Table 3, each factor is presented with its corresponding eigenvalue and percentage of variance explained by each component.

Table 3. Eigenvalue and total variance explained by the components

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	8.189	32.756	32.756	8.189	32.756	32.756	4.323	17.293	17.293
2	2.031	8.125	40.882	2.031	8.125	40.882	3.616	14.465	31.758
3	1.673	6.690	47.572	1.673	6.690	47.572	2.814	11.258	43.016
4	1.399	5.595	53.167	1.399	5.595	53.167	1.964	7.857	50.873
5	1.301	5.205	58.372	1.301	5.205	58.372	1.548	6.192	57.065
6	1.122	4.487	62.859	1.122	4.487	62.859	1.449	5.794	62.859
7	0.976	3.906	66.765						
8	0.874	3.494	70.259						
9	0.851	3.402	73.662						
10	0.763	3.052	76.713						

11	0.699	2.798	79.511						
12	0.617	2.468	81.980						
13	0.546	2.184	84.164						
14	0.504	2.016	86.179						
15	0.474	1.896	88.075						
16	0.448	1.793	89.868						
17	0.411	1.645	91.513						
18	0.391	1.563	93.077						
19	0.344	1.376	94.453						
20	0.311	1.245	95.697						
21	0.288	1.152	96.850						
22	0.234	0.935	97.784						
23	0.226	0.906	98.690						
24	0.167	0.668	99.358						
25	0.161	0.642	100.00						

Component 1 has the highest eigenvalue of 8.19 and accounts for 32.76% of the variance, followed by Component 2 with an eigenvalue of 2.03 and explaining 8.13% of the variance, Component 3 with an eigenvalue of 1.67 and explaining 6.69% of the variance, Component 4 with an eigenvalue of 1.40 and explaining 5.60% of the variance, Component 5 with an eigenvalue of 1.30 and explaining 5.21% of the variance, and Component 6 with an eigenvalue of 1.12 and explaining 4.49% of the variance. Overall, these six factors account for a combined 62.82% of the total variance in the barriers to implementing safety measures.

Factor Rotation and Interpretation for Barriers to Implementing Safety Measures

Table 4: Principal component analysis of barriers to implementing safety measures

Barriers to implementing safety measures	Components					
	Inappropriate safety guidelines	Psychological working pressure	Inadequate hygiene monitoring and control	Lack of safety awareness	Improper working culture	Insufficient planning and scheduling
Ignorance of COVID-19					0.855	
Poor safety culture	0.817					
Lack of strict enforcement of WHO regulations	0.701					
Lack of resources for implementing public health and social measures	0.709					
Sanitizing all materials				0.720		
New procedures to provide health and safety on-site				0.712		
Incorrect use of face mask			0.764			
Inadequate work planning to avoid close contact			0.781			
Inappropriate hygiene at work place (Hand washing, promoting hygiene, guidance for cleaning of hygiene areas)			0.747			
Thinking of personal and family while working		0.790				
Major concerns about the risk of being exposed to the virus at work		0.700				
Taking responsibility for personal and family needs while working		0.782				
Adjusting to a different workplace and work schedule						0.825

Rotation method: Varimax with Kaiser normalization.

Table 4 shows that out of the 25 barriers to implementing safety measures, only 13 were identified as major critical barriers, and all of these were further divided into six components. The remaining 12 barriers to implementing safety measures with factor loading less than 0.5 were omitted.

Component 1: Inappropriate Safety Guidelines

'Inappropriate Safety Guidelines' is the first critical barrier in building construction projects to implementing safety measures which contain three factors that strive for poor safety culture, lack of strict enforcement of WHO regulations, lack of resources for implementing public health and social measures. These factors have a correlation of 0.817, 0.701, and 0.709 with component 1, respectively, and account for 32.756% of the total variance with an eigenvalue of 8.189. Previous studies (Maqbool and Khan, 2020) have also shown that poor safety culture, inadequate enforcement of WHO regulations, and insufficient resources hinder the implementation of public health and safety measures to prevent COVID-19 in construction projects.

Component 2: Psychological Working Pressure

‘Psychological Working Pressure’ is considered the as second major critical safety barrier to implementing safety measures in building construction projects, which is explained with 8.125% variance with an eigenvalue of 2.031. This component contained three items such as thinking of personal and family while working, major concerns about the risk of being exposed to the virus at work, and taking responsibility for personal and family needs while working, and have correlation of 0.790, 0.700, and 0.782 with Component 2 respectively. Several past research studies have identified that considering personal and family needs while working, worrying about the risk of being exposed to the virus at work, and being responsible for personal and family needs while working are significant safety barriers to implement in the construction industry (Pamidimukkala et al., 2021, Bou Hatoum et al., 2021, Pamidimukkala and Kermanshachi, 2021).

Component 3: Inadequate Hygiene Monitoring and Control

'Inadequate Hygiene Monitoring and Control', is identified as the third critical barrier to implementing safety measures in building construction projects. It contains three factors namely “incorrect use of face mask”, “inadequate work planning to avoid close contact with different lifestyles”, and “inappropriate hygiene at workplace” and which have a correlation of 0.764, 0.781, and 0.747 with Component 3 respectively. This component contributes to 6.690% of the total variance and holds an eigenvalue of 1.673, underscoring its significance in the overall analysis. Previous research (Amoah and Simpeh, 2021, Stiles et al., 2021) also proves that inadequate use of a face mask for stress reduction, insufficient work planning to avoid close contact with people who have different lifestyles, and poor cleanliness at work are all major impediments to implementing safety measures in the construction business.

Component 4: Lack of Safety Awareness

'Lack of Safety Awareness', is identified as the fourth critical barrier to implementing safety measures in building construction projects. It contains two factors namely “incorrect sanitizing of all materials”, and “new procedures to provide health and safety on-site” and which have a correlation of 0.720, and 0.712 with Component 4 respectively. This component accounts for 5.595% of the total variance and has an eigenvalue of 1.399, indicating its importance in the overall analysis. (Sierra, 2022, Maqbool and Khan, 2020) also found that sanitizing all materials, and new procedures to provide health and safety on-site should be considered as they are all major safety measures barriers to implement in the construction industry.

Component 5: Improper Working Culture

The 'Improper Working Culture,' is the fifth critical safety barrier in building construction projects, posing challenges to the effective implementation of safety measures. This component specifically pertains to one key factor: the incorrect handling of COVID-19 precautions, which shows a strong correlation of 0.855 with Component 5. This component accounts for 5.205% of the total variance and has an eigenvalue of 1.301. (Amoah and Simpeh, 2021) also shows that an ignorance of knowledge of COVID-19 is one of the most significant safety barriers to address in the construction industry.

Component 6: Inadequate Planning and Scheduling

'Inadequate Planning and Scheduling,' represents the sixth critical barrier to implementing safety measures in building construction projects. It contains one factor namely adjusting to a different workplace and work schedule which has a correlation of 0.825 with Component 6. This component accounts for 4.487% of the total variance and possesses an eigenvalue of 1.122. (CDC, 2022) additionally, shows that adjusting to a different workplace and work schedule makes it difficult to maintain safety measures owing to its varied job nature and work schedule.

Reliability and Validity of Retained Components

The Cronbach alpha (α) score was calculated to assess the internal consistency and reliability of each component. The obtained results demonstrated that the α coefficients of the dimensions ranged from 0.727 to 0.796, which indicated a high level of reliability, as the values exceeded the acceptable threshold of 0.70 suggested (Baggio and Klobas, 2017). The Component Transformation Matrix (Table 5), derived from Principal Component Analysis (PCA) with Varimax rotation, reveals the intricate relationships between six original variables and the resulting extracted components. Employing Varimax rotation aims to maximize component independence, enhancing interpretability. Within the matrix, the loadings clearly illustrate the magnitude and direction of each variable's influence on the components. It is noteworthy that each component prominently loads on specific variables, while others exhibit comparably lower loadings. This distinctive pattern suggests a substantial degree of independence between the components, reflecting distinct dimensions. Consequently, this Varimax-rotated PCA method effectively elucidates distinct and meaningful facets of the underlying data structure.

Table 5: Component transformation matrix

Component Transformation Matrix						
Component	1	2	3	4	5	6
1	0.600	0.393	0.310	0.382	0.216	0.027
2	-0.320	0.858	-0.310	0.196	0.153	0.056
3	0.255	-0.221	0.590	-0.452	-0.330	0.453
4	0.317	-0.397	-0.035	0.637	-0.141	-0.238
5	-0.304	-0.101	-0.388	0.237	0.568	-0.135
6	-0.009	-0.092	-0.121	0.386	-0.335	0.846
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.						

Research Implication

Policymakers should prioritize developing and implementing clear and appropriate safety guidelines against a pandemic like COVID-19 in the coming future in building construction projects, with the collaboration of construction professionals, government organizations, and other related stakeholder organizations. The policy intervention could include strict enforcement of WHO regulations and the promotion of a strong safety culture in the construction industry.

Policymakers should address various components identified in the study, including providing workers with necessary support for reducing psychological pressure and promoting proper hygiene monitoring. They can do this by implementing guidelines for proper hygiene practices, providing adequate sanitation facilities, and supporting workers to reduce misunderstandings related to pandemics. These policy interventions can promote a safer and healthier work environment, minimizing the impact of pandemics, and enhance safety of construction workers.

Conclusion

The barriers to implementing safety measures in building construction projects during the COVID-19 pandemic were identified and categorized into six principal components, that are inappropriate safety guidelines, psychological working pressure, inadequate hygiene monitoring and control, lack of safety awareness, improper working culture, and insufficient planning and scheduling. These six components explained the 62.859% of the variation in barriers to implementing safety measures in building construction projects indicating inappropriate safety guidelines as the most critical barrier to implementing safety measures. Construction professionals, government organizations, and other related stakeholder organizations should work together to establish clear and appropriate safety guidelines to overcome the barriers to implementing safety measures during pandemic situations in building construction projects.

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ISSN NO. 2091-1742

SCITECH NEPAL

Journal of Scientific and Technical Studies
Nepal Engineering College, Pokhara University

Research Article

DOI:10.3126/scitech.v17i1.60495

Microbial Quality Assessment of Fresh Sugarcane Juice in Retail Shops Inside Kathmandu Valley

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Received: June 25, 2023
Accepted: October 9, 2023

Abstract

This study aims to assess the microbial quality of fresh sugarcane juice sold in retail shops inside Kathmandu Valley, as there is limited information available on the safety of popular fresh juices like sugarcane juice, which can cause food-borne illnesses when improperly prepared, despite the known health benefits of consuming fresh fruits juices. Sixty fresh sugar cane juice samples were collected from selected thirteen areas inside Kathmandu Valley. Out of 60 samples, 42 samples were contaminated with bacteria. The quality of each sample was assessed by total plate count, total coliform count, yeast and mold count, and isolation of pathogenic bacteria. The isolated bacteria were identified based on biochemical characteristics. The pH of collected samples ranged from 4.33 to 6.34, acidity from 0.01% to 0.09%, and total soluble solids from 13 to 21ºBrix. The mean bacterial count was 5.26 $\log_{10}$ CFU/ml, the coliform count was 4.67 $\log_{10}$ CFU/ml, and the yeast mold count was 4.94 $\log_{10}$ CFU/ml. *E. coli* was present in 38.1%, *Citrobacter freundii* in 47.6%, and *Salmonella* species in 14.3% of the total sample. *Vibrio cholerae* was not detected. Gentamicin, Ciprofloxacin, and Ofloxacin were effective, while Ampicillin was less effective. The study found that sugarcane juice samples from shops in Kathmandu Valley have high levels of contamination, including a high microbial load and slightly acidic pH with high total soluble solid values. The bacterial isolates exhibited varied degrees of antimicrobial susceptibilities and resistances, and the contamination was attributed to poor hygienic conditions during juice processing and handling, possibly due to the use of poor-quality water and a lack of training on food hygiene and safety. These findings suggest potential health hazards for consumers of fresh sugarcane juice.

Keywords: Foodborne diseases; fresh sugarcane juice; Kathmandu Valley; microbial quality assessment; retail shops

Introduction

Codex Alimentarius (Alimentarius, 2005) defines fruit juice as a liquid that is unfermented but has the potential to ferment. It is made from either the edible parts of fresh, healthy, and mature fruit or fruit preserved in a healthy state using appropriate techniques, including postharvest surface treatments allowed under relevant provisions. Even though pips, seeds, and peel that cannot be removed using authorized manufacturing techniques may be processed into various juices even if they are not typically included in the juice, some sections or components of pips, seeds, as well as other peel will be permitted. During the whole manufacturing process, the key physical, chemical, organoleptic, and nutritional qualities of the fruit juices from which the juice is derived are maintained. The juice may be transparent or cloudy and include recovered aromatic components (Bittisnich and Gorst, 2006).

Non-fermented and non-sparkling, fruit juice is a beverage that is made by diluting the juice, pulp, and vegetable extract of the original fruit with drinkable water, according to (Pilo et al., 2009). Fruit juices and fruit-based beverages are popular products that appeal to a diverse demographic, particularly youngsters and young adults, and represent a significant domestic and global market segment (Vasavada, 2003). Fruit juices could be chosen based on taste, product cost, and nutritional value. Fresh fruit juices are frequently consumed globally because of their nutritional value and health advantages. Fruit juices seem to be nutritious and perishable meals that might serve as a perfect substrate for harmful microbe development and proliferation (Mengistu et al., 2022). However, sugarcane juice tends to degrade rapidly even when refrigerated due to its pH, high sugar and water content, and inappropriate temperature (Ali et al., 2018).

Occasionally, production requirements for hygiene need to be properly followed. Without safety equipment and also with badly cleaned raw materials, squeezing might compromise the microbiological quality of the fresh juices. Such unsanitary processing conditions could accelerate various physicochemical changes that affect the product's constitution and pH and promote the growth of bacteria. Juices with an unusually high concentration of harmful bacteria provide a significant risk of contracting foodborne illnesses. Unpasteurized fruit juices have been linked to multiple foodborne epidemics in the previous 20 years, increasing morbidity, infections, and mortality in developing nations (Jackson and Meah, 2017, Bhunia, 2018).

The World Health Organization (WHO) report from 2017 approximations that there are about 600 million cases of foodborne infections worldwide each year, with 420,000 deaths, including 125,000 under the age of 5. Unpasteurized juices such as apple, pineapple, orange, carrot, coconut, sugarcane, lemon, mango, acai, and mixed fruit drinks were the major factors in most of these outbreaks (Raybaudi-Massilia et al., 2009, Ghenghesh et al., 2005, Bevilacqua et al., 2011).

Fresh and unpasteurized fruit juice is a favored option among people in Kathmandu Valley due to its delicious taste and nutritional benefits. Consequently, there has been a surge in the number of retail outlets offering various types of fresh fruit juices. However, the absence of a proper food safety system poses a significant threat to the long-term health, safety, and economic development of the population in Kathmandu Valley. In the summer season, microbial foodborne outbreaks such as diarrhoea, vomiting, cholera, and so on have been reported in the Kathmandu District (Maharjan et al., 2006).

In urban areas like Kathmandu, poor reporting and underreporting of foodborne disease outbreaks further aggravate this issue, making it more widespread. With the growing demand for fast food due to changes in lifestyle, the consumption of locally prepared fresh fruit juices that require microbial quality testing has increased. Hence, there is a need to establish a database on the current quality status of fresh fruit juice to address this situation. This study aims to assess the microbial quality of fresh sugarcane juice sold in retail shops inside Kathmandu Valley, Nepal.

Methodology

Study Area

This study was conducted between April and September 2022 in the Kathmandu Valley. Thirteen locations were chosen to obtain freshly squeezed sugarcane juice, and a total of 60 fruit retail shops were selected from these locations to collect the juice.

Sample Type

Freshly squeezed sugarcane juice was taken for the assessment of its microbial quality.

Sample Analysis

The collected samples were examined in the Food Microbiology Laboratory of the National College, Kathmandu. Samples were tested for the presence of:

- Total Mesophilic bacteria
- Coliforms
- Yeasts and Molds
- *Salmonella* spp.
- *Vibrio cholerae*

Laboratory Procedure

Determination of pH of the sample:

Each sample of fruit juice was tested for pH using a pH meter inside the lab.

Determination of degree Brix of sample:

In a lab setting, a refractometer was used to determine the total soluble solids of each juice sample.

Determination of titrable acidity of the sample:

The titrable acidity of all the individual juice samples was determined by using the titration method. A 10ml aliquot was titrated with 0.1N sodium hydroxide (NaOH) using phenolphthalein as an indicator. The percentage of acidity in the form of citric acid was calculated. The following relationship was used to calculate the percentage of titrable acidity.

$$Titrable\ Acidity = \frac{Vol.of\ titrate \times N\ of\ NaoH \times equivalent\ weight\ of\ citric\ acid \times volume\ made\ up \times 100}{aliquot \times Volume\ of\ sample \times 1000}$$

Serial Dilution

10 ml of the sample was pipetted with the help of a sterile pipette and mixed with 90 ml of peptone water by shaking. It was then considered as 10^{-1} dilutions. From 10^{-1} dilutions, 1 ml was transferred into a second tube containing 9 ml of peptone water and labeled 10^{-2} dilutions. Similarly, the process

was repeated up to 10^{-6} dilutions, labeled as 10^{-3}, 10^{-4}, 10^{-5}, and 10^{-6} dilutions. After each dilution, the tube was shaken well.

Enumeration of microorganisms

Enumeration simply assumes that a single microbial cell forms a visible colony in a suitable agar medium when the diluted sample is incubated at optimum temperature.

Enumeration of total mesophilic bacteria, total coliform, total yeast, and mold

A pour plate was conducted using plate count agar (PCA) from previously produced alternative diluents, i.e., 10^{-2}, 10^{-4}, and 10^{-6}, and incubated at 37°C for 24h for the total mesophilic count. After the necessary dilutions, a pour plate on violet-red bile agar (VRBA) was done to determine the total coliform count. To achieve this, the diluted sample and agar medium were thoroughly and consistently mixed before the plate was allowed to harden. The plate was then covered with VRBA and left to dry. It was then incubated at 37°C for 24h. For complete fungal growth, 0.1 ml of the required dilutions were surface-plated on pre-poured Potato Dextrose Agar (PDA). PDA plates were then incubated for 48 hours at 28 °C.

After incubation, several culture plates were evaluated for microbial growth. Colonies were enumerated and represented as colony-forming units per mL (CFU/ml) of material. Many morphological properties of colonies were examined and documented. Typical colonies were isolated and sub-cultured on nutrient agar before being preserved at four degrees Celsius for future identification.

Identification of Bacteria (Cheesbrough, 2005)

To identify the various microorganisms via laboratory tests, the following procedure was conducted.

Detection of E. coli:

A sterile micropipette transferred 10 ml of the sample to a conical flask containing 90 ml of sterile buffered peptone water. It was followed by proper mixing and incubation at 37°C for 24h. After incubation, the culture was streaked on previously prepared and dried Eosin Methylene Blue (EMB) using an inoculating loop and incubated at 37°C for 24h. Morphological and biochemical tests further confirmed different isolated colonies with a metallic sheen.

***Detection of Salmonella* spp.:**

A sterile micropipette piped a 10 ml sample into a conical flask filled with 90 ml of sterile buffered peptone water. Then it was properly mixed and incubated for at 37°C for 24h. A little shaking was applied to the incubated sample combination. Using a sterile micropipette, one ml of the sample was then moved to a tube containing 10 ml of selenite-F broth (SF), where it was incubated for 24 hours at 37 °C. Using an inoculating loop, the culture was spread on previously made and dry-dried Salmonella-Shigella agar (SS) and then cultured at 37°C for 24 hours. Using morphological and biochemical testing, various isolated colonies with or without black centers were further validated.

Detection of Vibrio cholerae:

A sterile micropipette piped a 10 ml sample into a conical flask filled with 90 ml of sterile alkaline peptone water. It was then properly mixed and incubated for at 37°C for 24h. The culture was properly incubated before being streaked with an inoculating loop on prepared and dried Thiosulfate-

Citrate-Bile Salts-Sucrose (TCBS) Agar and incubated at 37°C for 24h. Biochemical and morphological studies further confirmed several isolated yellowish colonies.

Biochemical Test

Additional biochemical tests were performed on the chosen isolates to help identify them. Both for gram-positive as well as gram-negative species, there are various sets of biochemical assays. Catalase, oxidase, oxidative/fermentative, and coagulase tests were done on gram-positive organisms, while IMVIC, TSI, citrate, and Urease tests were performed on gram-negative species.

Catalase Test

This test determines whether or not the catalase enzyme is present. The catalase enzyme in bacteria transforms hydrogen peroxide into oxygen and water. A clean glass rod was used to pick up the bacterial colony to be investigated, which was then emulsified on a slide. For this reason, a few drops of hydrogen peroxide (3%) were applied to the slide. The presence of gas bubbles showed that the catalase test was positive.

Oxidase Test

During this test, the presence of the enzyme oxidase, which catalyzes the transfer of electrons between a bacterial electron donor and the redox dye tetramethyl-p-phenylene-diamine dihydrochloride, is checked. The dye has been lightened to a rich purple hue. Oxidase paper was placed on a dry, clean glass slide and impregnated with 1% tetramethyl-p-phenylenediamine dihydrochloride for this test. The colony to be examined was picked up and smeared on the paper with a clean, sterile glass rod. A positive test result was shown by the appearance of violet within 10 seconds. However, the formation of the violet hue within 10–60 seconds and a negative response to the lack of color suggested that the test was ineffective.

Oxidative/Fermentative Test

Hugh and Leifson's semisolid media were used in this test to determine if the organisms are fermentative or oxidative. For this test, two test tubes containing the media were used. The organism samples were stabbed into both tubes with a sterile wire. Both tubes were closed with cotton and cultured at 37°C for 24h after one was filled with sterile paraffin oil to create one cm-thick column just on media. When both tubes turn yellow, the organism is oxidative and produces acid under aerobic and anaerobic conditions. However, if only the open tube goes yellow, the organism is aerobic.

Indole Production Test

This test aims to determine whether the tryptophan enzyme can break the tryptophan found in the sulfide-indole-motility media to generate indole as the byproduct of cleavage. The organism turned red when Kovac's reagent was added, indicating indole positive. Prior to autoclaving and cooling in the tubes, the SIM medium had to be prepared. With a straight wire, a small amount of organism from the subculture was extracted and stabbed into a SIM medium tube before being cultured at 37°C for 24h. After incubation, 4-5 drops of Kovac's reagent were added to the tubes containing the inoculated organisms, and the color of the liquid was checked.

Methyl Red Test

The basic principle of this test is to detect the organism's ability to produce and maintain good stable acid end products from glucose fermentation. The reagent used in this test is methyl red, and the media used is MR/VP media. After adding the reagent, the media became red after being inoculated with organisms, showing methyl red positivity. For this test, MR/VP media were prepared, inoculated with organisms with the help of a sterile inoculating loop, shaken well, and then incubated at 37°C for 24h. After incubation, the medium was thoroughly shaken, 5-6 drops of the methyl red reagent were added and thoroughly mixed, and a color change in the medium was observed.

Voges Proskauer Test

This test aims to see if the organism can ferment glucose and produce the neutral end product acetyl methyl carbinol or the reducing product 2, 3-butylene glycol. The reagent employed is Barrit's reagent, while the medium is MR/VP medium. This Barrit's reagent comprises a 3:1 mixture of 40% KOH and 5% alpha naphthol. A small amount of an organism was added to the MR/VP medium, and it was thoroughly agitated before use. After that, this medium was incubated for at 37°C for 24h. After culture, 3 ml of alpha naphthol and 1 ml of 40% KOH were added, and everything was thoroughly mixed. The media's hue changed after that, as was noticed.

Citrate Test

This test establishes whether an organism can utilize citrate as its sole carbon source. Because of the conversion of ammonium salts into ammonia and the ensuing alkalinity, the medium's indicator changes color. Simmons's citrate media is the name of the substance used in citrate testing, which also uses bromothymol blue as a pH indicator. Simmons' citrate medium tube was then taken out. After incubation, the organism was streaked over the media's incline and incubated for at 37°C for 24h. It was visible that the slant's color had changed. The citrate-positive organism has a striking blue color when viewed from a slant.

Urease Test

This test is run to determine whether or not the organisms created the Urease enzyme, which breaks down the chemical urea into carbon dioxide and ammonia. Urea agar media, which uses phenol red as an indicator, is the test medium. The urea agar media tube was removed from this location. Afterward, a small organism was removed and scattered on the media's incline using a sterile loop for inoculation before being cultured at 37°C for 24h. A change in the media's hue was noticed after incubation. When urease-positive organisms are present, the medium turns deep pink, but not when urease-negative organisms are present.

Triple Sugar Iron Agar Test

This test is used to identify which type of glucose, lactose, or sucrose the organism uses and whether or not it also produces gas and hydrogen sulfide. The medium used is triple sugar iron agar, which contains iron that reacts with hydrogen sulfide to detect its presence. It also contains 0.1% glucose, 1% lactose, as well as 1% sucrose. The triple sugar agar medium tube was removed. The organism was streaked and poked into the medium in small amounts, then incubated for at 37°C for 24h. After incubation, the media's color changed as expected.

Antibiotic Susceptibility Test

Ten antibiotic discs from seven different families were used to evaluate antibiotic susceptibility (Table 1). The discs were chosen following CLSI (Clinical & Laboratory Standards Institute) recommendations. *Salmonella*, *E. coli*, and *Citrobacter* spp. were tested against chloramphenicol (10 mg) and ampicillin (10 mcg) antibiotic discs that are available commercially (30 mcg). Modified Kirby Bauer, disk diffusion method procedures are used with Ceftazidime (30 mcg), Gentamicin (10 mcg), Ciprofloxacin (5 mcg), and Co-trimoxazole (25 mcg). Five colonies of each isolate were added to 5 ml of nutrient broth and cultured for 4 hours, and then the culture turbidity was adjusted to a McFarland standard of 0.5. The Mueller-Hinton Agar surface was then uniformly covered with the suspension after dipping the sterile cotton swab into it. The antibiotic-impregnated discs were placed over the inoculation plates, which were incubated at 37°C for 16–18 hours. After incubation, the inhibitory zone widths were determined, and susceptible, intermediate, and resistant conditions were identified using millimeter measures (Humphries et al., 2021).

Table 1: Chart for antibiotic sensitivity

Antibiotics	Strength	Diameter of zone of inhibition in mm		
	Mcg	Resistant	Intermediate	Sensitive
Ampicilin (A/S)	10/10	11	12-14	15
Cefotaxime (CTX)	30	22	23-25	26
Ceftazidime (CAZ)	30	17	18-20	21
Ciprofloxacin (CIP)	5	21	22-25	26
Norfloxacin (NX)	10	12	13-26	17
Ofloxacin (OF)	5	12	13-15	16
Gentamicin (GEN)	10	12	13-14	15
Chloramphenicol (C)	30	12	13-17	18
Nitroflurantoin (NIT)	300	14	15-16	17
Cotrimoxazole (COT)	25	10	11-15	16

Data Analysis

The laboratory test data were entered into MS Excel and cleaned. Some values were transformed to $\log_{10}$ for statistical analysis. Descriptive statistical tools such as mean, standard deviation, frequency, and percentage were used to summarize the data, and bar charts were utilized to visually present the findings.

Results and Discussion

Physiochemical Parameters

The fresh sugarcane juice samples were tested for various physicochemical parameters, which included pH, titratable acidity, and total soluble solids (measured in ºBrix). The pH of the sugarcane juice was found to be moderately acidic, with a range of 4.33 to 6.34. The total soluble solids (measured in ºBrix) ranged from 13 to 21. Additionally, the titratable acidity of the juice samples was found to range between 0.01% to 0.09%.

pH has an impact on the stability and beneficial properties of sugarcane juice (Chia et al., 2012). The juice is slightly acidic, ranging from pH 4.3 to 6.34, with a titratable acidity of 0.01% to 0.09%. The Brix value ranged from 13 to 21. Some bacteria, such as *S. typhi* and *E. coli*, are considerably more acid-resistant than others. The juice's pH and sugar content may have inhibited the growth of some organisms (Chia et al., 2012). Most of the fresh juice samples had brix levels ranging from 14º to 21ºbrix, as recommended by CODEX STAN 247:2005 for fruit juice and nectars (Bittisnich and Gorst, 2006). According to FAO, juices with more than 1.2% acid are sour, regardless of brix. Neither is classified as weak and watery of all the samples assessed, as their ºBrix is not less than 7. However, juices with less than 7º brix are categorized as weak and watery (Bates et al., 2001).

Enumeration of Microorganisms

Total Bacterial Count:

In the study area, the average total bacterial count was determined 5.26 $\log_{10}$ CFU/ml. Among the tested locations, the highest total bacterial count was observed 6.75 $\log_{10}$ CFU/ml with a standard deviation of 0.55. On the other hand, the lowest total bacterial count was found 3.77 $\log_{10}$ CFU/ml with a standard deviation of 0.12. The presence of bacteria in fruit juice is a serious concern as it can pose a threat to consumer health (Oladipo et al., 2009). Microorganisms present in fruits can be indicative of the hygienic conditions in which the product was grown, harvested, transported, stored, and processed (Bhunia, 2018, Beuchat, 1992). In Salaam City, Tanzania, the total bacterial counts in fresh sugarcane juice ranged from 1.44×10^5 to 6.0×10^5 CFU/mL (Mwambete and Mpenda, 2019). Similarly, in Dhaka, Bangladesh, street-vended fresh sugarcane juices had total viable counts within the 0 to 10^7 CFU/mL range, with significant loads of coliforms, fecal coliforms, *Vibrio*, and s*taphylococcal* counts (Afroz et al., 2019). To elaborate further, the findings of this study align with previous research that has also identified the presence of mesophilic aerobic bacteria in fresh sugarcane juices. There are several possible reasons for the prevalence of these bacteria, one of which is the storage practices of the vendors. Typically, the sugarcane is peeled and left in an open environment at room temperature before it is consumed. This environment provides an ideal setting for the growth and proliferation of mesophilic aerobic bacteria, which can result in a high bacterial load in fresh sugarcane juice.

Total Coliform Count:

The overall average total coliform count was determined 4.67 $\log_{10}$ CFU/ml with a standard deviation of 0.22. Among the tested locations, the highest total coliform count observed was 5.82 $\log_{10}$ CFU/ml with a standard deviation of 0.36. On the other hand, the lowest total coliform count was 3.72 $\log_{10}$ CFU/ml with a standard deviation of 0.12. In a related research by Alamgir et al. (2015), all samples revealed the presence of fecal coliforms between 2.51 and 0.78 $\log_{10}$ MPN/100 mL, while the coliform count ranged from 0.8×10^4 to 22.2×10^4 CFU/100 mL in the study by (Lewis et al., 2006).

The higher overall coliform count in the present study compared to other similar studies may be attributed to inadequate quality control during fresh juice preparation. Coliform bacteria in fruit juice may suggest inadequate hygiene and sanitation during preparation and handling, necessitating the use of clean and hygienic water for preparation, utensils and equipment cleaning, and machine operation to prevent contamination. Fruit juice containing coliforms, such as *E. coli* and *Citrobacter*, can cause water-borne illnesses and are therefore not safe for consumption.

Total Yeast and Mold Count:

The highest total fungal count observed in the fresh sugarcane juice was 6.16 $\log_{10}$ CFU/ml with a standard deviation of 0.68. On the other hand, the lowest total fungal count was found which was 3.7 $\log_{10}$ CFU/ml with a standard deviation of 0.11. Additionally, the average total fungal count in the study area was determined 4.94 $\log_{10}$ CFU/ml with a standard deviation of 0.45.

Contamination could be caused by mixing rotting parts with new stock, using unclean and dusty settings with insects, and delivering juice in dirty containers. These factors may account for the high levels of yeast and mold observed in this study. Fungi are the main cause of food spoilage and their presence in PDA can indicate contamination of fresh fruit juices, with the possibility of toxin production that can be harmful to human health (Samson et al., 1981).

Isolation and Identification of Pathogenic Bacteria

Samples collected from different locations contained various bacteria, including *Citrobacter freundii*, *E. coli*, and *Salmonella* spp. Among them, *Citrobacter freundii* was the most commonly found bacteria, present in 47.6% of the total samples. *E. coli* was isolated from 38.1% of the samples, whereas *Salmonella Typhimurium* was detected in the fewest samples, only 14.3%. None of the juice samples tested positive for *Vibrio cholerae* (Table 2).

During transporting, washing, rinsing, or processing by the processors, some of the bacteria discovered in this investigation may be pollutants from soil, water sources, and the outdoors or maybe a part of the natural flora (Ofor et al., 2009). *E. coli* indicates fecal contamination since it is present in the human gut. *E. coli* are naturally occurring bacteria. Urinary tract infections, gastroenteritis, and diarrhea have all been connected to certain strains of *E. coli* (Yu et al., 2006).

Because sellers do not use boiling or potable water for cleaning and juicing, *Salmonella* may have entered through contaminated water. *Salmonella* has been a growing concern to fresh foodstuffs and has caused foodborne diseases all over the world (Begum et al., 2010).

The microorganisms discovered in the current study include *Salmonella* spp. and *Escherichia coli*. The Food Safety and Standards Authority of India has said that the presence of this specific type of pathogenic bacteria might be dangerous to the public's health. Thus, these harmful microorganisms must not be present. Particularly for small children and older individuals with compromised immune systems, these bacteria may increase the risk of foodborne disease. Prospective consumers, food producers, and government agencies should be made aware of the likelihood that certain bacteria species might cause food poisoning by ingesting contaminated food. In addition to being a part of the normal flora in the human gut, *C. freundii* is also a conditionally pathogenic bacterium that may infect people with low immunity and cause a variety of ailments, such as pneumonia, meningitis, sepsis, bacteremia, urinary tract infections, and others (Jia et al., 2020).

Table 2: Frequency and percentage of different bacterial organisms detected in sugarcane juices

S.N.	Bacterial isolates	Number	Percentage (%)
1	*Citrobacter freundii*	20	47.6
2	*E. coli*	16	38.1
3	*Vibrio cholerae*	0	0
4	*Salmonella* spp.	6	14.3
5	Total	42	100.0

Antibiotic Susceptibility Test:

All 42 identified isolates from fruit juices were subjected to antimicrobial susceptibility testing using the Kirby-Bauer disc diffusion technique. The isolates were tested against ten antibiotics from seven different families: Ampicillin (AS 10/10 mcg), Ceftazidime (CAC 30/10mcg), Cefotaxime (CX 30mcg), Ciprofloxacin (CIP 5mcg), Norfloxacin (NX 10 mcg), Ofloxacin (OF 5 mcg), Chloramphenicol (C30 mcg), Co-trimoxazole (COT 25 mcg), Gentamicin (GEN10 mcg), and Nitroflurantoin (NIT 300 mcg). The results showed that Gentamicin, Ciprofloxacin, and Ofloxacin were effective against all bacterial isolates. In contrast, Ampicillin showed low efficacy against most bacterial isolates (Fig 1).

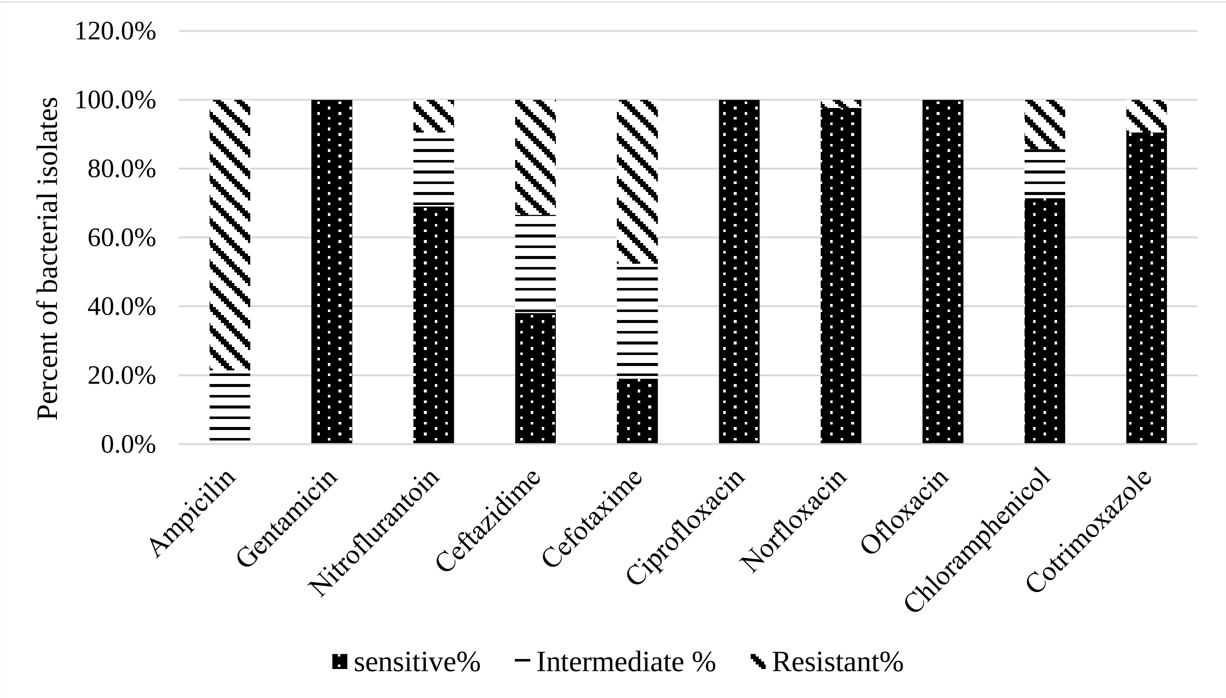

Fig 1: Antibiotic susceptibility pattern of isolated bacteria

Antibiotic Sensitivity pattern of Citrobacter freundii:

Table 3 displays the results of the antimicrobial susceptibility test conducted on 20 isolates of *Citrobacter freundii*. The table shows that 75% of the isolates were resistant, and 25% exhibited intermediate resistance to ampicillin. Regarding ceftazidime, 50% of the isolates were sensitive, 25% were intermediate, and 25% were resistant. For cefotaxime, 60% of the isolates were resistant, and 40% showed intermediate resistance. All (100%) of the bacterial isolates were sensitive to

Ciprofloxacin, Norfloxacin, Gentamicin, and Ofloxacin. For chloramphenicol, 70% of the isolates were sensitive, and 30% were intermediate. Nitrofurantoin showed 55% sensitivity and 45% intermediate resistance, while 80% of the isolates were sensitive and 20% were intermediate to Cotrimoxazole.

Most of the antibiotics were found to be effective against the isolates. Ciprofloxacin, Norfloxacin, Ofloxacin, and Gentamicin were effective against all isolates, while 75% and 25% of *Citrobacter* spp. were resistant to Ampicillin and ceftazidime, respectively. Cefotaxime resistance was found in 60% of the isolates.

According to Arens et al. (1997) the antibiotic susceptibility of *Citrobacter* spp. showed that only 2% of *Citrobacter freundii* was sensitive to Ampicilin and Cefatoxime and 80% was sensitive to Ceftazidime. Similarly, 93% were sensitive to Nitroflurantoin and Ofloxacin. Our study agrees with another study where *Citrobacter freundii* is also less sensitive to Cefatoxime and more sensitive to Ofloxacin.

Table 3: Antibiotic Sensitivity pattern of *Citrobacter freundii*

Antibiotic used	Sensitive Percent	Intermediate Percent	Resistant Percent	Total Percent
Ampicillin (AS 10/10 mcg)	0.0	25.0	75.0	100.0
Ceftazidime (CAZ 30 mcg)	50.0	25.0	25.0	100.0
Cefotaxime (CTX 30 mcg)	0.0	40.0	60.0	100.0
Ciprofloxacin (CIP 5 mcg)	100.0	0.0	0.0	100.0
Norfloxacin (NX 10 mcg)	100.0	0.0	0.0	100.0
Ofloxacin (OF 5 mcg)	100.0	0.0	0.0	100.0
Gentamicin (GEN 10 mcg)	100.0	0.0	0.0	100.0
Chloramphenicol (C 30 mcg)	70.0	30.0	0.0	100.0
Nitroflurantoin (NIT 300 mcg)	55.0	45.0	0.0	100.0
Cotrimoxazole (COT 25 mcg)	80.0	20.0	0.0	100.0

Number of isolates = 20

Antibiotic Sensitivity Pattern of E. coli

Table 4 presents the results of the antimicrobial susceptibility test conducted on 16 isolates of *E. coli.* The table shows that 75% of the isolates were resistant, and 25% showed intermediate resistance to ampicillin. For ceftazidime, 18.8% of the isolates were sensitive, 56.3% were resistant, and the remaining 25% showed intermediate resistance. All (100%) of the bacterial isolates were sensitive to Ciprofloxacin, Norfloxacin, Ofloxacin, Gentamicin, and Cotrimoxazole, respectively. For chloramphenicol, 62.5% of the isolates were sensitive, and 37.5% were resistant. Similarly, 75% of the isolates were sensitive, and 25% were resistant to Nitrofurantoin.

Geta et al. (2019) showed that most *E. coli were* sensitive to Ampicillin, contrary to this observation. Likewise, 75% of *E. coli* were resistant to Ampicillin, and 56.3% of *E. coli* were resistant to Ceftazidime. Similarly, 43.8% showed resistance to cefotaxime. 37.5% of *E. coli* isolates were resistant to chloramphenicol, 25% were resistant to Nitrofluorantoin, and 100% were sensitive to Ciprofloxacin, Norfloxacin, Ofloxacin, and Gentamicin. While the choice of antibiotics used in a similar study by (Geta et al., 2019) differed, isolates of *E. coli* showed the highest resistance (75%) to Tetracycline and the lowest resistance (50%) to Ampicillin, while all isolates were responsive to Penicillin. The differences in the concentrations of antimicrobial drugs employed, the sources of isolates, the transmission of drug resistance, and the widespread use of antibiotics in the environment may be to blame for the variability in the values of percentage susceptibilities in this study.

Table 4: Antibiotic Sensitivity pattern of *E. coli*

Antibiotic used	Sensitive Percent	Intermediate Percent	Resistant Percent	Total Percent
Ampicillin (AS 10/10 mcg)	0.0	25.0	75.0	100.0
Ceftazidime (CAZ 30mcg)	18.8	25.0	56.3	100.0
Cefotaxime (CTX 30 mcg)	25.0	31.3	43.8	100.0
Ciprofloxacin (CIP 5 mcg)	100.0	0.0	0.0	100.0
Norfloxacin (NX 10 mcg)	100.0	0.0	0.0	100.0
Ofloxacin (OF 5 mcg)	100.0	0.0	0.0	100.0
Gentamicin (GEN 10 mcg)	100.0	0.0	0.0	100.0
Chloramphenicol (C 30 mcg)	62.5	0.0	37.5	100.0
Nitroflurantoin (NIT 300 mcg)	75.0	0.0	25.0	100.0
Cotrimoxazole (COT 25 mcg)	100.0	0.0	0.0	100.0

Number of isolates =16

Antibiotic Sensitivity Pattern of Salmonella Species

Table 5 shows the antimicrobial sensitivity pattern of Salmonella spp. Altogether 6 *Salmonella* spp. were taken for antibiotic susceptibility test. All the isolates 100% isolates were resistant to ampicillin. 50% were sensitive, and 50% were intermediate to Ceftazidime. 66.67% were sensitive and 16.67% showed resistant and intermediate patterns to Cefotaxime. 100% of bacterial isolates were sensitive toward Ciprofloxacin, Ofloxacin, Gentamicin, Chloramphenicol, Nitroflurantoin, and Cotrimoxazole. While 83.3% of isolates were sensitive and 16.7% were resistant to Norfloxacin. All *Salmonella* spp. were resistant to Ampicillin, while other isolates of *Salmonella* spp. were sensitive to other antibiotics, including Ciprofloxacin, Chloramphenicol, Ofloxacin, Cotrimoxazole, Nitroflurantoin, and Gentamicin. This study agreed with a similar study by (Kebede et al., 2016) where *Salmonella* isolates were tested for susceptibility to antibiotics: Ampicillin, amikacin, ceftriaxone, chloramphenicol, ciprofloxacin, gentamycin, and nitrofurantoin. *Salmonella* contaminants were susceptible to all tested antibiotics. 92% of bacteria were susceptible to Gentamicin, while 85% were susceptible to Ampicillin.

Table 5: Antibiotic Sensitivity Pattern of *Salmonella Species*

Antibiotic used	**Sensitive Percent**	**Intermediate Percent**	**Resistant Percent**	**Total Percent**
Ampicillin (AS 10/10 mcg)	0.0	0.0	100.0	100.0
Ceftazidime (CAZ 30 mcg)	50.0	50.0	0.0	100.0
Cefotaxime (CTX 30 mcg)	66.7	16.7	16.7	100.0
Ciprofloxacin (CIP 5 mcg)	100.0	0.0	0.0	100.0
Norfloxacin (NX 10 mcg)	83.3	0.0	16.7	100.0
Ofloxacin (OF 5 mcg)	100.0	0.0	0.0	100.0
Gentamicin (GEN 10 mcg)	100.0	0.0	0.0	100.0
Chloramphenicol (C 30 mcg)	100.0	0.0	0.0	100.0
Nitroflurantoin (NIT 300 mcg)	100.0	0.0	0.0	100.0

Cotrimoxazole (COT 25 mcg)	100.0	0.0	0.0	100.0

Number of isolates =6

Sensitivity Pattern

The sensitive pattern of isolated bacteria is shown in Table 6. In total, 68.6% of bacteria were sensitive to the assayed antibiotics while 19.5% were resistant and the remaining 11.9% showed an intermediate pattern toward examined antibiotics.

Table 6: Sensitive Pattern in percentage

Sensitive Pattern of bacteria	Percent (%)
Sensitive	68.6
Intermediate	11.9
Resistant	19.5

Research Implication

Ensuring the safety of fresh sugarcane juice is of utmost importance. This can be achieved by following proper storage, handling, and processing practices. Retail shop vendors must be made aware of the importance of hygiene and food safety practices, such as using clean utensils, washing fruits before processing, and storing juice at the correct temperatures.

To address the microbial quality status of fresh fruit juice, it is important for the government to establish a database. Additionally, regular monitoring and testing of fresh sugarcane juice and other fruit juices by the government should be conducted to ensure compliance with national and international food safety standards. This will help prevent the spread of foodborne illnesses and improve public health.

Conclusion

The study concludes that fresh sugarcane juice samples from the retail shops in Kathmandu Valley have high levels of contamination, with slightly acidic pH and high total soluble solid values. The high microbial load found in the freshly squeezed sugarcane juice samples exceeds the specifications set for fruit juices in some parts of the world, and varied degrees of antimicrobial susceptibilities and resistances were observed on bacterial isolates. These findings reflect poor hygienic conditions during juice processing or handling, potentially due to the use of poor-quality water and the lack of training on food hygiene and safety. As a result, the study highlights potential health hazards for consumers of fresh sugarcane juice.

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ISSN NO. 2091-1742

SCITECH NEPAL

Journal of Scientific and Technical Studies
Nepal Engineering College, Pokhara University

Research Article

DOI:10.3126/scitech.v17i1.60496

Performance evaluation of three grid-connected monocrystalline silicon solar photovoltaic systems in Nepal

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Received: July 30, 2023

Accepted: October 8, 2023

Abstract

This study evaluates three grid-connected solar photovoltaic (PV) systems using four criteria: final yield, performance ratio, capacity utilization factor, and system efficiency. The PV systems were installed on the rooftop of the Nepal Telecom office at Sundhara, Pokhara, and Biratnagar. The generation data was collected through the web interface of the data logger installed at the sites. Long-term comparison (four years) of the plant at Sundhara and the same system comparison of plants at Pokhara and Biratnagar were performed. Long-term analysis of the plant at Sundhara found that the final yield decreased from 2.91 kWh/kW_p in 2019 to 2.21 kWh/kW_p in 2022. Similarly, the performance ratio decreased from 91.0% in 2019 to 67.3% in 2022, capacity utilization factor decreased from 12.1% in 2019 to 9.2% in 2022, and system efficiency decreased from 16.8% in 2019 to 12.5% in 2022. The same system installed at Pokhara and Biratnagar had slightly varied performance owing to the variation in meteorological parameters. The average air temperature at Biratnagar (26.7^{0}C) was higher than at Pokhara (13.1^{0}C) while the amount of solar radiation at Biratnagar was just higher by 4%. This led to the reduction of final yield by 9% at Biratnagar than at Pokhara as higher temperatures at Biratnagar caused more reduction in the power output from the solar panels. Finally, this study provides insights to researchers, PV installers, and panel manufacturers on the actual performance of grid-connected solar PV in Nepal.

Keywords: comparison; monocrystalline; grid-connected photo voltaic; long-term analysis; Nepal Telecom solar plants; performance parameter

Introduction

Nepal’s energy needs are mostly dependent on traditional sources like fuelwood. However, in the recent years, the use of commercial and renewable energy sources has been on the rise. The consumption of traditional fuel has decreased from nearly 90% to less than 70 % in 15 years while the consumption of commercial fuels, like petroleum, electricity and coal, has increased from nearly 10% to 30% during the same interval (Kathmandu University et al., 2022). Among the commercial sources, consumption of petroleum products, electricity, and other modern energy like coals, stood at 65%, 15%, and 20% respectively. However, the portion of modern renewable energy, solar and wind, is still less than 3% (Lohani et al., 2022).

Nepal has good sunshine for about 300 days a year and the solar radiation varies from 3.6 – 6.2 kWh/m^2/day (Water and Energy Commission Secretariat [WECS], 2010), with a national average of 4.66 kWh/m^2/day (Adhikari et al., 2013). After the 680.4 kW_p solar photovoltaic (PV) plant at Kathmandu Upatyaka Khanepani Limited (KUKL), Sundarighat, Lalitpur was connected to the national grid on Sept. 28, 2012, a lot of grid-tied projects have been commissioned in the recent years. A grid-tied or grid-connected PV system generates electricity through a solar PV power system and is connected to the utility grid. Its components include solar panels, grid inverters, power conditioning units, and grid connection equipment. July 2008 assessment of solar and wind energy in Nepal gives the commercial potential for grid connection of solar power to be about 2,100 MW (Nepal Electricity Authority [NEA], 2014). Recently, Nepal Electricity Authority has called for proposals to set up grid-tied solar plants through competitive bidding (Shrestha, 2022). They plan to buy a maximum of 100 MW of power from such solar plants at 16 locations across the country. This is the first time that NEA is buying power through bids. Earlier, it was fixed at Rs. 7.30 per unit based on the "Working Procedure on Grid Connected Alternative Electric Energy Development – 2017" formulated in February 2018, which was later capped at Rs. 5.94 per unit in March 2022. Bidding would require NEA to sign a power purchase agreement (PPA) with developers who pass the technical evaluation and offer competitive bids below the maximum price ceiling. As various technologies, such as mono-crystalline, poly-crystalline, and thin-film solar cells have been used in building the plants, it is necessary to consider their performance so that the developers can use the information to design their systems, be it for selling to NEA or other purposes.

This study considers the grid-connected plants with solar panels made from monocrystalline Silicon technology and evaluates their performance. Cells in monocrystalline panels are formed by making silicon into bars and cutting them into wafers (American Solar Energy Society, 2021). This process differs from the polycrystalline where the fragments of silicon are melted together to form the wafers. Because of this process, monocrystalline solar cells have a uniform dark appearance and rounded edges square with small spaces between each cell, while polycrystalline solar cells have a bluish hue and no rounded edges. Performance analysis requires a comparison of parameters such as final yield, performance ratio, capacity utilization factor, and system efficiency. There are various comparative studies of the performance of grid-connected PV plants globally. Ameur et al. (2022) performed long-term performance and degradation analysis of three silicon-based PV technologies including amorphous silicon, poly-crystalline silicon, and mono-crystalline silicon in Morocco. They found that crystalline silicon technologies were better than amorphous PV system based on performance ratio analysis with the values of 84.25% for mono, 84.32% for poly, and 79.14% for amorphous. Ayadi et al. (2022) investigated experimentally the performance of mono-crystalline, poly-crystalline, and thin-film solar panels under sunny climatic conditions. They found that mono-crystalline PV systems had better performance than other technologies in terms of specific yield per unit area (267 kWh/m^2), performance ratio (80.5%), and efficiency (12.8%), whereas thin-film systems performed somewhat better in specific yield per installed capacity compared to mono-crystalline due to its low-temperature coefficient. Bahanni et al. (2022) compared two mini-grid connected PV plants based on mono-crystalline, poly-crystalline and amorphous technologies located in Beni Mellal and El Jadida, Morocco. They found that ambient temperature had a greater impact on the performance ratio of mono-crystalline as for every 8^0C rise in temperature, the PR decreased by 2.5%, 2%, and 1% for monocrystalline, polycrystalline, and amorphous technologies at Bemi Mellal. The values were 5.5%, 5.2%, and 3% at El Jadida. Bajracharya & Maharjan (2019) conducted a techno-economic analysis of a 64.6 kWp grid-tied mono-crystalline solar PV system installed at Nepal Telecom, Sundhara, and found that the performance ratio and capacity utilization factor was 85.9% and 14.09%, respectively. Elshazly et al. (2021) studied effect of high temperature and dust accumulation on solar panels in natural outdoor conditions at El-Sherouk City, Egypt and found that increase in temperature of monocrystalline panels by 10^0 resulted in a degradation of panel's efficiency by approximately 7% and accumulation of dust on the surface of panels could reduce the efficiency by 30%. Owolabi et al. (2022) compared a 5 kWp grid-tied mono-crystalline silicon (m-si) solar PV system and a 4.6 kWp grid-tied polycrystalline silicon (p-si) solar PV system installed on the rooftop of the Engineering building at Kyungpook National University, Republic of Korea and found that m-si solar cell technology performed better than the p-si solar cell annually when considering the final energy output, system yield, capacity factor, and system efficiency. But, the p-si solar cell outperformed the m-si solar technology in performance ratio. Satsangi et al. (2018) studied a 40 kW grid-interactive monocrystalline PV system installed at Dayalbagh Educational Institute, Agra, India and found that PV efficiency decreased as cell temperature increased. PV efficiencies were highest in rainy season due to the natural cleaning of panels and in winter due to lower temperatures. Zain et al. (2013) compared the performance of mono-crystalline and poly-crystalline PV plants using the performance ratio as an indicator. They found that the PR for monocrystalline was 77% and for polycrystalline, it was 80%; though the efficiency for mono was 11.8% compared to 11.5% for poly. This showed that a higher performance ratio just indicated higher energy yield compared to expected energy yield under STC and needs to be taken as relative data.

This study has the main objective of comparing the performance of monocrystalline Silicon (m-Si) PV plants installed at Nepal Telecom offices located at Biratnagar, Pokhara, and Sundhara with the following specific objectives.

- Long-term comparison of a system (NTC Sundhara).

- Comparison of system with the same components (NTC Pokhara and Biratnagar).

Overview of the grid-tied solar photovoltaic systems

Three grid-tied solar PV systems installed at Nepal Telecom offices at Sundhara, Biratnagar, and Pokhara were considered for this study. The PV systems follow the system archetype (Owolabi et al., 2022) as shown in Figure 1, where the solar panels and grid-tied inverter are the central components of the system. Variables like air temperature, wind speed, and solar irradiation are measured, which affects the performance of solar panels. The measured solar irradiation gives the reference yield based on which the yield of solar panels can be compared. The DC output of the panel gives the array yield, while the AC output gives the final yield; which is always less than the array yield because of inverter efficiency. The final energy output can be used to determine performance parameters such as performance ratio, capacity utilization factor, system efficiency, and final yield.

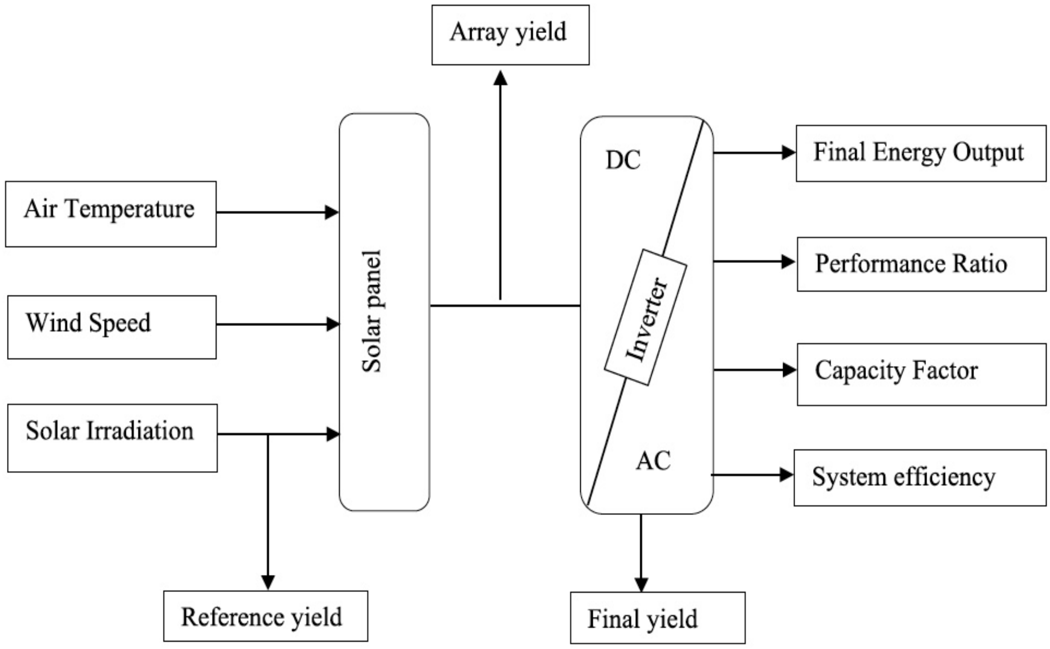

Figure SEQ Figure * ARABIC 1 Archetype of solar photovoltaic system

Nepal Telecom, Sundhara

The 64.6 kW_p solar plant at Sundhara is located at the latitude of 27.70^0 N and longitude of 85.31^0 E in the Kathmandu District of Bagmati Province in Nepal which was commissioned in March 2019. The system consists of 10 strings of solar panels (each string consisting of 19 solar panels in series), a single grid-tied inverter, protection and measuring devices, and a data logger. The description of the solar panel and inverter is mentioned below:

a) **Solar panel:** 340 W_p solar panels composed of 72 pieces of mono-crystalline silicon (m-si) solar cells manufactured by Vikram Solar are used in the system. The panel has a dimension of 1,956 x 992 x 36 mm with efficiency of 17.52%. The panel has a linear power warranty of 27 years with 3% degradation in the 1st year and 0.65% degradation from year 2 to year 27. The electrical parameters of the solar panel are as shown in Table 1.

b) **Inverter:** A single 80 kW Delta grid-tied transformerless solar inverter has been used in the system. It connects up to 18 strings with a recommended DC power of 95 kW_p in the 400/415 V_{AC} range. It operates at a nominal voltage of 620 V with a maximum input current of 140 A. It can operate in a temperature range of -25^{0}C – 40^{0}C at full power. The technical data of the inverter is shown in table 2.

Nepal Telecom, Pokhara

The 45.32 kW_p solar plant at Pokhara is located at the latitude of 28.22^0 N, longitude of 84.00^0 E and altitude of 822 m in Kaski district of Gandaki province in Nepal which was commissioned on April 23, 2021. The system consists of 2 strings of solar panels with 14 panels in series and 5 strings with 15 panels in series, two grid-tied inverters, protection and measuring devices, and a data logger. The description of the major components is given below:

a) **Solar panel.** Longi 440 W_p solar panels composed of mono-crystalline silicon (m-si) solar cells are used in the system. The solar panel has two identical parts with cells half the size of ordinary solar cells, so it has 144 cells than the usual 72 cells. Single panel dimension is 2,094 x 1,038 x 35 mm with an efficiency of 20.2%. The panel has a linear power warranty of 25 years with 2% degradation in the 1^{st} year and 0.55% degradation from year 2 to year 25. The electrical parameters of the solar panel are as shown in table 1.

b) **Inverter.** Two Solis inverters of capacities 20 kW and 25 kW have been used for the system. Solis-25K-5G (25 kW) transformerless inverter has four Maximum Power Point Tracker (MPPT) designs with a precise algorithm that reduces string mismatch and has over 98.8% maximum efficiency. It can handle maximum input power of 33 kW can start as low as 180 V and handle as high as 1100 V of input voltage. Solis-3P20K-4G (20 kW) transformerless inverter has a dual MPPT design with a precise MPPT algorithm and has over 98.7% maximum efficiency. It can handle maximum input power of 24 kW. The technical data of the inverters are shown in table 2.

Nepal Telecom, Biratnagar

The 45.32 kW_p solar plant at Biratnagar is located at latitude of 26.46^0 N, longitude of 87.29^0 E and altitude of 80 m in Morang district of Koshi province in Nepal which was commissioned on October 16, 2020. The components of the system are like the one installed at Nepal Telecom, Pokhara.

Table 1 Electrical specification of solar panels

Electrical parameter at Standard Test Condition (STC*)	Vikram Solar 340 W_p module	Longi 440 W_p module
Model	VSM.72.AAA.03.04	LR4-72HPH-440M
Maximum power, P_{max} (W_p)	340	440
Cells	m-Si (72 pcs)	PERC m-Si (144 pcs)
Voltage at maximum power, V_{mpp} (V)	37.98	41.1
Current at maximum power, I_{mpp} (A)	8.98	10.71
Open circuit voltage, V_{oc} (V)	47.10	48.9
Short circuit current, I_{sc} (A)	9.42	11.46
Module efficiency, η (%)	17.52	20.2

** STC means solar irradiance of 1000 W/m^2, Air mass of 1.5, and air temperature of 25^{0}C.*

Table 2 Technical data of inverters

Technical parameter	Solis-3P20K-4G	Solis-25K-5G	Delta 80 kW
Maximum DC power (kW_p)	24	33	95
Maximum DC input voltage (V)	1000	1100	1100
MPPT voltage range (V)	160 - 850	200 – 1000	200 – 1000
Maximum operating input current (A)	44	52	140
Rated/Maximum output power (kW)	20 / 22	25 / 27.5	69 / 76
Rated/Maximum output current (A)	28.9 / 31.8	36 / 41.8	96 / 106
Nominal AC voltage (V)	3-ø, 400	3-ø, 400	3-φ, 400

Maximum efficiency (%)	98.7	98.8	98.8
Self-consumption at night (W)	< 1	< 1	< 3

Materials and Methods

This is a quantitative study where after identifying the problem and conducting relevant literature study, the performance data from the sites were collected. Data related to energy generation from solar plants was collected from the website that displayed the data from the data logger installed at the sites. Radiation and temperature data were then obtained from the National Solar Radiation Database portal available online at the website of the National Renewable Energy Laboratory. The data was entered in MS Excel to calculate the parameters (final yield, capacity utilization factor, performance ratio, and system efficiency) on a monthly, seasonal, and yearly basis. Long-term analysis of the system at Sundhara and performance analysis of systems (Pokhara and Biratnagar) with the same components were done. Charts were made to visualize the differences in the parameters among the various sites. Conclusion and recommendation were written based on the results obtained. Figure 2 below shows the research methodology flowchart followed for this study.

Figure 2 Research Methodology Flowchart

Array yield

Array yield is the ratio of direct current energy output from the PV array over a certain period to its rated power. It indicates the number of hours that the PV array must operate at its nominal power to generate the energy produced (Owolabi et al., 2022). It is given by,

$$Y_a = \frac{E_{DC}}{P_{STC}} \text{ (kWh/kW}_p\text{)},$$

where E_{DC} is the direct energy (DC) energy output from the PV array and P_{STC} is the installed power at STC.

Final yield

Final yield is the ratio of the net energy output of the entire PV system to its rated power. It indicates the duration of hours the PV system must operate at its rated power to produce the recorded amount of energy. It is given by

$$Y_f = \frac{E_{AC}}{P_{STC}} \text{ (kWh/kW}_p\text{)},$$

where E_{AC} is the net energy output and P_{STC} is the installed power at STC conditions. Usually, the specific yield (array yield and final yield) [kWh/kW$_p$] is used to evaluate the solar PV system performance but it does not consider the footprint of the system. As rooftop area comes as a design constraint in most cases, specific yield per unit area (kWh/m^2) is also used as an important indicator for comparing solar PV systems (Ayadi et al., 2022).

Reference yield

Reference yield is the ratio of total in-plane solar radiation, H_t (kWh/m^2) to the reference irradiance at STC, G_{STC} (kW/m^2). It is given by $Y_r = \frac{H_T}{G_{STC}}$ (kWh/kW$_p$). It represents an equivalent duration in hours that the system needs to operate at the reference irradiance (Roumpakias & Stamatelos, 2017) and defines the solar radiation resource for the PV system (Marion et al., 2005).

Performance ratio

Performance ratio (PR) measures the quality of a solar photovoltaic and is also called the quality factor that is independent of location (Verma & Singhal, 2015). It indicates how close a PV system is to its ideal performance during actual operation and it also allows comparison of PV systems independent of location, tilt angle, orientation and rated power capacity (Sharma & Goel, 2017). It is given by, PR = $\frac{Y_f}{Y_r}\ x\ 100\%$. Normalization with irradiance provides the cumulative effect of losses on the rated output due to wiring losses, inverter inefficiency, reflection from the front surface, system down-time, PV module temperature, dust accumulation, and component failures (Marion et al., 2005). By itself, it doesn't represent the total energy produced as a system having low PR in a location with high solar resources might produce more amount of energy than a system having high PR in a location with low solar resources.

Capacity utilization factor

Capacity utilization factor (CUF) is the ratio of AC energy produced by the PV system over a given period (usually one year) to the possible amount of energy produced if the system were operated at full capacity during that period (Adaramola & Vagnes, 2015). It is given by, $CUF = \frac{E_{AC}}{P_{STC}\ x\ 8760}\ x\ 100\%$

3.6. System efficiency

System efficiency is the ratio of AC output energy generated to the total possible energy generation from the surface area of the solar panel. It is given by,

$$_{sys} = \frac{E_{AC}}{H_T \ x \ A_m} \ x \ 100\%,$$

where A_m is the module area in m^2.

PV Cell Temperature

It is the temperature of the surface of the PV array. At night, the value is same as the ambient temperature, while at day, the value can exceed the ambient temperature by 30^0C or more. Using the energy balance equation for PV array given by Duffie and Beckman, the PV cell temperature can be given as (HOMER ENERGY, n.d.):

$$T_c = \frac{T_a + \left(T_{c,NOCT} - T_{a,NOCT}\right)\left(\frac{G_T}{G_{T,NOCT}}\right)\left[1 - \frac{\eta_{mp,STC}\left(1 - \alpha_P T_{c,STC}\right)}{\tau\alpha}\right]}{1 + \left(T_{c,NOCT} - T_{a,NOCT}\right)\left(\frac{G_T}{G_{T,NOCT}}\right)\left(\frac{\alpha_P \eta_{mp,STC}}{\tau\alpha}\right)}$$

where,

T_c = PV cell temperature

$T_{c,\ NOCT}$ =Nominal operating cell temperature

$T_{c,\ STC}$ = Cell temperature under standard test condition = 25^0C

T_a = Ambient temperature

$T_{a,\ NOCT}$ = Ambient temperature at which the NOCT is defined = 20^0C

G_T = Solar radiation striking the PV array [kW/m^2]

$G_{T,\ NOCT}$ = Solar radiation at which NOCT is defined = 800 W/m^2

$\eta_{mp,\ STC}$ = Maximum power point efficiency under standard test condition

α_p = temperature coefficient of power

τ = solar transmittance of any cover over the PV array

α = solar absorptance of the PV array

The loss in power generation is then calculated using the relation:

$P_{corrected} = P_{rated} \{1 + \alpha_p (T_c - T_{c,\ STC})\}$

where,

P_{rated} = rated power of the solar panel

$P_{corrected}$ = Corrected power of the solar panel after the temperature is considered.

Results and Discussion

This section discusses the results obtained from the data analysis. It is divided into two sections;

a) a long-term comparison of a system (NTC Sundhara), and

b) a comparison of systems with the same components (NTC Pokhara and Biratnagar).

Long-term comparison of a system

The **final yield** (kWh / kW_p) has been constantly decreasing since 2019. The value of 2.91 kWh per kW_p in 2019 has decreased by 24% in 2022 (see fig. 3). Besides, the per square meter energy generation also has decreased from 0.54 kWh/m^2 in 2019 to 0.41 kWh/m^2 in 2022. Although the solar manufacturer has mentioned linear power warranty for 27 years with 3% degradation in the 1st year and 0.65% degradation from year 2 to year 27, the actual decrease is relatively high compared to this. As Kazem et al. (2022) also found that just 35 days of dust accumulation caused a decrease in power from monocrystalline panels by 20%, this huge decrease seems mainly because of dust accumulation. Similarly, Salimi et al. (2019) had also found that the output power of a panel with dust covering was approximately 8 – 12% less per month compared to the clean panel. A new tower is being built nearby, alongside the fallen Dharahara, and the dust from the construction works coats the panels with a layer of dust. This would require regular cleaning of the panels.

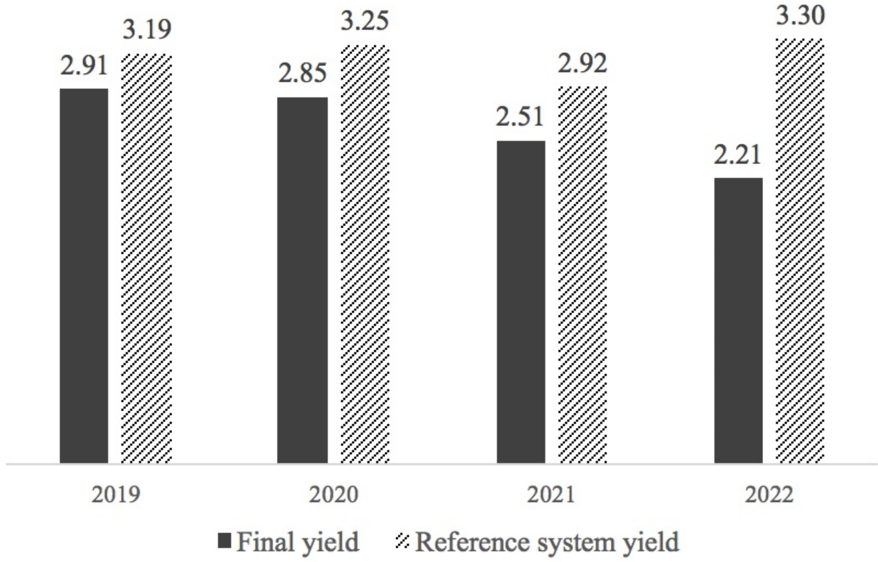

Figure 3 Yearly average final yield and reference system yield (kWh/kWp) at NTC Sundhara

However, the panels do not get cleaned regularly and the accumulated dust reduces the incident solar energy that the panels can get for electricity production. Besides, there are some strings in the system that were at considerable shading zones. Bajracharya (2020) performed shading analysis for summer morning at 9:00 AM, summer noon, summer afternoon at 3:00 PM, winter morning at 9:00 AM, winter noon, and winter afternoon at 3:00 PM, and found that there was considerable shading in the winter for three strings in any time of the day, whereas there was some shading in the summer morning in one of the strings. This shading by building structures reduced the generation resulting in the lower value of final yield. Shading simulation in PVsyst showed that the annual generation without shading and with shading condition would generate 117.5 MWh and 96 MWh of electricity, respectively, causing overall loss of 18.3% energy in a year (Bajracharya, 2020). The shading loss was more pronounced in winter than summer (see fig. 4).

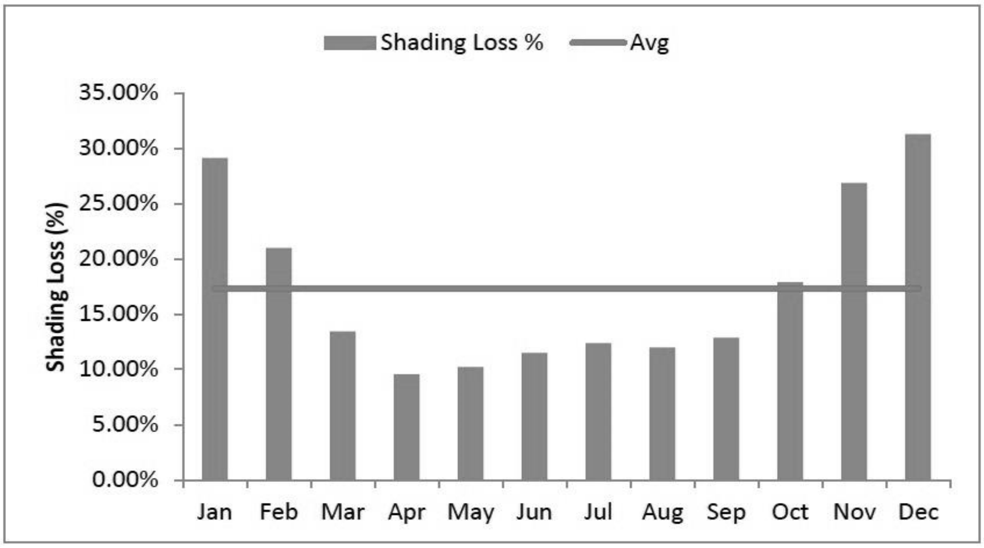

Figure 4 Shading losses (simulated) in the solar plant at NTC Sundhara

The performance ratio was 91.0% in 2019 and 87.8% in 2020 and 2021, but it drastically dropped to 67.3% in 2022 (fig. 5). The final yield continuously decreased as expected. But, the reference yield dipped in the year 2021 compared to the other years. This was because of the lesser value of solar radiation in the spring (March–May) of that year.

This dip resulted in a higher value of performance ratio in the year 2021 causing a drastic decrease from 2021 to 2022. As the energy output continuously decreased over the years, the capacity utilization factor also continuously decreased from 12.1% in 2019 to 9.2% in 2022. And, the system efficiency dropped drastically

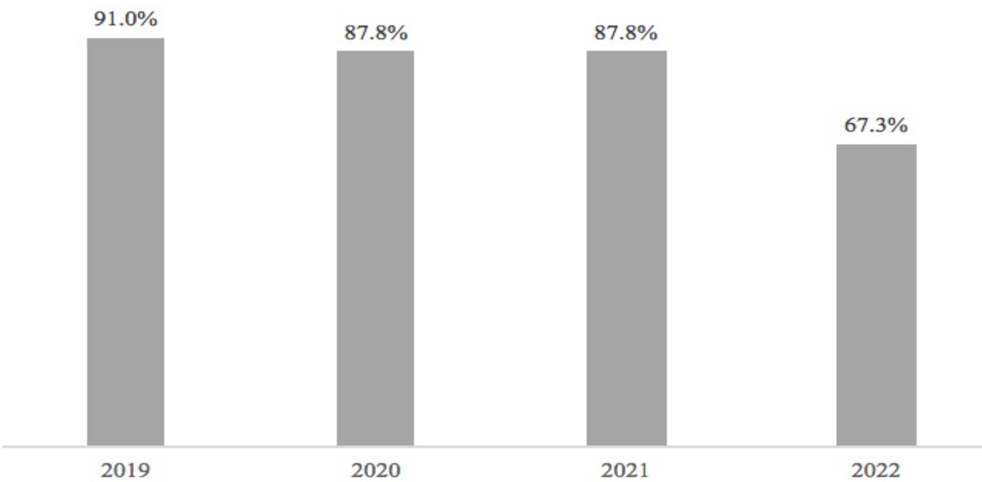

Figure 5 Yearly performance ratio of the solar plant at NTC Sundhara

from 16.3% in 2021 to 12.5% in 2022, due to the lesser value of solar irradiance in spring 2021.

Comparison of systems with the same components

The systems installed at Pokhara and Biratnagar consisted of the same components (45.32 kW_p solar system consisting of 103 numbers of 440 W_p Longi solar panels and two SOLIS inverters of capacities 20 kW and 25 kW). Pokhara lies in the hilly region of Nepal while Biratnagar lies in the Terai region (fig. 6). The impact of temperature and radiation on the various parameters was conducted.

	Pokhara	Biratnagar
Latitude	28.22^0 N	26.46^0 N
Longitude	84.00^0 E	87.29^0 E
Altitude	822 m	80 m
Solar irradiance	4.83 kWh/m^2/day	5.01 kWh/m^2/day

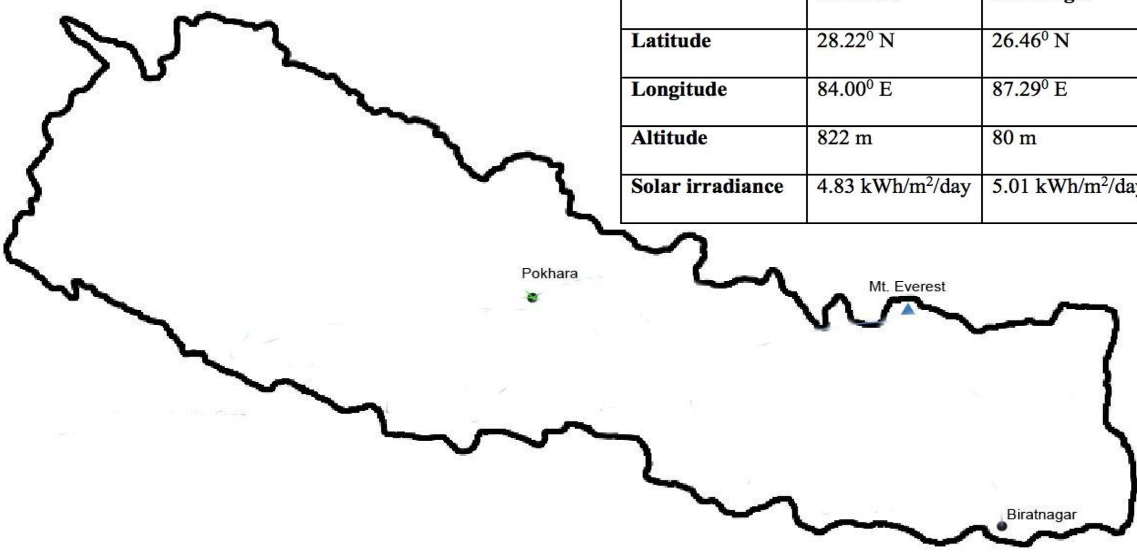

Figure 6 Location of Pokhara and Biratnagar in Nepal

4.2.1. Weather data

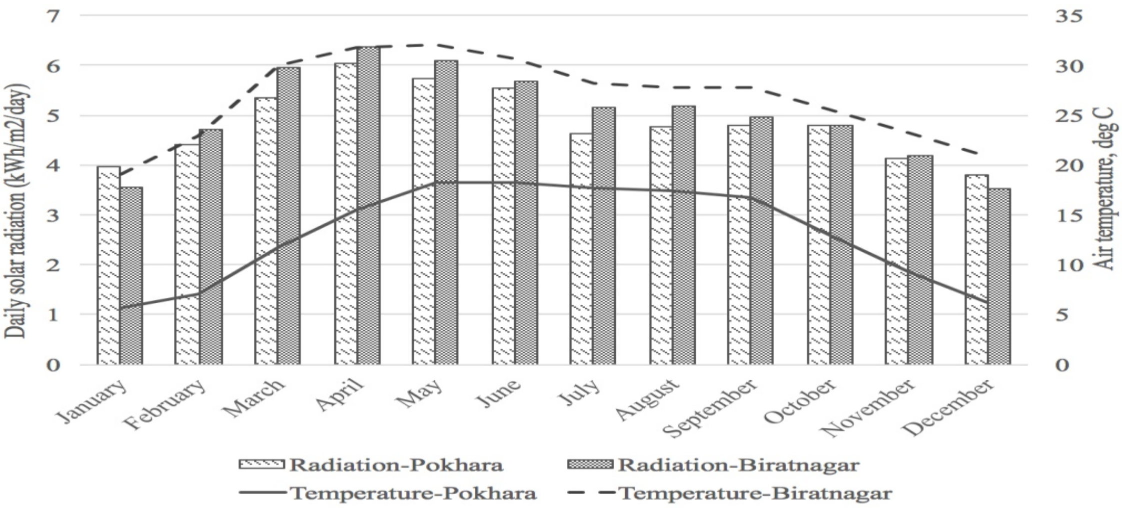

Figure 7 Temperature and radiation data of plants at Pokhara and Biratnagar

Temperature and radiation data were obtained from NREL for a typical meteorological year for both locations. The air temperature at Pokhara ranged from 5.7^{0}C in January to 18.3^{0}C in June with an average of 13.1^{0}C while the air temperature at Biratnagar ranged from 19.1^{0}C in January to 32.0^{0}C in May with an average of 26.7^{0}C. This showed that the average temperature at Biratnagar is double than that of Pokhara. Similarly, the solar radiation at Pokhara ranged from 3.80 kWh/m^2/day in December to 6.05 kWh/m^2/day in April, with an average of 4.83 kWh/m^2/day, and the solar radiation at Biratnagar ranged from 3.53 kWh/m^2/day in December to 6.36 kWh/m^2/day in April, with an average of 5.01 kWh/m^2/day (fig. 7). This showed that the solar radiation at Biratnagar is higher by 4% on average. Only, during December and January, the radiation at Pokhara was significantly higher than at Biratnagar by 11.1% and 7.6%, respectively. The temperature and radiation data of Pokhara and Biratnagar were highly correlated (correlation for Pokhara = 0.72 and correlation for Biratnagar = 0.97), which means, higher air temperature was related to higher radiance.

Final Yield vs Temperature

While the average air temperature at Biratnagar (26.7^{0}C) was higher than at Pokhara (13.1^{0}C), the final yield

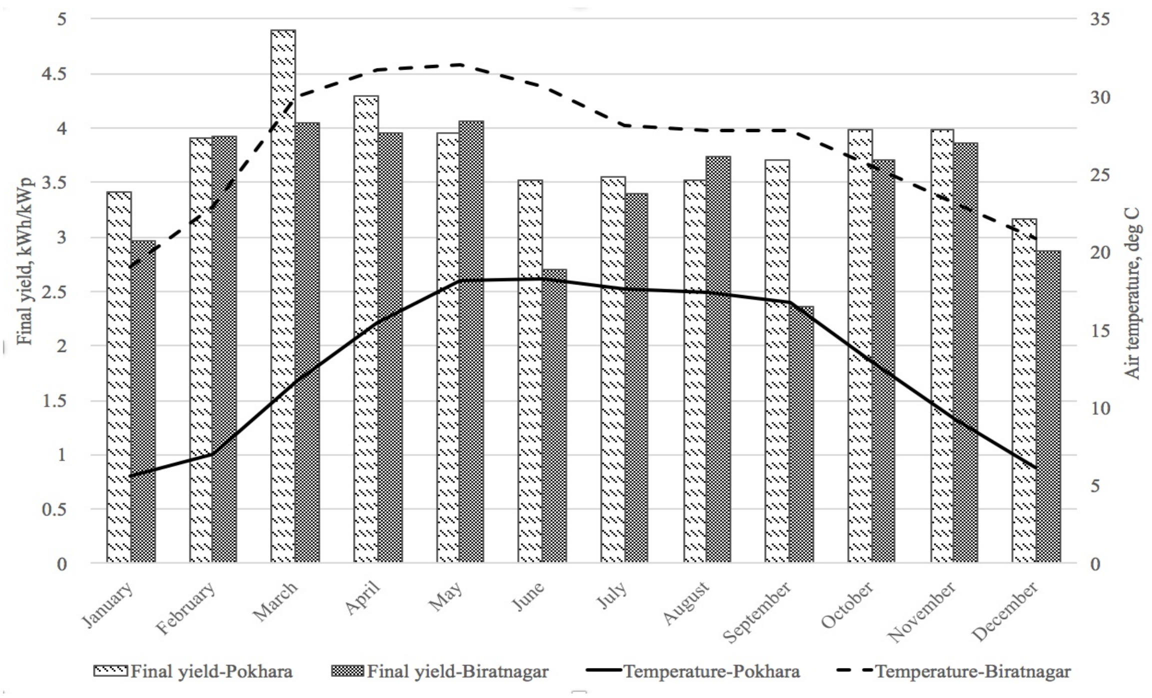

Figure 8 Final yield (kWh / kW$_{p)}$ vs temperature data of plants at Pokhara and Biratnagar

(kWh/ kW$_p$) was found to be lower by an average value of 9% (fig. 8). Only the final yield in the months of May and August was higher at Biratnagar by 3% and 6%, respectively, than at Pokhara. This kind of higher temperature's relation to less energy generation was confirmed by determining the relation between temperature and power generated by the solar panel. Using weather data for a typical meteorological year, it was found that the 440 W$_p$ solar panel operated normally in the range between 412.3 W$_p$ (in June) and 432.3 W$_p$ (in January) at Pokhara (i.e. 93.7% - 98.2% of the system capacity) and, 390.6 W$_p$ (in May) and 411.1 W$_p$ (in January) at Biratnagar (i.e. 88.8% - 93.4% of the system capacity). The monthly variation of power produced at the locations is shown in Figure 9. Although winter months had higher power generation due to lower cell temperature, the final yield was lesser because of less solar radiation.

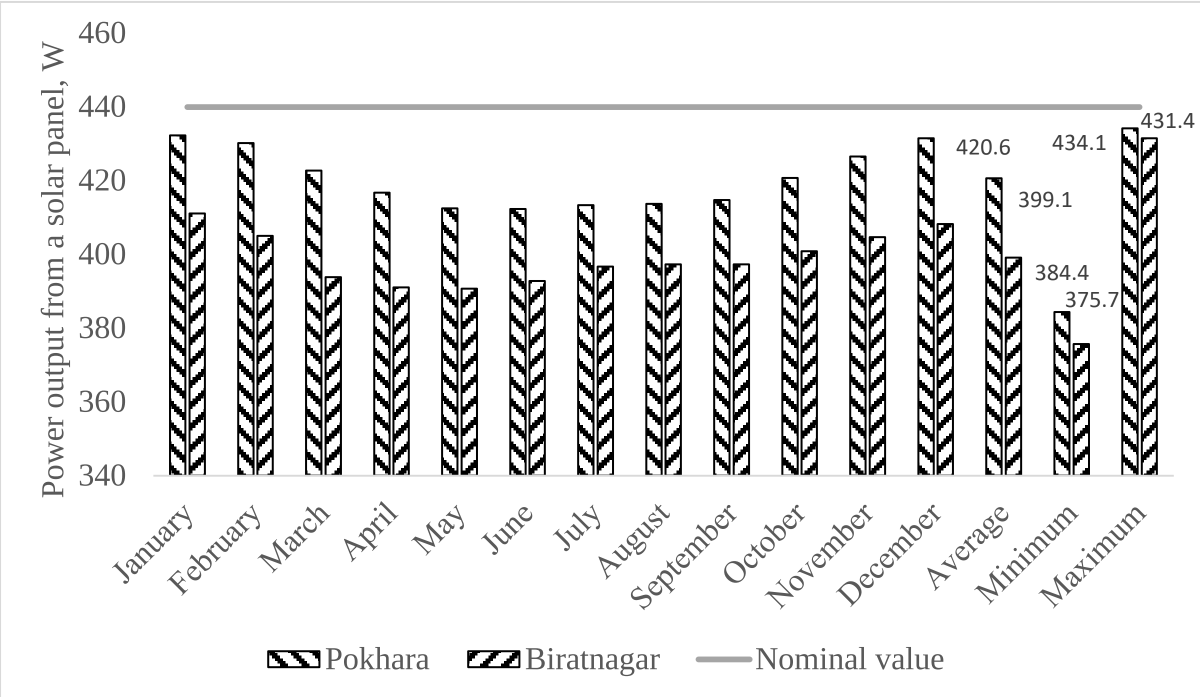

Figure 9 Average monthly power produced from 440 W solar panel at Pokhara and Biratnagar

The values seen in fig 9 is in accordance to the panel specifications which mentioned that the temperature coefficient of maximum power is -0.35%/^{0}C, which means that for every temperature above 25^{0}C, the power generated decreases by 0.35%. Revati and Natarajan (2016) found that the performance of solar cells increased with a decrease in temperature. Besides, for each location, the higher temperature month was usually associated with lesser energy generation or final yield. This was more pronounced for the plant at Pokhara than at Biratnagar (Fig. 10a and 10b).

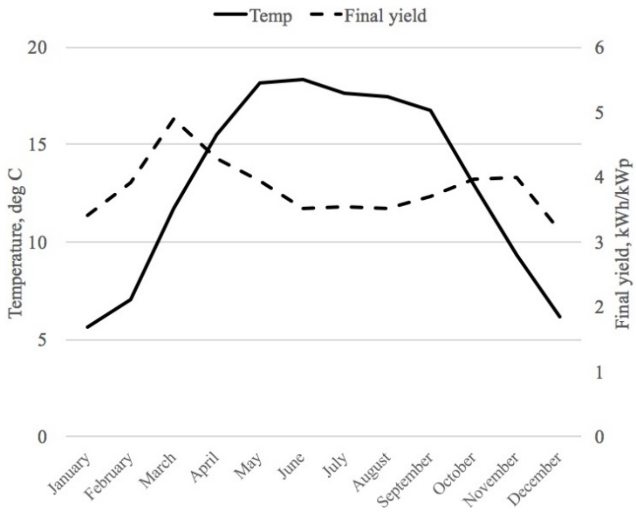

Figure 10a Final yield vs temperature for Pokhara plant

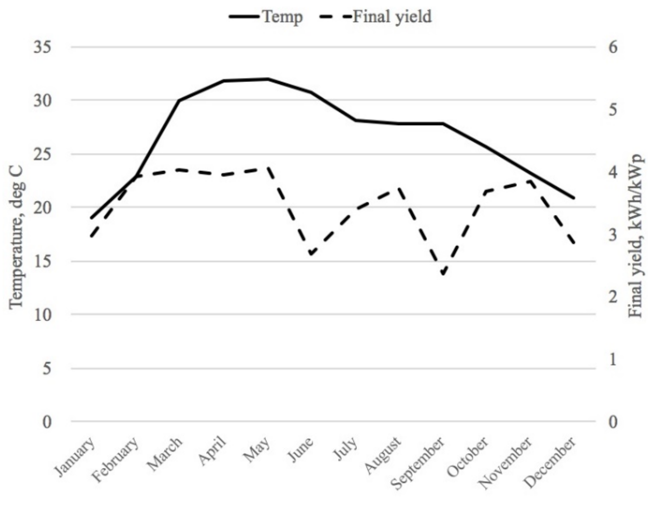

Figure 10b Final yield vs temperature for Biratnagar plant

Capacity utilization factor vs Temperature

The capacity utilization factor of a plant at Pokhara was usually higher than at Biratnagar, except for the months of February, May, and August (fig. 11). The yearly average value was 15.9% at Pokhara and 14.3% at Biratnagar. The value was the highest for both plants in the month of March. For each location, the higher temperature month was usually associated with lesser energy generation or final yield. This was more pronounced for the plant at Pokhara than at Biratnagar just as seen in the final yield.

System Efficiency vs Temperature

The system efficiency of the plant at Pokhara was always higher than the plant at Biratnagar (fig. 12). The average system efficiency of Pokhara and Biratnagar plants was 16.1% and 14.2% respectively. For each location, the higher temperature month was usually associated with lesser system efficiency. Farahmand et al. (2021) also found that the panel efficiency during winter was higher than summer due to air temperature decrease. Also, it was calculated that for every 10^0C rise in cell temperature, the efficiency decreased by 11.5%. This was somewhat close to the value of 7% determined experimentally by Elshazly et al. (2021).

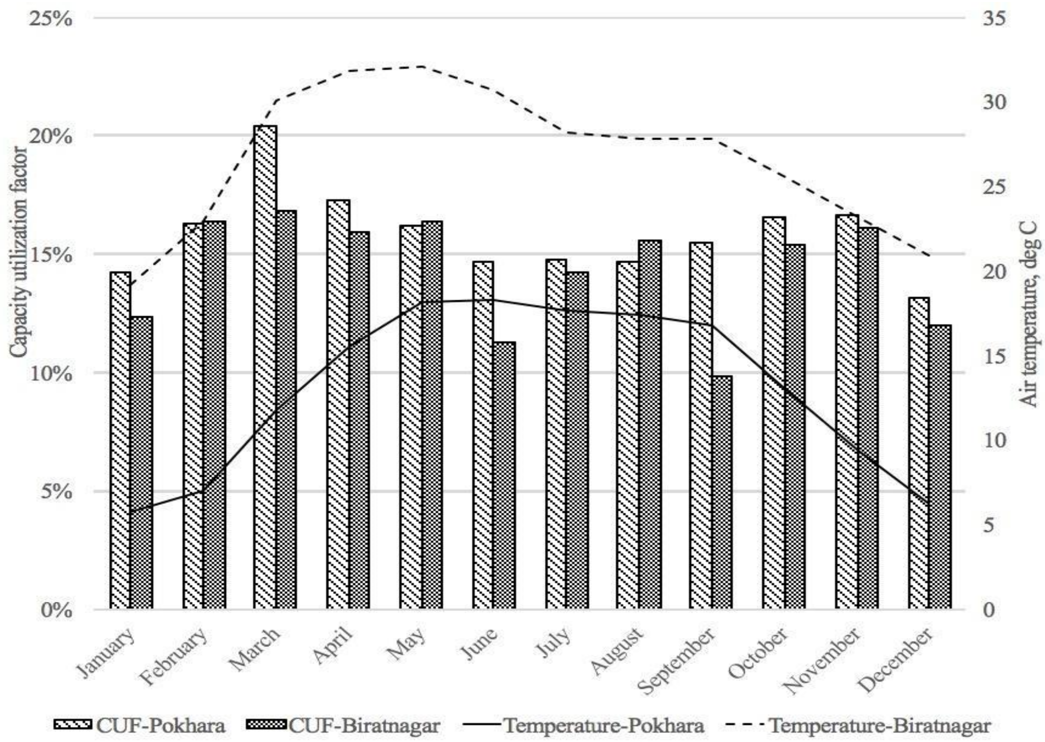

Figure 11 Capacity utilization factor vs temperature for Pokhara and Biratnagar plants

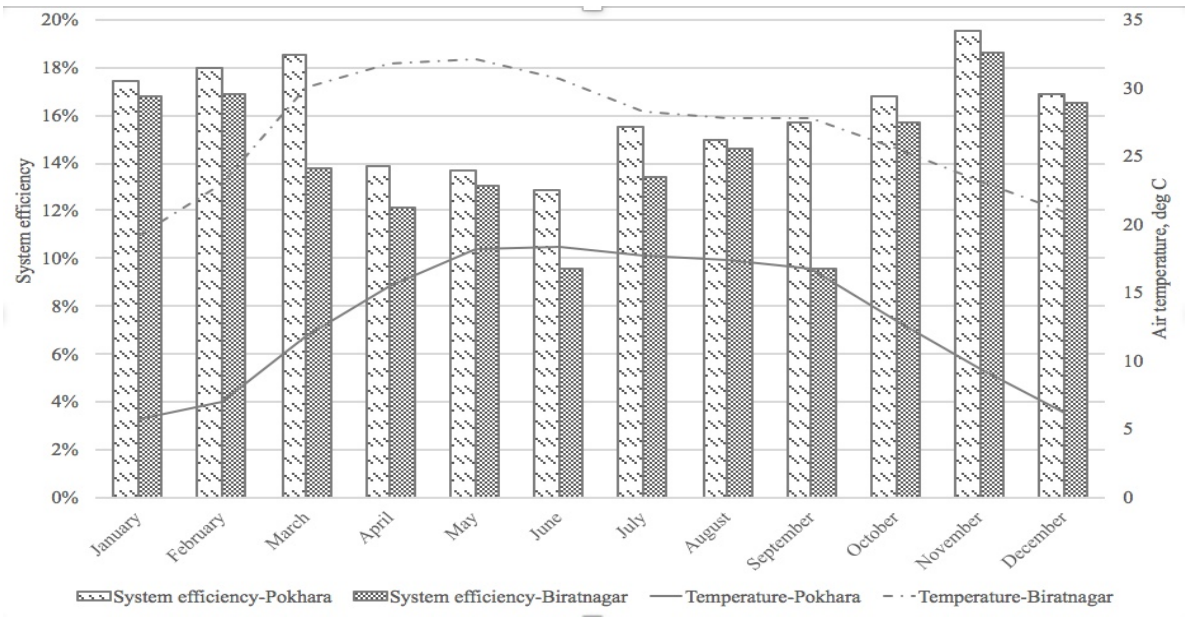

Figure 12 System efficiency vs temperature for Pokhara and Biratnagar plants

4.3. Summary

Table 3 Summary of technical performance parameters of all the plants

S. No.	Technical parameters	NTC Sundhara	NTC Pokhara	NTC Biratnagar
1	Reference yield (Y_r) (kWh/kW_p)	3.16	4.81	5.01
2	Final yield (Y_f) (kWh/kW_p)	2.60	3.76	3.46
3	Final yield (Y_f) (kWh/m^2)	0.48	0.76	0.70
4	Performance Ratio (PR)	83.0%	79.1%	70.6%
5	Capacity Utilization Factor (CUF)	10.8%	15.6%	14.3%
6	System Efficiency (η)	15.4%	16.0%	14.2%

Conclusion

This study was conducted to evaluate the performance of grid-connected mono-crystalline silicon-based solar plants in Nepal by using the data from solar plants installed at Nepal Telecom offices of Sundhara, Pokhara, and Biratnagar. The following conclusions can be derived from the study:

- Since its operation in March 2019, the solar plant at Sundhara has been generating less energy from the installed solar modules. While the plant produced 2.91 kWh/kW_p in 2019, it dropped to 2.21 kWh/kW_p in 2022. Dust accumulation in the panels due to its location might be a major reason for this decrease. Similarly, the performance ratio decreased from 91.0% in 2019 to 67.3% in 2022, capacity utilization factor decreased from 12.1% in 2019 to 9.2% in 2022, and system efficiency decreased from 16.8% in 2019 to 12.5% in 2022.

- Biratnagar had slightly higher (by 4%) solar radiation than Pokhara but the final yield was 9% lower because the average temperature at Biratnagar (26.7^{0}C) was higher than at Pokhara (13.1^{0}C). The 440 W_p module worked at 431.1 W_p (2% reduction) at Pokhara and 409.6 W_p (6.9% reduction) at Biratnagar in the average temperature. Similarly, the performance ratio of Pokhara (80.0%) was better than that of Biratnagar (70.6%), the capacity utilization factor of Pokhara (15.9%) was better than that of Biratnagar (14.3%), and the system efficiency of Pokhara (16.1%) was also better than that of Biratnagar (14.2%). All the parameters were found to be lower in the months with higher temperatures, especially the spring and summer seasons.

Recommendation

This study has been conducted with limited resources and information. Data from the developers and clients were not available as much as required. The 680 kW_p plant at KUKL Sundarighat used heterojunction with an intrinsic thin layer (HIT) solar cell but the data logger was out of order. A few private developers were reluctant to provide data citing copyright issues. So, to truly understand the performance of solar cells under our climatic condition for technical as well as economic feasibility, the following recommendations are provided:

- Data from solar plants using various solar cell technologies need to be available for research purposes. This can be coordinated by the solar technology division at the Alternative Energy Promotion Center (AEPC).
- Proper technical research to identify the efficacy of half-cut solar cells in comparison to normal solar cells, under our climatic conditions, should be done.
- Provision of installing weather systems, at a clear location, at the solar plants should be made compulsory to have accurate meteorological data so that research does not depend only on satellite data.

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Supporting information

ANNEX A: METEOROLOGICAL DATA

The air temperature and global horizontal irradiance (GHI) data taken from the National Solar Radiation Database of National Renewable Energy Laboratory (NREL) for a typical meteorological year:

Table 4 Average temperature and global horizontal irradiance of Pokhara and Biratnagar taken from NREL

Location	**Pokhara**		**Biratnagar**		**Chhauni**		**Sundhara**	
Lat (N) /Long (E)	28.22^0	84.00^0	26.46^0	87.29^0	27.71^0	85.29^0	27.70^0	85.31^0
Month	Average temp, ^{0}C	GHI, kWh/m^2/day	Average temp, ^{0}C	GHI, kWh/m^2/day	Average temp, ^{0}C	GHI, kWh/m^2/day	Average temp, ^{0}C	GHI, kWh/m^2/day
January	5.7	3.96	19.1	3.56	8.4	4.24	7.4	4.13
February	7.0	4.41	23.0	4.71	11.1	4.72	9.0	4.86
March	11.8	5.35	30.0	5.95	14.7	6.04	13.4	5.80
April	15.5	6.05	31.8	6.36	20.4	6.41	18.4	6.24
May	18.2	5.74	32.0	6.09	22.3	6.07	20.7	6.09
June	18.3	5.54	30.7	5.69	20.9	5.65	19.6	5.51
July	17.7	4.64	28.2	5.14	20.4	4.79	19.5	4.97
August	17.4	4.77	27.8	5.17	20.3	4.83	19.5	5.06
September	16.8	4.78	27.8	4.97	19.5	4.72	18.0	4.88
October	13.0	4.80	25.6	4.79	16.8	5.03	15.1	4.98
November	9.3	4.13	23.2	4.20	13.0	4.17	11.3	4.41
December	6.2	3.80	20.9	3.53	9.5	3.87	8.5	3.88
Average	13.06	4.83	26.68	5.01	16.44	5.04	15.02	5.07

ANNEX B: MONTHLY DATA

Table 5 Monthly average parameters of all the plants

Location	**Month / Category**	**Final yield, Y_f (kWh/kW$_p$)**	**Final yield, Y_f (kWh/m^2)**	**Reference system yield, Y_r (kWh/kWp)**	**Performance ratio, PR = Y_f/Y_r**	**Capacity utilization factor, CUF = E_{ac} / (P * 24)**	**System efficiency, η (E / (H_t * A_m))**
Sundhara	January	1.89	0.35	2.56	76.8%	7.9%	14.2%
	February	2.41	0.45	2.97	84.8%	10.0%	15.7%
	March	3.14	0.58	3.47	93.0%	13.1%	17.2%
	April	3.38	0.63	3.50	98.0%	14.1%	18.2%
	May	3.11	0.58	3.43	91.1%	13.0%	16.9%
	June	2.97	0.55	3.32	89.8%	12.4%	16.6%
	July	2.55	0.47	2.86	89.4%	10.6%	16.6%
	August	2.87	0.53	3.18	90.8%	11.9%	16.8%
	September	2.55	0.47	2.90	89.5%	10.6%	16.6%
	October	2.84	0.53	3.65	78.4%	11.8%	14.5%
	November	1.87	0.35	3.18	59.4%	7.8%	11.0%
	December	1.54	0.29	2.82	5k6.2%	6.4%	10.4%
Pokhara	January	3.42	0.69	3.96	86.2%	14.2%	17.5%
	February	3.91	0.79	4.41	88.7%	16.3%	18.0%
	March	4.90	0.99	5.35	91.6%	20.4%	18.5%
	April	4.29	0.84	6.05	70.9%	17.3%	13.9%
	May	3.95	0.79	5.74	68.8%	16.2%	13.7%
	June	3.52	0.71	5.54	63.5%	14.7%	12.9%
	July	3.55	0.72	4.64	76.5%	14.8%	15.5%
	August	3.52	0.71	4.77	73.8%	14.7%	14.9%
	September	3.71	0.75	4.78	77.5%	15.4%	15.7%
	October	3.98	0.81	4.80	82.9%	16.6%	16.8%
	November	3.99	0.81	4.13	96.6%	16.6%	19.5%
	December	3.16	0.64	3.80	83.2%	13.2%	16.8%
Biratnag	January	2.96	0.60	3.56	83.2%	12.3%	16.8%

ar	February	3.92	0.79	4.71	83.2%	16.4%	16.8%
	March	4.04	0.82	5.95	67.9%	16.8%	13.7%
	April	3.95	0.77	6.36	62.1%	15.9%	12.2%
	May	4.06	0.80	6.09	66.8%	16.4%	13.1%
	June	2.69	0.55	5.69	47.4%	11.2%	9.6%
	July	3.40	0.69	5.14	66.2%	14.2%	13.4%
	August	3.74	0.76	5.17	72.3%	15.6%	14.6%
	September	2.36	0.48	4.97	47.4%	9.8%	9.6%
	October	3.70	0.75	4.79	77.3%	15.4%	15.6%
	November	3.85	0.78	4.20	91.8%	16.1%	18.6%
	December	2.87	0.58	3.53	81.4%	12.0%	16.5%
Chhauni	January	2.79	0.53	3.56	78.3%	11.6%	14.8%
	February	3.46	0.65	4.15	83.2%	14.4%	15.8%
	March	3.65	0.69	4.64	78.7%	15.2%	14.9%
	April	3.76	0.71	4.91	76.5%	15.6%	14.5%
	May	3.29	0.62	4.92	66.9%	13.7%	12.7%
	June	2.96	0.56	4.87	60.7%	12.3%	11.5%
	July	2.88	0.55	4.88	59.1%	12.0%	11.2%
	August	2.30	0.43	4.88	47.1%	9.6%	8.9%
	September	2.26	0.43	4.69	48.3%	9.4%	9.1%
	October	3.12	0.59	4.21	74.0%	13.0%	14.0%
	November	3.04	0.58	3.62	83.9%	12.7%	15.9%
	December	2.84	0.54	3.27	86.8%	11.8%	16.4%

ANNEX C: SEASONAL DATA

Table 6 Seasonal average parameters of all the plants

Location	Season / Category	Final yield, Y_f (kWh/kWp)	Final yield, Y_f (kWh/m^2)	Reference system yield, Y_r (kWh/kWp)	Performance ratio, PR = Y_f/Y_r	Capacity utilization factor, CUF = E_{ac} / (P * 24)	System efficiency (E / (H_t * A_m))
Sundhara	Spring	3.22	0.60	3.47	94.2%	13.4%	17.4%
	Summer	2.79	0.52	3.12	90.0%	11.6%	16.7%
	Autumn	2.42	0.45	3.25	75.7%	10.1%	14.0%
	Winter	1.89	0.35	2.78	70.6%	7.9%	13.1%
Pokhara	Spring	4.27	0.85	5.72	75.0%	17.5%	14.9%
	Summer	3.53	0.71	4.98	71.2%	14.7%	14.4%
	Autumn	3.89	0.79	4.57	85.7%	16.2%	17.3%
	Winter	3.41	0.69	3.99	85.3%	14.2%	17.3%
Biratnagar	Spring	4.02	0.80	6.13	65.6%	16.4%	13.0%
	Summer	3.28	0.66	5.33	62.0%	13.7%	12.5%
	Autumn	3.30	0.67	4.65	72.2%	13.8%	14.6%
	Winter	3.25	0.66	3.94	82.6%	13.6%	16.7%
Chhauni	Spring	3.57	0.68	4.82	74.0%	14.9%	14.0%
	Summer	2.71	0.51	4.87	55.6%	11.3%	10.5%
	Autumn	2.81	0.53	4.17	68.7%	11.7%	13.0%
	Winter	3.08	0.58	3.68	83.7%	12.8%	15.8%

ISSN NO. 2091-1742
SCITECH NEPAL
Journal of Scientific and Technical Studies
Nepal Engineering College, Pokhara University

Research Article
DOI:10.3126/scitech.v17i1.60497

COVID-19 Lockdown's Effect on Building Construction Projects in Kathmandu Valley Nepal

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Received: May 15, 2023
Accepted: October 10, 2023

ABSTRACT

This research intends to assess the critical factors as an effect of COVID-19 lockdown on selected building construction projects within the Kathmandu Valley in Nepal. The research identifies “Health and Safety risk management” as the most critical factor compared to the other critical components namely supply chain operation, contractual and construction financial market. This research focuses on utilizing systematic partial least squares structural equation modeling to assess the effect of COVID-19 lockdown. Further, it seeks to demonstrate the direct relationships between COVID-19 effects and the critical factors that have been affected as a result of the pandemic. The study considers these factors as essential components in assessing the overall impact of COVID-19. This study attempts to evaluate and examine the significant pandemic effects on building construction projects. Nepal-based construction firms, government agencies, and non-government organizations were surveyed to identify critical factors affected by COVID-19 in building projects. The quantitative design method of this study included the use of smart partial least squares structural equation modeling (PLS-SEM), one of the statistical tools. Information like the fundamentals of the project, its state, etc., have been considered. 104 valid responses were received out of 130 questionnaires distributed supported at less than 1 % significance level. The inner structural model analysis, with a highest value of 7.014 and a beta value of 0.474, highlights the significance of the relationship between safety and risk management factors and COVID-19 effect in building construction projects. This relationship stands out as highly significant when compared to other constructs examined in the study. The findings underscore the crucial role of safety and risk management practices in mitigating the effects of the pandemic on construction projects.

KEYWORDS: COVID-19; Lockdown; Construction; Health and Safety; Supply chain; Contractual Issues; Financial Market.

INTRODUCTION

COVID-19- Lockdown

Over the years, the construction industry has developed a reputation for being associated with significant safety and health risks. The introduction of COVID-19 has resulted in an additional threat that poses substantial risks to the safety and well-being of its workers in the construction industry. In order to stem the spread of COVID-19 inside the industry and lessen its effects on construction workers and overall progress, a number of safeguards have been put in place due to the extraordinary nature of this once-in-a-century event. The usefulness and viability of the laws that the Centers for Disease Control and Prevention (CDC) and

Occupational Safety and Health Administration (OSHA) have recommended and put into place to safeguard the safety of construction workers are subject to disagreement within the industry (Nnaji et al. 2022).
The COVID-19 pandemic's onset had wide-ranging effects on the social, political, and economic sectors, as well as on health. As a result, the global economy suffered a severe downturn and entered its most critical situation in decades, with the building industry suffering the most severe effects. These included delays in the supply chain for essential building materials, as well as the suspension or cancellation of construction activities, increased uncertainty about upcoming projects, work force issues, rising costs, extended project timelines, and a wide range of legal complexities (Husein et al. 2021).
Different stakeholders in the construction sector, including owners, developers, contractors, subcontractors, and supply chain suppliers, have been impacted differently by the COVID-19 outbreak. The type of effects and scope of consequences are largely influenced by the locations of the underlying projects and the corresponding businesses (Chivilo et al. 2020).
Since World War II, the pandemic has caused the worst worldwide recession. As per the IMF report dated on April 2021, the global economy shrank by 3.5 percent in 2020, which is a 7 percent decline from the 3.4 percent growth prediction provided in October 2019. Even while every country the IMF surveyed witnessed negative growth in 2020, the effects were more pronounced in the world's poorest regions (Yeyati et al. 2021).
The construction industry has been significantly affected in numerous ways including both personal and professional levels. These new realities have an impact on nearly every aspect of the construction process, particularly those related to contract or project notices for default, scheduling, adjustments; project suspension, termination, and reinstatement; OSHA and workplace safety compliance; work force management; material, subcontractor, and supply chain delays and impacts; risk management and insurance; claims avoidance or management; and the dispute resolution process (Holland & Knight 2020).
In Nepal, the COVID-19 pandemic has led to employment losses and disruptions in the food supply chain, putting thousands of people who depend on daily wages at risk of hunger and poverty. The nation's efforts to meet its 2015 UN Sustainable Development Goals targets have also been hampered by the pandemic (Joshi 2021).
Similarly, the pandemic has caused labor shortages and delays in Nepal's construction projects as a result of infected and quarantined workers. These issues remained even after lockdowns were lifted due to supply chain problems, border closures with India (Timilsina et al.2021).
Large-scale infrastructure projects in Nepal, such as those promoting national pride, were severely impacted by the COVID-19 outbreak and its lockdown. As a result, there have been projections that the time and cost required to complete these projects would overrun.
An assessment concluded the contractors lost their income in site management, staff salary, and rent. Likewise, the machinery used in the construction sector also resulted in a big loss. As a result, it has been estimated that 65 million will be required within the next three months to resume construction work (FCAN 2020).
According to the post–pandemic adjustment of national accounts, production of the construction sector is anticipated to be Rupees 488 billion for the fiscal year 2019–20, down 0.31 percent from the previous year (The Asia Foundation 2020).
Previous research and literature have shown that critical factors, including building construction projects, can have a substantial impact on the construction industry during COVID-19 pandemic. Existing research, on the other hand, has mostly focused on the overall impact on construction projects, demanding a more in-depth investigation of the consequences on the building construction sector. Adopting thematic approaches is vital for effectively identifying and measuring the impact of critical aspects on building construction. It is critical to recognize that the impact of COVID-19 on individuals in the construction industry will vary depending on organizational features and management methods. Because of the specific nature of building projects and work arrangements, implementing COVID-19 procedures in the construction industry can present practical obstacles. Future research initiatives should prioritize closing this knowledge gap.
As each project is unique in its own nature, identifying the root cause of the issues and challenges brought on by COVID-19 and exploring the possible measures to minimize the effects of the pandemic could be a breakthrough.

Major Critical Factors

Numerous studies have been conducted to investigate the effects of COVID-19 epidemic on construction industry. These studies have carefully considered many implications and difficulties, the industry has faced as a direct result of the pandemic.
The effects of COVID-19 on the construction industry are both immediate and long-term. The workforce-related issues include worker shortages brought on by infections and preventive quarantines as well as worker layoffs caused by project cancellations and delays. The project and workplace-related issues include implementing new workplace practices and policies; procurement and supply chain issues include restrictions and closures in international exchange markets; and the consequences of contracts, laws, and insurance, including relevance about the force majeure clause (Assaad & El-adaway Islam 2021).
Sierra (2021) discussed on undergoing period of shrinkage of the construction industries in the context of a pandemic that is constantly evolving and creating an uncertain situation with many interrelated factors to take into account. These factors include sudden slowdowns or interruptions of on-site work, lack of manpower, disruptions with supply chain and subcontractors' work, rise in insolvency, complicated contractual exposures, and a decline in cash flow.
Hence, an extensive literature review and KII were undertaken in order to identify and comprehend the main consequences of COVID-19 on the building construction sector, which resulted in the identification of 24 thematic impacts.

Construction Financial Market:

Zamani (2021) summarized about the operational and financial issues that COVID-19 has caused in the building industry. The study covered the material delays brought on by cross-country procedures, supply limitations caused by the supplier company's operations being halted and the increased demand for supplies. Moreover, it discussed how industry struggled with shortage of skilled worker, particularly international labor and how labor shortages caused delay in construction projects. A few recognized variables, such as the costlier materials and COVID-19 test processes, have driven up the project's cost. Fluctuations in foreign exchange rates, along with a surge in demand for supply, have led to increased material costs associated with the COVID-19 test processes, increasing the company's costs. The second COVID-19-related challenge is financial. Late payments, rising project costs, and fewer projects are three elements that contribute to financial issues during COVID-19.

According to Timilsina (2021), COVID-19 has caused a decrease in construction projects as result of government budget cuts. Moreover, the contractors are facing financial difficulties due to the industry's poor financial performance, along with issues of delayed payments and project cost overruns. Also, the influence of COVID-19 on the building construction business has been demonstrated by Zamani (2021) due to financial concerns. To deal with their financial problems, the majority of businesses need financial assistance.

Hypothesis 1*: Effects of COVID-19 is directly associated with the construction financial market*

Contractual Implication

Construction projects are being significantly impacted by COVID-19, although the legal effects will differ between countries and contracts. Events like the COVID-19 pandemic often typically activate contractual clauses addressing the effects of unforeseen events (White & Case LLP 2020).
It depends on the precise clauses and interpretation of the contract itself as to how COVID-19 would affect contractual obligations regarding its uncertainty.
Only 40.7% of engineers in the study of COVID-19's effects on Jordanian civil engineers were aware that legal contract regulations contained a Force Majeure clause, but defining COVID-19 as a Force Majeure would depend on the types of contracts that were approved. According to Bista (2021), the most significant contractual challenges associated with the pandemic were time extension cost increment, claim and conflicts.
In many Public-Private Partnership (PPP) contracts spanning foreign countries, force majeure clauses frequently use unclear language and result in hazy risk checklists rather than precise legal definitions. It is challenging to respond since, in practice, the phrasing of the clause, the nature of the contractual duty, and the

actual impact of the pandemic, all matters. Reduced tax collection, fluctuating currency values, and significant stimulus spending are causing governments to have financial problems. Government treasury income have decreased as a result of the pandemic's abrupt and significant effects, which could make it more difficult for public agencies to meet all of their contractual responsibilities (Cassady & Baxter 2020).

Nair & Suresh (2021) noted how idle resources, including equipment and manpower, could delay project completion and raise consumer complaints, or lead the bank to confiscate property if a loan is not repaid during the lockdown. This underutilization of renewable resources effects legal issue indirectly.

The primary contractual issue that arises frequently in construction projects include inconsistent language and ambiguity in the contract documents, a lack clarity in the project's scope, ineffective negotiation techniques, and inadequate contract communication. Legal ramifications of these issues may include fines and lawsuits for breaking contract conditions, invalidating contracts that do not follow current laws, and strained relationships between project parties (Al-Mhdawi et al. 2021).

Sierra (2021) emphasized the lack of a definite legal definition for force majeure, as well as the interpretation of such provisions being dependent on the contractual language. In light of the COVID-19 outbreak, many contractors have cited "force majeure" to justify deadline extensions, despite the fact that courts have generally construed force majeure terms narrowly, admitting them only when the outbreak was directly stated in the contract. Therefore, this is a grey area. Hence, contractors need to take caution when implementing force majeure clauses in contracts while stakeholders should exercise caution when thinking that filing a claim for force majeure will immediately remove them from their contractual obligations.

Hypothesis 2: *Effects of COVID-19 is directly associated with the Contractual implication*

Health and Safety risk management

The research on the Impact of COVID-19 on Construction Projects in Developing Countries indicated that safety and risk management were the construction themes most impacted by the pandemic (Al Mhdawi et al. 2021). The research's findings draw attention to several issues in risk management. These comprise: (1). inadequate necessary knowledge, (2) lack of systematic approach to risk management, and unawareness of standard procedures and methods for risk identification, analysis, and response, and (3) risk management based primarily on subjective judgment. During the pandemic, these challenges have been particularly the key obstacles, hindering the application of effective risk management approaches.

Workplace safety literacy and risk perception in the construction sector have been impacted by a number of variables, such as safety training, hazard recognition, risk-taking behaviors, attitudes, and the industry’s dynamic character. The inability of workers to communicate effectively enough to identify and discuss COVID-19 concerns in the construction industry is an additional problem. From the standpoint of the construction business, there is little data available on workplace COVID-19 literacy, risk perception, and infection probability (Choi & Staley 2021). The limitation of fieldworkers' viewpoints on safety and health initiatives put in place in response to a pandemic like COVID-19 was underlined by Nnaji (2022).

The construction sector’s poor safety culture and climate have been linked that highlighted the difficulties in successfully implementing safety interventions. This has led to inadequate conditions for the actual application and enforcement of safety resources to workers (Nnaji et al. 2022).

For field employees in the construction business, the lack of a safe working environment and health and safety issues have created a stressful work environment. Restricted access to tools and equipment can make it harder for employees to do their jobs, and a non-secure workplace can expose workers to the COVID-19 virus. Additionally, the social isolation brought on by teleworking can cause workers to experience mental health problems (Pamidimukkala & Kermanshachi 2021).

Hypothesis 3: *Effects of COVID-19 is directly associated with the health and safety risk management*

Supply chain operation

The COVID-19 pandemic has notably impacted the construction industry, manifesting operational-level challenges such as compressed construction timelines, delayed approvals, scarcity of skilled workers and supplies, and logistical difficulties. These factors have collectively influenced the overall execution of building construction projects (Zamani et al. 2021).

According to Timilsina (2021), the COVID-19 pandemic's operational level impact on the construction sector includes project completion delays, supply chain issues, workers health and safety concern, workforce management challenges, and insufficient support from government and professional association. The study also shows the scarcity of qualified local labor in the building industry.

In the research on how the COVID-19 pandemic has affected Pakistan's construction industry, the problems related to budgetary constraints, inflation of material costs, unavailability of labor, difficulty in following the Standard Operating Procedures, logistics disruption and psychological issues was identified. One issue that stands out is the fund problem due to the imposed shutdown as many industries failed to pay their debts, ultimately resulting in bankruptcy (Nadeem et al. 2022).

Projects have been delayed or suspended as a result of COVID-19's shortage of labor, disruptions in the construction industry's supply chain, and subcontractor work. To reduce risks and be ready for supply chain interruptions, contractors must maintain communication, evaluate suppliers and subcontractors, and explore for alternate options (Sierra 2021).

Hypothesis 4: *Effects of COVID-19 is directly associated with the Supply chain operation*

METODOLOGY

Questionnaire Design

According to the Likert scale, which has five ordinal measurements of agreement for each item, the replies to structured questionnaires range from one (1) to five (5), with five being the strongest level of agreement (5=strongly agree; four=agree; three=no opinion; two being the weakest level of disagreement); and one being the least.

Respondents chose a number from a range of five on a Likert scale based on their opinions and work environment. The questionnaire was designed based on the criteria used to determine the critical factors impacted by COVID-19. This study surveyed 104 construction industry professionals in Nepal to determine the critical factors affected by COVID-19 and compare the extent of its impact on projects. The respondents were from reputable construction firms, government organizations, and non-governmental organizations. Out of 130 questionnaires distributed, 104 valid responses were collected.

Table 1. Latent factors and corresponding indicators

Latent factor	Code	Indicator	Supporting Sources
Construction financial market	CFM1	Limitation of insurance coverage available	(Assaad & El-adaway 2021)
	CFM2	Government fiscal year faced challenges due to sharp declines in project revenues	(Casady & Baxter 2020)
	CFM3	Increment of Building material and Construction equipment prices	(Zamani et al. 2021, Alsharef et al. 2021)
	CFM4	Increased labor costs resulted choosing from limited pool	(Zamani et al. 2021)
	CFM5	Financial obligations of contractor and consultant has increased	(Alsharef et al. 2021)
Contractual implications	CIF1	Increment of legal claims and disputes	(Alsharef et al. 2021)
	CIF2	Poor interpretation of the contract language addressing the effect of COVID -19	(Casady & Baxter 2020)
	CIF3	Lack of clarity in understanding of contractual obligation	(Casady & Baxter 2020)
	CIF4	Failure To apply Force majeure condition of contract	(Sierra 2021)
	CIF5	Insufficient coordination between contracted parties	(Alenezi et al. 2020)
Safety and risk management	SRM1	Improper implementation of health and safety guideline	(Nadeem et al. 2022)
	SRM2	Increased costs and workload implementing safety management measures	(Alsharef et al. 2021, Nnaji et al. 2022)
	SRM3	Limited detail risk management practices in design and construction	(Choi & Staley 2021)
	SRM4	Work redesigned to improve safety	(Alsharef et al. 2021)
	SRM5	Review health and safety policies and protocols complying the Labour Law	(Nnaji et al. 2022)
Supply chain operations	SCO1	Disruption with shortages of raw materials and other inputs	(ILO 2021)
	SCO2	Worker shortages due to infections, preventive quarantines, layoffs	(Zamani et al. 2021)
	SCO3	Bankruptcy of sub-contractors due to the supply chain disruptions	(Nnaji et al. 2022)
	SCO4	Idle equipment left on inoperative sites	(Alsharef et al. 2021, Ilyas et al. 2022)
	SCO5	Delay issues due to cross-country procedures and suspension of operations	(ILO 2021, Nair & Suresh 2021)
Effect of COVID-19	EC1	Diversification and innovation in construction sector	(Zamani et al. 2021)
	EC2	Vulnerable condition of migrant construction workers	(ILO 2021)
	EC3	The construction industry is undergoing a period of shrinkage	(Sierra 2021)
	EC4	Crucial duty of Governments and policymakers in improving resiliency of contractors	(Sierra 2021)

Response to Questionnaire

Likert’s-scale is significant to understand respondents' opinions or attitudes. A rating scale must be used by the responders to indicate how closely perception match the question or statement.

The questionnaire was designed taking into account the crucial factors that were identified as being impacted by the COVID-19 pandemic. Likert’s scale of five ordinal measurements of agreement toward each item from one (1) to five (5) according to amount of frequency is used to calculate replies to structured questionnaires (5=strongly agree; 4=agree; 3=No opinion; Disagree=2; strongly disagree=1).

Additionally, a pilot survey was consulted with experts to ensure that the questions were clear, and in response to the input obtained, the questions were modified to ensure content validity. Out of total 130 questionnaires distributed; 104 responses submitted the response. Therefore, 104 out of 130 responses were taken as legitimate responses. The data were collected from field, emails, person, phone and virtual interviews – based data collection methodology.

RESULTS

For this study, the quantitative design approach, using statistical tools i.e., Smart PLS-SEM was applied. Information like basic project details, project status etc. have been taken into account.

A questionnaire survey and interviews with five carefully chosen construction industry experts were used to gather primary data. To evaluate the condition of the construction sector during the middle of the pandemic, their perspectives and views were sought after. The comprehensive literature review was conducted which was associated and converted into a questionnaire, including the expert’s insights for supporting the methodological framework. The findings of the questionnaire were quantitatively analyzed and justified with the previous findings.

The data collected from both primary and secondary source were summarized, classified, tabulated and categorized in several categories. All data from individual projects have been be analysed separately and analysis of all projects were done compiling together. Computer software such as SPSS, MS Excel have been used for the derivations of the data. And the logically interpreted outcomes have been presented in tables, charts, graphs.

PLS-SEM Model Testing and Results

Partial least squares structural equation modelling (PLS-SEM) is a statistical method used for analysing the links between observed variables and latent constructs. Unlike traditional methods, PLS-SEM calculates these relationships simultaneously and is especially effective for studying complex models with many variables, small sample sizes, and non-normal data (Hair et al.2011).

The partial least squares (PLS) method was used to statistically test the hypothesis based on structural equation modelling. In contrast to latent variables, which are inferred from observed variables, while observed variables are measured directly using SEM. A structural equation model is made up of structural models and measurement models.

It used specially identified constructs for this study. The initial criteria used to evaluate the measurement model are consistency reliability, indicator reliability, discriminant validity, and convergent reliability. And, using a structural model multi collinearity issue, structural path coefficient and hypothesis assessment is examined.

The measurement model and structural model were evaluated for validity and reliability using Smart PLS version 3 software.

Analysis and Validity of the Measurement Model

In reflective measurement models using PLS-SEM, evaluating convergent and discriminant validity is essential to ensure accurate measurement of latent variables. The measurement model in PLS-SEM validates the precision of latent variable measurement through evaluation of composite reliability, measurement item loadings, and average variance extracted (AVE). Cronbach's alpha is commonly employed to estimate the internal consistency reliability, assuming equal reliability among all indicators. Cronbach's alpha, is a reliable measure of internal consistency, providing standardized loadings for observed variables within a latent construct Numerous research concluded that Cronbach's alpha values above 0.7 and composite reliability levels exceeding 0.7 indicate a stronger and more reliable measurement model (Hair et al. 2011).

AVE of the measurement items is used to evaluate convergent validity. The latent variable's variance capture is measured by AVE in relation to measurement error in the corresponding manifest variables. Measurement item loadings over a cut-off of 0.7 are advised (Fornell & Larcker 1981). While the latent variable's AVE value should be more than 0.5 in order to ensure convergent validity (Hair et al. 2011).

Discriminant validity is determined by ensuring the cross-loading value of a latent variable is higher in its corresponding construct compared to other constructs. This confirms that each construct is distinct and accurately represents its intended latent variable (Chin 1998).

Indicators SCO4, CFM3, CIF1, and SRM1 were removed from the analysis as they exhibited outer loadings below 0.6 and AVE values below 0.5. This was done to enhance the reliability and convergent validity of the constructs. Table 2 shows enhanced results for CR, AVE, and Cronbach's alpha in the PLS software after the removal of inappropriate indications. With these updated values, the measurement model now satisfies the minimal standards for convergent validity and reliability.

Moreover, HTMT calculations are performed to evaluate the discriminant validity. When evaluating discriminant validity, HTMT calculation is used to determine the correlation between indicators within the same construct. A HTMT result below 0.85 is typically seen as proof of excellent discriminant validity (Radzi et al. 2011, Henseler et al. 2015).

Table 2. Result of Indicator and Convergent Validity

Construction Theme	Items	Loading	AVE	CR	CA
Safety and risk management	SRM2	0.816	0.554	0.830	0.732
	SRM3	0.916			
	SRM4	0.427			
	SRM5	0.636			
Supply chain operations	SCO2	0.856	0.529	0.815	0.70
	SCO3	0.827			
	SCO4	0.727			
	SCO5	0.582			
Effect of COVID-19	EE1	0.882	0.739	0.895	0.827
	EE2	0.823			
	EE3	0.873			
Contractual Implications	CIF1	0.688	0.571	0.839	0.743
	CIF2	0.746			
	CIF3	0.573			
	CIF5	0.871			
Construction financial market	CFM1	0.766	0.523	0.804	0.738
	CFM2	0.774			
	CFM3	0.584			
	CFM5	0.830			

Strong internal consistency reliability is shown in Table 2 by CR and CA values exceeding 0.7 (Gefen et al. 2000). The optimal value for the AVE measure, which evaluates convergent reliability by measuring the variance of indicators, should be 0.50 or greater. The AVE value above 0.5 confirms convergent validity (Fornell & Larcker 1981, Bagozzi & Yi 1988).

In Table 3, the cross-loadings of all indicators on their respective latent variables are higher compared to their cross-loadings on other latent variables (Chin 1998, Chin 2010). The bolded diagonal parts show how the indicators are cross-loaded on their respective constructs.

Table 3 Discriminant validity: Heterotrait -Monotrait Ratio (HTMT)

Factors	SRM	SCO	Effect of COVID	CIF	CFM
SRM					
SCO	**0.609**				
EC	**0.390**	**0.572**			
CIF	**0.477**	**0.449**	**0.565**		
CFM	**0.725**	**0.506**	**0.458**	**0.360**	

Note: In Table 3 correlations between the model constructs are shown as HTMT ratios. The reported values fall below (Henseler et al. 2009) cutoff of 0.9.

Analysis and Validity of the Structural Model

The structural model examines how the evaluated constructs relate to one another. Utilizing the collinearity test, the significance and applicability of the structural model coefficient, the structural model validity is evaluated (Hair et al. 2011). At 6% significance level, the t-value should be more than 1.96 and a higher beta value indicates a stronger relationship.

In the structural equation model, multicollinearity is found using the inner variance inflation factor (VIF) values and tolerances. VIF values below the threshold of 5 indicate the absence of multicollinearity issues (Cassel 1999, Henseler et al. 2009, Hair et al. 2011).

Table 4 Result of Collinearity Assessment

Predictor Construct	Dependent variable	Variance Inflation Factor (VIF)
Safety and risk management	Effect of COVID	1.478
Supply chain operations	Effect of COVID	1.310
Contractual implications Factors	Effect of COVID	1.836
Construction financial market	Effect of COVID	1.917

In the structural model, the expected change in the endogenous construct for a unit change in the predictor construct is represented by the path coefficient. The structural model's beta value quantifies the strength of the relationship between the predictor and dependent variables. The effect of the predictor variable on the dependent variable is stronger when the beta value is higher. Based on the t-test result, which is obtained using non-parametric bootstrapping, the beta value is determined. The study used 5000 bootstrapped samples to compute t-values (Hoonakker et al. 2010, Henseler et al. 2016). For a two-tailed test with p-values of 0.05, 0.01, and 0.001, respectively, significance of the beta value was evaluated using recommended threshold values of 1.96, 2.58, and 3.29 (Hair et al. 2011). At a 5% level of significance, every path in the model showed t-values over the cut-off of 1.96, indicating a significant impact on safety performance. Additionally, with highest beta value of 0.474, the effect of COVID-19 in building construction projects and Safety and Risk Management factor were observed to be strongly correlated.

Additionally, all parameters exceeded the threshold values and were in the excellent range in the model fit test. Both the outer measurement model and the inner structural model had notable reliability and validity. Table 5 presents the results of all four hypothetical paths (H1-H4), highlighting the importance of the SEM model. Also, all four hypotheses were supported at less than 1 % significance level.

Table 5 Hypothesis Testing in the Structural Model (Direct)

Hypothesis	**Relation**	**Beta**	**LLCI (5%)**	**ULCI (95%)**	**(STDEV)**	**T Statistics (|O/STDEV|)**	**Values**	**Decision**
H1(a)	EC -> SRM	0.474	0.321	0.546	0.059	7.014	0.000***	Supported
H2(b)	EC -> SCO	0.445	0.338	0.613	0.070	6.807	0.000***	Supported
H3(c)	EC -> CIF	0.411	0.320	0.601	0.074	6.030	0.000***	Supported
H4(d)	EC -> CFM	0.381	0.212	0.569	0.088	4.317	0.000*	Supported

Note: t- value >=1.96 at p=0.05 level*, t value >= 2.58 at p=0.01 level**, t- value>= 3.39 at p=0.001 level***

DISCUSSION AND IMPLICATIONS

The analysis of path coefficients in the inner structural model demonstrated a highly significant relationship between safety and risk management factors and the impact of COVID-19 in building construction projects, surpassing other constructs with a maximum value of 7.014 and a beta coefficient of 0.474 (Choi et al. 2021, Husien et al. 2021, Timilsina et al. 2021).

Likewise, the supply chain operation factor demonstrated the second highest significance to the impact of COVID-19 in building construction projects, with a t-value of 6.807 and a beta value of 0.445. This result is in line with earlier studies, supply chain operation parameters indicate the impact of COVID-19 in the construction industry studies (ILO 2021, Husien et al. 2021, Sierra 2021, Zamani et al. 2021, Timilsina et al. 2021, Rani et al. 2022). The COVID-19 has caused hindrance in the material supply chain, resulting significant challenges for equipment rental businesses that have reported problems with damaged equipment at sites (ILO 2021).

Likewise, with 6.030 of t-value and 0.411 of beta value, contractual implication factors showed third significance to COVID-19 effect in building construction projects. Many past reports suggested that contractual implication factors are a predictor of COVID-19 effect in construction (Al-Mhdawi et al. 2021). The applicability of force majeure clauses in contractual agreements, particularly in the context of building, has received a lot of attention ever since the COVID-19 outbreak started. The purpose of force majeure clauses, along with other provisions addressing excused delays, aim to handle delays and effects brought on by events outside the control of the contracting parties.

Moreover, construction financial market factors showed last significance to COVID-19 effect in building construction projects with a t- value of 4.317 and a beta value of 0. 381.Past report suggested that Construction financial market factors is a predictor of COVID-19 effect in construction. Due to COVID-19, it was seen that the contractors' financial situation was getting worse due to the industry's subpar financial performance. Additionally, contractors had to deal with late payments and project cost overruns (Timilsina et al. 2021).

CONCLUSIONS

Construction is a natural cyclical industry, and the COVID-19 epidemic had a significant negative impact on it, while the recovery process may span several years. This led to the anticipation that many public projects would be postponed or cancelled, which left limited room for the formation of new public projects. Also, the impact of the COVID-19 pandemic on building construction projects has been recognized by stakeholders, given the diverse circumstances of its development and the institutional frameworks involved. Consequently, taking preventative measures into account while planning building projects has become crucial. Hence, the subjects must be thoroughly studied and investigated in order to recognize and overcome their effects in addition to mitigating measures, allowing the construction of the buildings to go without interference.

Based on the identified factors, it might be useful for the various parties engaged in the construction industry to map out their short- and long-term planning and decision-making processes in adverse condition. It can be related to prioritization for project, revisiting of the scope of the project and delivery strategy in post pandemic time period. Further studies in this may help to strengthen various contractual provisions, health and safety provision, supply chain operation and financial market related to construction related to the issues of similar kind.

This study utilizes SEM-PLS modeling to explore the relationship between the effects of COVID-19 and major critical factors in building construction projects, aiming to provide a comprehensive understanding of their correlation. Positive path coefficients are found in all relationships within the hypothesis, indicating that they have a positive influence on the entire hypothesis.

The study exhibit that the COVID-19 pandemic had an impact on a different factor in the construction sector. Based on their interrelationships and common themes, these issues were divided into four themes: contractual implications, construction finance market, supply chain operations, and safety and risk management.

The findings of the study indicate that the safety and risk management was the most impacted theme by the pandemic, implying that the industry had significant challenges in managing safety and mitigating risks during the pandemic.

Interestingly, the theme of construction financial market was discovered to have the least impact, showing that the pandemic had very modest repercussions on the industry's financial aspects. These findings have significant implications for policymakers and professionals giving vital insights for developing ways to limit the consequences on the construction business.

Based on our study result and findings, Safety and Risk management factor appeared to be the most critical factor impacted which has also been supported and validated by experts and previous research finding. Furthermore, our results concluded that to effectively face the pandemic, a thorough understanding of the effects and need for response strategies is necessary.

It is anticipated that redefining safety procedures for workers to create a healthy workplace environment during disease outbreaks like COVID-19 is crucial (Stiles et al. 2021). However, limitation in the proper explanation to respondent through questionnaire survey, the result may have been distinct on its own way. Stiles (2021) shows that in the light of COVID-19 guidance, it has underlined the necessity of work re-design and procedures, giving a chance for total work re-design prospect to improve safety. This method can be supplemented by incorporating COVID-19 management measures into current risk management frameworks, resulting in cost savings and increased familiarity with the essential procedures. Practical guidance can be given to organizations to help them adopt these methods more effectively.

Also, this study illustrates how this pandemic situation has changed the concept of workplace safety with the introduction of new provisions and act in order to cope and minimize the risk of health hazards with long term resiliency. This can clearly illustrate from the indirect increment in cost related to safety and safety management in projects.

New procedures have been circulated to prioritize the safety of construction employees. These procedures aim to reduce the threats posed by the COVID-19 pandemic while improving worker safety. Many solved and unsolved contractual issues and claims are being faced by the involved parties in projects. Research of this nature will be helpful to study about the issue of this nature and support to strengthen the contractual provisions in future days. Also, it will helpful to understand and assess various seen and hidden factors that persist as a challenge due to pandemic situation of this kind in construction sector.

The study will provide an insight to the stakeholders in developing contingency plans to address future pandemics or comparable crises, as well as in minimizing problems and issues in construction projects. Lastly, the research paper could act as a bottleneck in the identification of thematic critical factors and proposing preventive measures for each factor in the building construction sector in Nepal.

RECOMMENDATIONS

The issues that this pandemic raise is many, both in the immediate and long term. Various studies, and research work is ongoing and is still in the phase of continuous change. The uncertainty related to the direct and indirect effect in terms of time and cost of the COVID-19 is incomprehensible.

Aside from the inherent risks associated with construction projects, the ongoing and long-term repercussions of the COVID-19 epidemic have introduced an entirely new set of risks that were previously inconceivable. Furthermore, owners and contractors face the challenge of identifying and effectively managing these risks amidst the complex landscape of continually evolving and sometimes conflicting state, country, and local directives that impose restrictions or even temporary halts on construction projects.

COVID-19 should be included, reinforced and promoted as part of a broader risk management plan. The effectiveness of mitigation efforts can be improved by introducing measures into existing safety processes.

Government officials and policymaker should be proactive in implementing and balancing risk management practices in the building construction business. This entails completing timely risk assessments and developing practical guidelines and steps to limit pandemic effects. They can successfully mitigate the negative effects on the construction sector by prioritizing the development of appropriate strategies. Likewise, the bucket approach for addressing the problems uniformly may not be sustainable.

Despite similarities in work nature, the disparities in impact felt across projects, highlight the importance of field-specific techniques. Recognizing the unique characteristics of each project enables to effectively address the industry's particular difficulties. Hence, theme- wise approach for addressing the identified major critical factors along with preventive measures may ensure developing a sustainable way-out while construction managers, policymakers, and systems should implement tailored tactics.

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ISSN NO. 2091-1742
SCITECH NEPAL Journal of Scientific and Technical Studies
Nepal Engineering College, Pokhara University

Research Article DOI:10.3126/scitech.v17i1.60498

Assessment of Labor Management Practices in Private Group Housing Developers in Kathmandu Valley

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Received: May 9, 2023
Accepted: October 5, 2023

Abstract

The construction industry is known for its labor-intensive nature, and companies must maintain high labor management standards to complete projects within time and budget. However, challenges related to labor management are common in the industry and can negatively impact project delivery times and costs. In Nepal, housing developers face the issue of not delivering projects on time, leading to increased costs. This study explores the current labor management practices, challenges, and remedial measures in the construction industry of Nepal, with a focus on housing developers in the Kathmandu Valley. The study collected data from 17 building projects using interviews and questionnaires and analyzed the data using the Relative Importance Index (RII) and Spearman's rank correlation coefficient. The findings indicate that labor management issues, including poor communication, planning, inadequate wages, occupational health and safety, labor policy, and unfair treatment, are major challenges faced by housing developers in Nepal. The study recommends implementing better employee staffing, performance evaluation, work environment, training, and compensation management to address these challenges. The results of this study offer insight into current labor management practices and potential solutions for housing developers in Nepal, contributing to the overall success of construction projects. Proper labor management can result in substantial savings in time and cost for construction projects, making this study relevant and valuable to researchers and practitioners in the construction industry. The findings of this research could have important implications for private housing developers in Nepal, as well as for the broader housing sector in developing countries facing similar challenges.

Keywords: *Compensation management; Housing developer; Labor management; Performance evaluation*

Introduction

The right to housing is a fundamental human right recognized by many international human rights treaties and instruments, including the Universal Declaration of Human Rights (Rawls, 2005). However, for many people in developing countries, access to affordable and adequate housing remains a challenge due to rapid urbanization and demographic changes. Nepal, one of the least developed countries of, is no exception to this trend. Every citizen shall have the right to appropriate housing and no citizen shall be evicted from the residence owned by him or her nor shall his or her residence be infringed except following the law as per Article 37 of the Constitution of Nepal.

The Central Bureau of Statistics of Nepal (CBS) data shows that the urban population has reached 66.08% of the total population in Nepal. In ten years, Nepal's population grew by 10.18% with a 0.93% annual growth rate for the last ten years (CBS, 2021). This rapid urbanization has led to unplanned urban growth, with many private housing developers taking advantage of the situation. Nepal Land and Housing Developers' Association (NLHDA), an umbrella organization of all private housing developers operating in Nepal lists 97 developers as its members (NLHDA, 2020). The escalating price of land, construction materials, and labor has been a major concern for many people to build houses by themselves. Also, the aspect of proper cost-quality control and supervision time has attracted many people towards housing colonies or residential colonies developed by private developers. Labor is the amount of physical, mental, and social effort used to produce goods and services in an economy. It supplies the expertise, manpower, and service needed to turn raw materials into finished products and services (Amadeo, 2021).

The CBS (2018) Nepal labor force survey shows that the construction sector employed 978,000 workers and the growth of the sector is 9% on average. From this, it can be assumed that in 2020 employment numbers could have been around 1.7 million with 500,000 seasonal and Indian workers (Prasai, 2020). The study on the construction sector in Nepal shows that 250, 000 informal laborers are involved in the private sector (Jha's, 2015). By assuming the same average rate of 9% growth there are around 4,57,000 informal laborers associated with the private construction sector in 2022. According to NLHDA around 1,80,000 laborers are involved in housing projects. Kathmandu Valley needs comprehensive planning and implementation to address the current and future urbanization and the housing sector is for sure to play a key role in fostering the global image of Kathmandu Valley as a livable city (KVDA, 2018) Therefore, proper implementation of good management practices can change dynamics of the housing sector in long-run.

The specific labor management challenges may vary across countries but the need for affordable and adequate housing and the importance of efficient labor management practices are universal. This study seeks to fill a critical gap in the literature by exploring labor management practices in the private housing sector of Nepal. The findings of this research could have important implications for private housing developers in Nepal, as well as for the broader housing sector in developing countries facing similar challenges.

This research focused on private group housing developers and their projects in Kathmandu Valley, employing convenience sampling. The data are based on 17 under-construction projects for study.

Methodology

The methodology for this study incorporates four stages: literature review, collection of primary and secondary data, analysis, and labor management assessment. A quota sampling technique was used to divide the sample size, with all 85 populations considered due to the small population size. The study employed both qualitative and quantitative approaches.

Primary Data Collection

The primary data were collected through a questionnaire survey and key informant interview (KII). Interviews with 5 key stakeholders, namely executives, project managers, supervisors, engineers, and foremen were conducted. The KII was conducted with experts in the housing field to gather firsthand knowledge of housing/colonies. The questionnaire survey was done with concerned respondents working in housing projects and stakeholders involved in the delivery of private building projects. The questionnaire was prepared using variables identified from the literature review and presented to the interviewees. Thematic analysis was used to analyze the KII data, while a scoring tool was used to measure levels of implementation and the risk of low productivity in construction. The Likert scale was used to analyze the data, and the Relative Importance Index (RII) and Spearman's rank correlation coefficient were used to determine the importance of different factors and the strength and direction of the relationship among various factors affecting labor management practices.

Secondary Data Collection

The annual NLHDA report was reviewed to identify private housing developers registered in Nepal, specifically within the Kathmandu Valley, and to gather information on the number and scope of housing projects. The specific project reports were analyzed to understand the nature and scope of the identified housing projects. These reports provided information on the budget and completion status of the projects. Additional documents were reviewed to identify the gaps in related information.

Validity and reliability

To ensure the validity of the research instrument, the questionnaire was shared with research experts, and their feedback was incorporated into the final version. The questionnaires were based on a review of relevant literature and underwent pre-testing to ensure their validity. Cronbach's alpha was utilized to assess the reliability of the instrument, and all sections of the questionnaire demonstrated a Cronbach's alpha greater than 0.7, indicating a reliable instrument (Cortina, 1993).

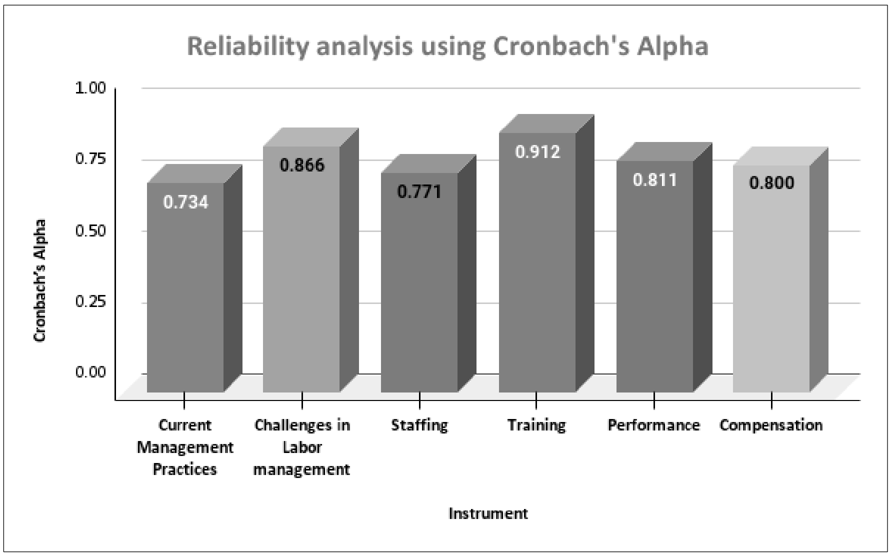

Figure 1: Reliability analysis using Cronbach's alpha

Results and Discussion

Current labor management practices in private group housing developers

The survey results show that a remarkable portion of respondents preferred trained labor over untrained, with 55.4% agreeing and 22.4% strongly agreeing (Table 2). Additionally, 42.4% agreed that the company prioritizes recruiting experienced and educated supervisors. However, 37.6% of respondents disagreed that there was a proper communication channel between labor and supervisors, and only 43.4% agreed that proper planning and scheduling were done prior to project execution. In terms of material management, 43.5% agreed and 8.2% strongly agreed that it was done properly, but 34.1% disagreed. Finally, 45.9% agreed that prioritizing cost control had led to lower productivity, while 22.4% disagreed. Trained labor is preferred over untrained labor due to their better skills and lower training costs for employers.

Table 2: Management perception (n=85)

S. N	Particulars	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	Young labor over experienced	12 (14.1%)	18 (21.2%)	12 (14.1%)	22 (25.9%)	21 (24.7%)
2	Trained labor over untrained	0 (0%)	8 (9.4%)	11 (12.9%)	47 (55.4%)	19 (22.4%)
3	Recruitment of educated supervisors	4 (4.7%)	26 (30.6%)	6 (7.1%)	36 (42.4%)	13 (15.3%)
4	Proper communication channel	8 (9.4%)	32 (37.6%)	10 (11.8%)	28 (32.9%)	7 (8.2%)
5	Prior proper planning	12 (14.1%)	22 (25.9%)	12 (14.1%)	36 (43.4%)	3 (3.5%)
6	Suitable control system	4 (4.7%)	34 (40.0%)	16 (18.8%)	25 (29.4%)	6 (7.1%)
7	Material management	3 (3.5%)	29 (34.1%)	9 (10.6%)	37 (43.5%)	7 (8.2%)
8	Lower productivity due to controlled cost	8 (9.4%)	19 (22.4%)	13 (15.3%)	39 (45.9%)	6 (7.1%)

The findings align with Franklin (1973) who found that trained labor is highly preferred by employers and are less likely to be unemployed than their untrained counterparts. This preference can be attributed to better skills of trained labor and reduced training costs for the employer (Foster, 1973). The results also indicate a lack of effective communication channels, with many individuals relying on mobile phones and the Internet, which are not widely available. This limits access to newer, more effective communication channels for many workers, particularly laborers. Additionally, there appears to be a lack of proper planning for workers, which can affect their motivation and output. This may be due to incompetence, lack of awareness, or other factors. Planning is crucial to any organization and can significantly influence the motivation and output of workers (Jeseviciute-Ufartiene, 2014).

The study found that while 63.5% of respondents reported the presence of a monitoring system, the lack of timely monitoring might impact labor productivity (Figure 2). On-site training and skill-sharing programs were conducted in 54.1% of projects, which is positive as on-the-job training can improve productivity. The lack of proper first aid and health facilities on construction sites was concerning, with only 36.5% of respondents reporting their presence. Similarly, only 23.5% of respondents reported the adoption of health and safety measures during project courses. Only 52.9% of respondents agreed that timely remuneration was provided to enhance labor productivity, and only 21.2% reported the provision of bonuses and incentives. Finally, only 16.5% of respondents reported the implementation of various motivation packages to encourage employees, highlighting the need for companies to focus on improving the work environment and implementing motivational strategies to improve labor productivity.

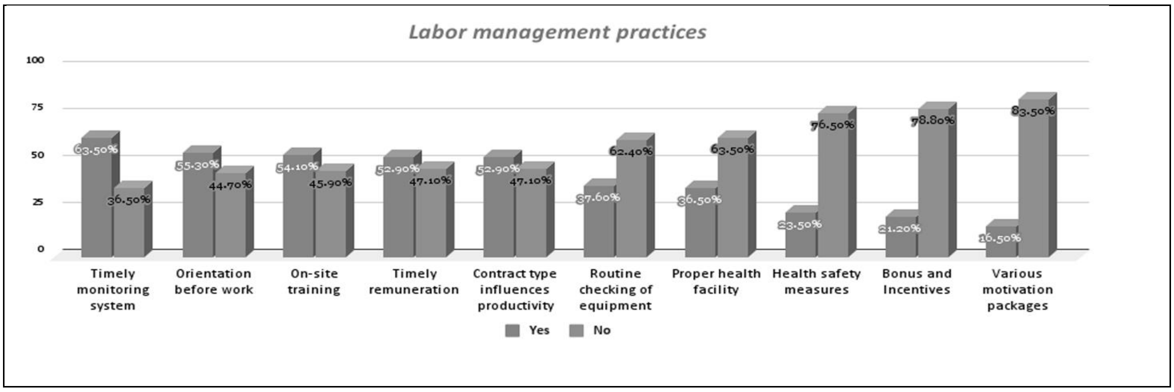

Figure 2: Labor management practices in private group housing developers in Kathmandu Valley

Approximately 63% of respondents reported the implementation of a time monitoring system, which is linked to improved workplace performance and productivity (Dupont et al., 1997). On-site training was provided to around 54% of respondents, which is critical to enhancing productivity and output by familiarizing workers with the environment and tools (Mital et al. (1999). However, on-site training seems to be insufficient. Half of the respondents reported that workers were not remunerated on time, which is essential for motivating and improving worker performance (Walker et al., 1977).

Challenges in Current Labor Management Practices

Table 3: Challenges in current labor management practices (n=85)

S. N	Particulars	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	Balanced supply/demand of laborer	10 (11.8%)	26 (30.6%)	10 (11.8%)	30 (35.3%)	9 (10.6%)
2	Low wages	0 (0%)	8 (9.4%)	8 (9.4%)	43 (50.6%)	26 (30.6%)
3	Availability of skilled labor	8 (9.4%)	33 (38.8%)	6 (7.1%)	27 (31.8%)	11 (12.9%)
4	Enough training and development	10 (11.8%)	27 (31.8%)	12 (14.1%)	28 (32.9%)	8 (9.4%)
5	Shortage of labor	9 (10.6%)	32 (37.6%)	8 (9.4%)	25 (29.4%)	11 (12.9%)
6	Trade unions	3 (3.5%)	18 (21.2%)	35 (41.2%)	26 (30.6%)	3 (3.5%)
7	Fair hearing	7 (8.2%)	31 (36.5%)	10 (11.8%)	31 (36.5%)	6 (7.1%)
8	Little OHS knowledge	9 (10.6%)	25 (29.4%)	11 (12.9%)	31 (36.5%)	9 (10.6%)
9	Lack of comprehensive labor policy	1 (1.2%)	8 (9.4%)	9 (10.6%)	39 (45.9%)	28 (32.9%)

Low wages and poor occupational health and safety were identified as significant challenges in labor management by the majority of respondents. Workers in Nepal are underpaid, with a minimum wage of Rs 77 per hour, which is below 1 USD per hour (Ministry of Labor, Employment and Social Security, 2021), and an inflation rate of 6.15% in 2020 further reduced the value of the wage. This lack of knowledge and concern regarding occupational health and safety negatively, indicated by an extremely low wage, impacts labor productivity. Additionally, the majority of respondents felt that there was a lack of a comprehensive labor policy and inadequate training and development opportunities for the laborers.

This finding aligns with the current management practices of prioritizing trained labor over untrained labor. Occupational health and safety have a positive and significant relationship with labor productivity (Adjotor, 2013). Despite the introduction of the new and updated Labor Act in 2017, the majority of respondents felt that it is yet to be implemented effectively.

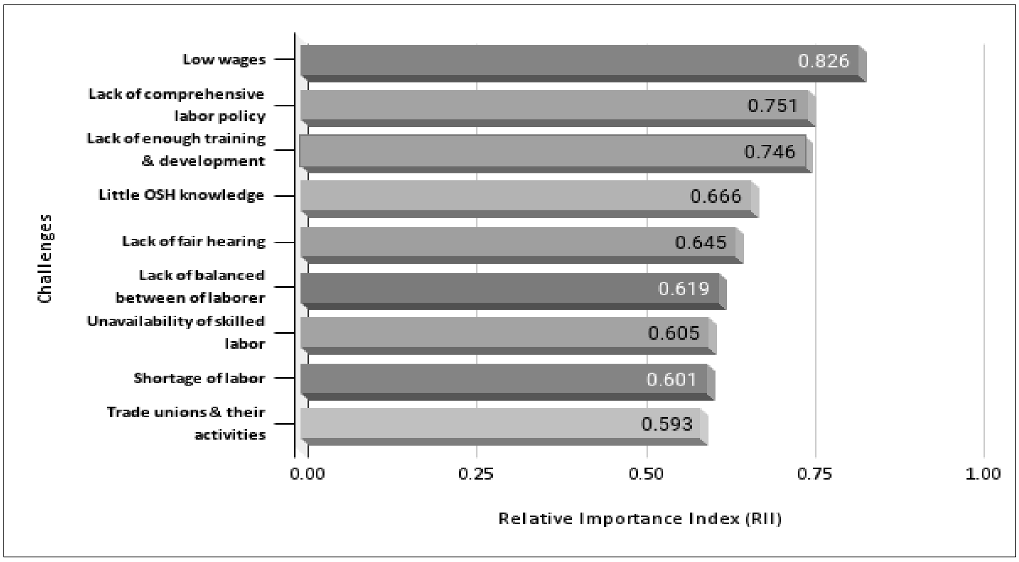

Figure 3: Challenges ranked using Relative importance index (RII)

Relative Importance Index (RII) was used to generate ranking for the Likert scale data. From the index, low wages were found to be the highest-rated challenge while trade union activities were the lowest-rated (Figure 3).

Table 4 shows the non-parametric Spearman’s correlation between the challenges. Supply and demand of labor have a significant positive correlation with training (0.973), indicating that as the supply of labor increases, the need for training also tends to increase. Properly formulated training programs and a focus on OSH can stimulate labor supply by improving satisfaction among laborers. Low wages were significantly related (0.960) to the lack of a comprehensive labor policy, indicating that labor policy should be detailed and specific to protect the interests of the laborers. However, the lack of specific details such as payment amount and timing makes laborers unable to take action against exploitation and end up receiving low wages.

Table 4: Spearman's correlation

Correlations	Supply	Low wages	Skilled labor	Training	Labor shortage	Trade union	Fair hearing	OSH	Labor policy
Supply	1.00	0.138	0.004	**0.973**	0.054	-0.131	-0.141	**0.955**	0.153
Low wages	0.138	1.00	0.196	0.132	0.173	0.051	0.177	0.109	**0.960**
Skilled labor	0.004	0.196	1.00	-.010	**0.926**	0.020	-0.148	-0.022	**0.222**
Training	0.973	0.132	-0.010	1.00	0.065	-0.110	-0.118	**0.981**	0.132
Labor shortage	0.054	0.173	**0.926**	0.065	1.00	0.061	-0.082	0.052	0.194
Trade union	-0.131	0.051	0.020	-0.110	0.061	1.00	**0.452**	-0.106	0.086
Fair hearing	-0.141	0.177	-0.148	-0.118	-0.082	**0.452**	1.00	-0.118	0.153
OSH	**0.955**	0.109	-0.022	**0.981**	0.052	-0.106	-0.118	1.00	0.111
Labor policy	0.153	**0.960**	**0.222**	-0.132	0.194	0.086	0.153	0.111	1.00

The training was significantly related (0.981) to OSH knowledge. Training is not just teaching how to do things but it also includes how to do things safely and in the correct way. Training is a part of OSH itself and the two are closely related. Similarly, labor shortage was linked to a lack of skilled labor (0.926), and trade union was linked with a lack of fair hearing (0.452). The preference for trained labor over untrained labor without proper training programs results in a shortage of labor and a lack of skilled labor.

Finally, the establishment of trade unions indicates a need for laborers to be heard and have their concerns addressed.

Remedial measures to improve the current labor management practices

Table 5 shows responses regarding employee staffing as a measure to improve current labor management practices. 60% agreed and 11.8% strongly agreed that finding and attracting suitably qualified people enhances labor management, while 64.7% agreed that companies must attract job candidates with needed abilities and attitudes. The proper selection process was supported by 58.8%. However, Wilson (1996) argued that team members' influence may impact productivity. 52.9% agreed and 30.6% strongly agreed on creating systematic and formal communication, and 61.2% agreed and 27.1% strongly agreed on implementing tools to improve staffing processes. Improving staffing procedures can boost productivity and reduce training costs. Proper staffing and hiring are seen as remedial measures for labor management challenges (Manthey, 1991).

Table 5: Employee staffing

S.N	Particulars	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	Finding qualified workers	3 (3.5%)	13 (15.3%)	8 (9.4%)	51 (60.0%)	10 (11.8%)
2	Attract candidates with abilities	1 (1.2%)	15 (17.6%)	7 (8.2%)	55 (64.7%)	7 (8.2%)
3	Proper selection process	4 (4.7%)	12 (14.1%)	7 (8.2%)	50 (58.8%)	12 (14.1%)
4	Formal communication	3 (3.5%)	5 (5.9%)	6 (7.1%)	45 (52.9%)	26 (30.6%)
5	Various tools and techniques	3 (3.5%)	7 (8.2%)	0 (0.0%)	52 (61.2%)	23 (27.1%)

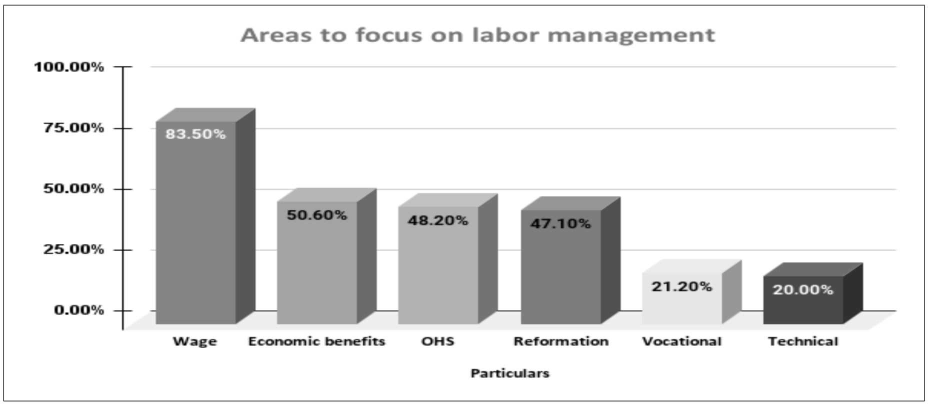

Figure 4: Areas to focus on labor management

83.5% of respondents felt that labor wages needed to be improved, while 50.6% felt that economic benefits could be enhanced. Low wages have been identified as a major challenge to labor management, and According to Anderson (2007), providing improved wages has been suggested as the most significant way to enhance labor productivity. In addition, 48.2% of respondents identified Occupational Health and Safety (OHS) as an area that needs improvement, while 20% felt that technical education and training should be the main focus. 21.2% of respondents felt that vocational training needed work, while 47.1% identified reformation in labor regulations as a priority (Figure 4).

Strict implementation of OHS policies could help improve labor productivity by providing hazard-free work conditions, and the development of comprehensive labor policies could ensure consistency and ease for both laborers and employers (Nasirzadeh & Nojedehi, 2013).

Table 6 shows that a significant proportion of respondents agree with the importance of vocational and on-site training, investment in employee development, providing appropriate equipment and technology, and creating a knowledge-sharing work environment. The effectiveness of training and development in enhancing workers' productivity has been supported by research, with vocational training found to boost productivity by 1.5% (Sala & Silva, 2013), while access to necessary tools and equipment can significantly improve labor productivity (Kazaz et al., 2016).

Table 6: Training and development

S. N	Particulars	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	Vocational and on-site training	0 (0%)	14 (16.5%)	31 (36.5%)	37 (43.5%)	3 (3.5%)
2	Investment in skills development	3 (3.5%)	12 (14.1%)	14 (16.5%)	47 (55.3%)	9 (10.6%)
3	Equipment provision	0 (0.0%)	0 (0.0%)	11 (12.9%)	42 (49.4%)	32 (37.6%)
4	Knowledge sharing environment	3 (3.5%)	8 (9.4%)	35 (41.2%)	36 (42.4%)	3 (3.5%)

The study found that the majority (67.1%) agreed that supervisors should track work progress, while only 12.9% disagreed (Table 7). Additionally, 63.5% agreed that a proper framework of planned goals, standards, and competent requirements should be developed prior to project commencement, with 27.1% strongly agreeing. Continuous monitoring of project progress and timely evaluation of results was also deemed important, with 49.4% agreeing and no one disagreeing. Regarding fair hearing and support from immediate managers or supervisors, 45.9% agreed and 42.4% remained neutral. Finally, 70.6% agreed that formal reporting of relationships and groupings within the project should be well-defined.

Table 7: Performance evaluation

S. N	Particulars	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	Work progress tracking	0 (0%)	11 (12.9%)	10 (11.8%)	57 (67.1%)	7 (8.2%)
2	Proper framework	0	4 (4.7%)	4 (4.7%)	54 (63.5%)	23 (27.1%)
3	Continuous monitoring	0 (0.0%)	0 (0.0%)	11 (12.9%)	42 (49.4%)	32 (37.6%)
4	Fair hearing	4 (4.7%)	6 (7.1%)	36 (42.4%)	39 (45.9%)	0 (0.0%)
5	Formal relationships defined	0 (0.0%)	12 (14.1%)	6 (7.1%)	60 (70.6%)	7 (8.2%)

These findings suggest that properly defined goals, tracking progress, continuous monitoring, and formal relationships are important aspects of performance evaluation, which can serve as remedial measures for labor management challenges. A well-developed appraisal system that is trusted by workers can improve productivity and motivation (Mani, 2002).

The survey found that 42.4% of respondents agreed that companies should provide insurance for every laborer, while 29.4% remained neutral (Table 8). In terms of adequate wages and bonuses/incentives, 51.8% agreed that there must be provision for this, and only 14.1% disagreed. Similarly, 51.8% agreed that companies must guarantee coverage of basic needs during crises or disasters, and 32.9% strongly agreed. In terms of a proper recognition and reward system, 44.7% agreed that this must be introduced to sustain labor and reduce turnover, while 35.3% remained neutral. 61.2% of respondents agreed that companies must look out for labor-favoring contracts, while only 14.1% disagreed.

Table 8: Compensation management

S. N	Particulars	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	Provision of insurance	0 (0%)	21 (24.7%)	25 (29.4%)	36 (42.4%)	3 (3.5%)
2	Adequate wages	3 (3.5%)	12 (14.1%)	17 (20.0%)	44 (51.8%)	9 (10.6%)
3	Coverage of basic needs	0 (0.0%)	1 (1.2%)	12 (14.1%)	44 (51.8%)	28 (32.9%)
4	Proper recognition system	4 (4.7%)	10 (11.8%)	30 (35.3%)	38 (44.7%)	3 (3.5%)
5	Labor favoring contracts	0 (0.0%)	12 (14.1%)	16 (18.8%)	52 (61.2%)	5 (5.9%)
6	Compulsory OHS	0 (0.0%)	4 (4.7%)	10 (11.8%)	67 (78.8%)	4 (4.7%)

Finally, 78.8% agreed that OHS structures at construction sites are compulsory for labor safety. Overall, the survey suggests that fair compensation is an important factor for employee motivation and can lead to improved labor productivity.

Conclusions

Based on the findings, it was observed that the current labor management practices in the private group housing sectors are inadequate and require substantial improvement. The workers are being paid below their worth, which has resulted in unsatisfactory labor management. The present labor management practices need more extensive labor policies, labor development programs, orientation, and training. The private group housing sector needs to adopt and prioritize standard occupational health and safety structures, as well as health and well-being initiatives. To address the current labor management challenges, developers should implement health and safety motivational packages, in addition to offering fair wages. Economic benefits, as well as training and development opportunities, were also deemed effective in enhancing labor management practices. Overall, it is crucial for companies to prioritize their workers' health, safety, and well-being, provide fair compensation, and invest in their development to create a productive and positive work environment. The implementation of the recommended remedial measures can lead to better labor management practices and improve productivity in private group housing sectors.

Acknowledgements

We would like to thank the Nepal Land and Housing Developers' Association for providing related facts and figures for analysis of the work carried out. Moreover, we would like to express our thanks and gratitude to Prof. Dr. Hari Krishna Shrestha, *nec*-CPS, and Senior Divisional Engineer Parikshit Kadariya, GoN-DUDBC for providing us with exclusive comments and reviews.

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