7th SONEUK CONFERENCE

# PROCEEDINGS

## Engineering and Technology for Sustainability

*Society of Nepalese Engineers in UK*

*9th July 2022*

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# *Editorial*

Human activities in every sector, including in construction, passenger & freight transportation, operation and maintenance may result in adverse environmental impacts. The intent should be that these impacts be minimised as far as reasonably practicable and that opportunities are taken with the use of appropriate, advanced and energy efficient engineering and technology approaches that lead to overall improvements in environmental, social and economic capital.

Engineering and technology have played and continue to play a pivotal part in the future of sustainable development. Technology can improve environmental sustainability and operational efficiency by enabling the development of new and sustainable products and services. Engineers have a significant role to play in sustainable development, starting from planning and designing to implementation of a project or service in every sector of industries from micro to macro levels.

In this context, the Society of Nepalese Engineers in UK (SONEUK) is organising its 7th SONEUK Conference on "Engineering and Technology for Sustainability" on 9th July 2022 in London. This conference proceedings comprises of eleven peer-reviewed papers, mostly related to Nepalese contexts and includes topics ranging from the impact of air pollution, sustainable and integrated transportation including Kathmandu Metro to safety practices and their improvements, recommendation of establishing a national ground research centre, and status of application of Building Information Modelling (BIM) in Nepal. Other papers provide insight into new and efficient project delivery approaches in the railway infrastructure sector, and a collaborative framework with shared responsibility for relief management in disaster scenarios, etc. Together, they provide valuable information for readers regarding engineering, technology, and sustainability.

We, as an editorial team, hope that the publication of this proceedings will further enhance the exchange and dissemination of technical & academic knowledge to a wider audience within and outside of SONEUK. It is acknowledged that there may be lack of some data in some areas covered in the proceedings, especially in the context of Nepal to inform the true content of the papers. We think that the topics covered in the proceedings will provide a foundation for further discussion in enhancing research & development and innovative engineering approaches for sustainable development through the SONEUK platform.

We welcome any feedback and constructive suggestions for future improvements to be addressed in future proceedings.

We are very honoured to facilitate the publication of the proceedings. We would like to take this opportunity to thank all the authors and keynote speakers for their invaluable contributions, without whom the proceedings would not be possible. It has been a pleasant experience to put these papers together and we hope you will enjoy reading them too.

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Mr Narad Bhandari – *Coordinator*
Prof Hom Nath Dhakal
Mr Krishna Kishor Shrestha
Dr Bidur Ghimire
Dr Jaya Nepal
Dr Raj Kapur Shah
Mr Sanyukta Shrestha
Prof Keshav Dahal
Dr Birendra Shrestha
Dr Ramesh Marasini
Dr Roshan Bhattarai
Dr Deepak GC
Dr Ramhari Poudyal
Ms Megha Paudyal

# Ambassador's Message

नेपाली राजदूतावास
EMBASSY OF NEPAL
LONDON, U.K.

AMBASSADOR

EMBASSY OF NEPAL
London

5 July 2022

**Message**

I am delighted to learn that the Society of Nepalese Engineers, UK (SONE UK) is going to publish the proceedings of the annual conference entitled 'Engineering and Technology for Sustainability'.

I believe that the international conference organized by SONE UK has been an important occasion where notable Nepalese professionals and engineers from various parts of the world have deliberated upon relevant topics of interest to Nepal. I would like to congratulate SONE, UK for the publication of the proceedings of the conference and hope that this publication will be successful in disseminating pertinent information to all the Nepali engineers and other interested people and organizations.

I would like to extend my sincere appreciation to the SONE, UK for its activities which has connected the Nepalese engineers in the UK and around the world. I equally value its generous contributions towards social and humanitarian causes in Nepal during the difficult times. The Embassy is pleased to work with the Society of Nepalese Engineers, UK to support the development efforts of the Government of Nepal utilizing the knowledge and expertise of Nepalese engineers.

I wish the Society of Nepalese Engineers UK all success in pursuing its objectives in the days ahead.

(Gyan Chandra Acharya)
Ambassador

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# *Chairperson's Message*

What value does a migrant organisation hold in the development of its community standards and inherent cultures? This is a question of self-realisation and collective benchmarking for a less studied and more challenged global society like that of Nepalese population spreading worldwide. A good number of organised human collectives exist in the UK, and their objectives are as major and significant in their own right. However, I definitely see a lot of ground for executional improvements that add deeper meaning while also getting tangible results.

In my experience of the last twelve odd years, direct handling of different Nepalese communities was akin to a forest ranger's job. In the woods, one gets to see different types of tall trees, bushy plants, and even layered algaes. Some are strong while others are reliant on them, however, everyone is capable of supporting each other. This mixed structure identifies any social segment but it is their coexistence that beautifully defines their wholesome natural value. As the chairperson of SONEUK for the last two years, my ambitions have always been no bigger than to bring them all together and help them run our engineering ecosystem.

It is indeed a matter of great pride that the SONEUK conference, the only purely technical and long-standing Nepalese academic endeavour of its kind in the UK, through all highs and lows, is successfully delivering its seventh edition. This technical festival of the engineering community is also being recognised far and wide, with an overwhelming contribution from Nepalese engineers from outside the UK, which has multiplied our responsibility manifold besides being something to be truly happy about. After five physical and one virtual arrangement, and a pandemic that challenged our personal, professional and public lives, fortunately we are back to the normality of a physical conference in 2022.

While I was growing up, both professionally and socially, under the shadows of SONEUK, I volunteered, presented and organised what has now become a ritual amongst the Nepalese engineers in the UK. I must remember the massive efforts put up for the previous many years by Dr Birendra Shrestha, in laying strong foundations of this program. I have no doubts that our current convener Mr Narad Bhandari has outperformed all our expectations in delivering content which has huge academic and research value within the engineering sector of Nepal. It is this kind of unmatched opportunity to contribute to Nepal that is most valuable about being a true member of SONEUK.

This conference is indeed one more important takeaway for my team before we terminate our tenure next month. It has been a great experience serving you all beyond any preference and prejudice, and I am confident that our members will appreciate our every effort while forgiving any unintended mistakes.

I was here to serve you all and my aspirations are independent of time and space.

Sanyukta Shrestha
Chairperson,
Society of Nepalese Engineers in UK

# Dynamics of Air Pollution in the Kathmandu Valley and the Control Measures

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## Abstract

The unacceptable level of air pollution in the Kathmandu Valley, which accommodates a large proportion of the national population, is of serious concern. Development of air pollution control measures for this valley, located in the complex terrains of Nepal Himalaya, remained a challenge. Resolving the meteorological flow fields, air pollution emission activities, and the dynamics of pollutants down to a kilometer-scale, the present study paved the way to ensure the National Ambient Air Quality Standard (NAAQS) in the valley. Gridded emission inventories of potential pollutants have been prepared over the area covering the Greater Kathmandu Valley and its immediate surroundings. Meteorological situations and the dynamics of pollution have been numerically simulated. Desired agreement between the observations and numerical predictions has been achieved for both the meteorological and air pollutant fields. The study reveals that the air pollution dispersion power of the valley, typically determined by the prevailing meteorological situations, is very poor, particularly, during the long dry winter season. Present emission loadings into the immediate atmosphere of the Kathmandu Valley are far beyond its carrying capacity. The NAAQS set for fine particulate matters (PM2.5) can be met by limiting the current emissions from domestic, transport, and industrial sectors, respectively, to 20, 30, and 40%. Among the emission sectors, realizing the desired emission control in the transport sector appears most challenging. A clean mass transit system such as metro rail can enormously help improve air quality, human health, and quality of life in the Kathmandu Valley.

*Keywords:* Kathamandu, Nepal Himalaya, Air pollution, WRF, CTM

# 1. Introduction

Air pollution has emerged as one of the major environmental problems in most of the urban centers of Nepal. Increased air pollution to unacceptable levels over the centers of unparalleled cultural, religious, historic, archeological, and touristic importance like Kathmandu Valley where a large number of people are living, is of serious concern. The annual premature-death toll attributed to ambient air pollution over Nepal is close to ten thousand (WHO, 2016) and the valley shares its largest proportion.

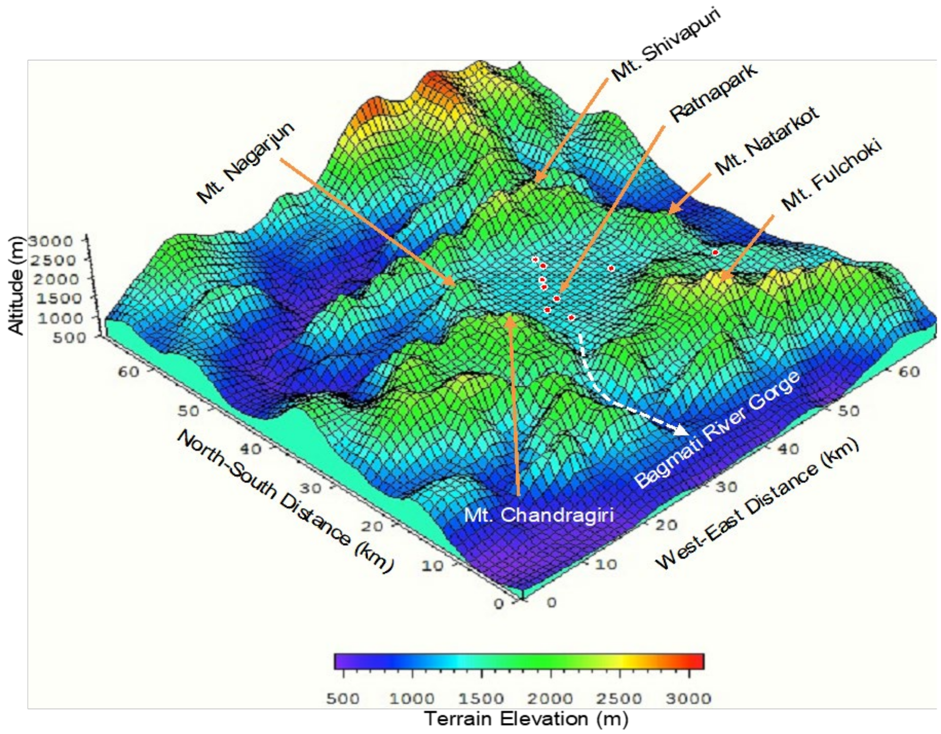



*Figure 1: Bird eye view of Greater Kathmandu Valley. The locations of the air quality monitoring stations (red dotted white circles) and some of the important locations are also indicated in the figure.*

Emission loadings above the carrying capacity of an area, typically determined by the prevailing meteorological condition, cause a higher level of air pollution. The Kathmandu Valley, located in the mid-hills of Central Nepal and surrounded by other lower valleys, is highly susceptible to severe air pollution. Indeed, observations and numerical simulation studies in the early 2000s on prevailing wintertime meteorology (Regmi et al, 2003) and the dynamics of air pollutants (Kitada and Regmi, 2003) have revealed that the bowl-shaped Kathmandu Valley holds adverse meteorological and topographic conditions, particularly, during the dry winter season, that may lead to a disaster if the trends of emission activities continued unabated. Concurrent investigation of human-air pollution exposure status (Regmi and Kitada, 2003) had also shown that more than 52 percent of the total Kathmandu residents were living in areas with a concentration of particulate pollutants of aerodynamic size less than 10 micrometers (PM10) above 40 micrograms per cubic meter. Significant health endpoints attributable to air pollution were predicted. Other studies (e.g., Panday and Prinn, 2009; Shrestha et al, 2010; Regmi et al, 2019; etc.) have also shown the levels of air pollutants several folds higher than the acceptable limits. As the population and activities related to air pollution emissions in domestic, transport, industrial, and commercial sectors are likely to increase further, air quality in the valley is expected to exacerbate in the future leading to unexpectedly high-level human suffering and unrecoverable damage to the ecosystems.

However, the lack of necessary knowledge on recent air pollution emission patterns, the regional-scale air pollution carrying capacities, mechanism of transport, and formation of pollutant fields in the valley have raised serious uncertainties concerning the air quality degradation, development of air pollution control system and environmental planning for the valley. The present study was, therefore, conceived to develop long-term solutions to curb air pollution over the Greater Kathmandu Valley. More specifically, meteorological conditions and their implications for air pollution transport have been clarified, high resolution gridded emission inventories of the valley have been developed, and the spatiotemporal distribution of the pollutants has been numerically simulated. Finally, control measures to ensure the necessary standard of near-surface air quality are recommended firmly based on the rigorously verified findings on the characteristic meteorological conditions, air pollution dispersion mechanism, transport paths, formation of pollutant fields, and safe limits of emissions in and around the Kathmandu Valley.

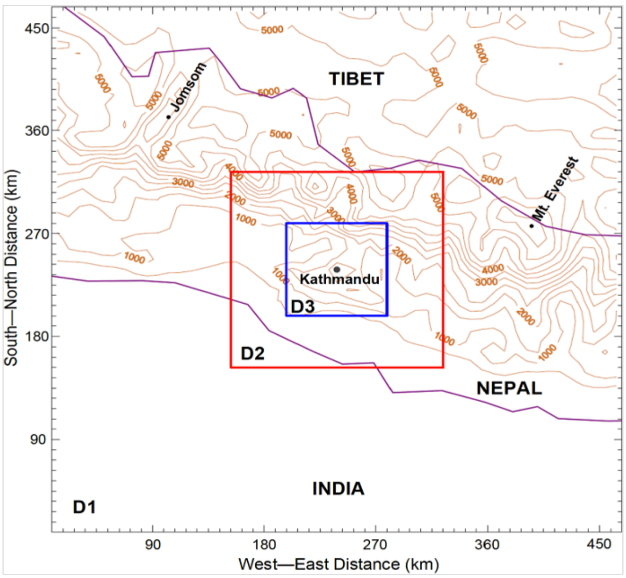



*Figure 2: Triply nested two-way interacting meteorological calculation domain configuration centered at (27.7° N, 85.3°E) the western central area of the Kathmandu Valley. The terrain contours are superimposed and important locations are indicated in the figure. Figure 1 is the terrain structure of the Greater Kathmandu valley area enclosed by D3 over which air pollution emissions and chemical transport modeling were performed.*

# 2. Methodology

The present study has been accomplished with the adoption of an integrated approach comprised of comprehensive gridded emission estimation, observations, and numerical meteorological and air pollution dispersion modeling for the Greater Kathmandu Valley.

## 2.1 Gridded emission fields

The gridded emission inventories of potential pollutants have been prepared at a 1 km × 1 km grid net over 70 km × 70 km domain for the Kathmandu Valley (see domain D3 in Figure 2) whose 3D terrain features are shown in Figure 1. The gridded emission maps have been prepared by adopting largely the procedures described in Kitada and Regmi (2003). The emission sources were first surveyed and classified into several sub-sectors and the sub-sectoral emission was prepared. The sub-sectoral emissions were then merged into three major sectors viz. domestic, industrial, and transport. In preparing sub-sectoral emission inventories, various reports were also taken into consideration (e.g., WECS, 2014; CBS, 2014; DoTM, 2017; NEEP/GIZ, 2012) and several other scattered studies.

## 2.2 Observation Data Acquisition

The ground-level air quality and meteorological data from the eight air quality monitoring stations were gathered and used to verify the numerically simulated spatiotemporal distribution of the ground-level meteorological and air pollutant fields. The Department of Environment (DoEnv), Government of Nepal maintains six air quality monitoring stations in the Kathmandu Valley, and the Embassy of the United States of America also operates two ground-level air quality monitoring stations at Phora Durbar and Maharajgunj (see Figure 1).

## 2.3 Meteorological Modeling

The meteorological simulation domain for the Kathmandu Valley captures extreme topographic features (see Figure 1). Therefore, the local flow comprised of mountain-valley and plain-to-plateau/plateau-to-plain winds having multiple origins are expected to intrude into, outflow from, and interact over the areas forming complex multi-layered structures of flow and temperature. These interactions were necessary to resolve to understand the dynamics of pollutants and the formation of pollutant fields over the Greater Kathmandu Valley. The Weather Research and Forecasting (WRF) modeling system (Skamarock et al, 2008), one of the widely used and well-validated models (e.g., Kumar et al, 2015; Lee et al, 2015), was, thus, used to simulate regional-scale meteorological flow fields over diverse types of complex terrains including Nepal Himalaya as well (Maussion et al, 2015; Collier and Immerzeel, 2015; Norris et al, 2005; Regmi, 2014; Regmi et al, 2017; Regmi et al, 2019).

The WRF simulations were performed with triply nested two-way interacting mesh for the Kathmandu Valley. The coarse (D1) and fine (D2) domains had 52 × 52 × 35 grid points each, and horizontal grid sizes were 9 and 3 km, respectively, whereas the finest domain (D3) was configured as 70 × 70 × 35 grid points with a horizontal grid size of 1km (see Figure 2). The center of all the three calculation domains was set at (27.7° N, 85.3°E) in the western central area of the valley. The model was initialized with 1° × 1° horizontal resolution meteorological data from the operational analysis performed every 6 hours at the National Centers for Environmental Prediction (NCEP Final Analysis). Furthermore, the 24-category land-use and 30-second terrain elevation data of the United States Geological Survey (USGS) were used.

The simulation was carried out with the WRF Version 3.8. We used the Dhudhia scheme (Dudhia, 1989) for shortwave radiation, the RRTM scheme (Mlawer et al, 1997) for long-wave radiation, the Thompson graupel scheme (Thompson et al, 2004) for cloud microphysics, the MYJ scheme (Janjić, 2001) for the planetary boundary layer, and the Noah land-surface model (Chen and Dudhia, 2001) for calculations with the WRF. The first 24 hours of the simulation were discarded as a spin-up of the model and the remaining hours were retained for the analysis. Ten consecutive days-long simulations were carried out from the 00:00 UTC (05:45 LST) on 01 January 2018 to 00:00 UTC (05:45 LST) on 10 January 2018 since the wintertime meteorological situation over the Kathmandu valley is thought to be the most adverse with respect to air pollution in comparison to the other season.

## 2.4 Chemical Transport Modeling

Dynamics of pollutants over the Kathmandu Valley were numerically simulated using a comprehensive Eulerian Chemical Transport Model (CTM) developed at Kitada Laboratory, Toyohashi University of Technology (TUT), Japan. The model has been successfully applied to various air pollution problems (e.g., Kitada et al, 1993; Kitada et al, 2000; Kitada and Regmi 2003; Kitada et al, 2008; Regmi et al, 2019; etc.). The horizontal dimensions of the CTM calculation domain remained the same as that of the finest domain of the WRF simulation, that is, 70 km × 70 km area over which the meteorological fields were simulated at 1 km × 1 km horizontal grid resolution. The CTM model top was set at 10 km above the mean sea level (AMSL) with 15 terrain-following vertical levels that gradually flattened from the surface to the model top. The lowest vertical grid level of CTM was set at about 2 meters above the ground level. Using the meteorological fields prepared from the finest domain (D3) of WRF simulation and the emission inventories prepared as described in sub-section 2.1, six day-long chemical transport simulation was performed for 02-08 January 2018.

### 2.5 Air Pollution Control Measures

Initializing with the WRF simulated meteorological fields validated with observations, a series of control CTM simulations were performed to examine the possible options for the improvements in the current status of air quality in the Kathmandu Valley. The control simulation presumed that 02–08 January 2018 represents the typical high wintertime pollution days. The control simulation included several types of emission restrictions in the domestic, transport, industrial and commercial sectors as well as relocations and displacement of potential emission sources. Additionally, individual sectorial contributions were explored to develop an integrated emission scenario to meet the NAAQS. Finally, the integrated control simulation, a smart proportional restriction on all possible sub-sectoral emissions, has been performed.

## 3. Results and Discussion

In this section, the spatiotemporal distributions and implications of meteorological fields for air pollution dynamics over the Greater Kathmandu Valley, gridded emission fields of potential pollutants, dispersion and formation of particulate pollutant fields, and the emission control measures to maintain national air quality standards for the valley are discussed.

### 3.1 Rationale of the WRF Simulated Meteorological Fields

This sub-section examines the accuracy of the calculated meteorological fields by comparing them with the ground-level observations at the air quality monitoring stations distributed over the valley. Examining the simulated and observed wind speed, temperature, and humidity; and, the corresponding regression analysis at seven different air quality monitoring sites, it can be said that the WRF simulation reasonably well reproduced the prevailing meteorological situations over the Kathmandu Valley during the winter season.

Figure 3 shows the resemblance of the observed and WRF simulated diurnal periodicity of the wind, temperature, and humidity for 10 consecutive days (01-10 January 2018) at one of the representative air quality monitoring sites (e.g., at Ratnapark) with the correlation coefficient of 0.69, 0.98 and 0.80, respectively. Similar resemblances were obtained in other sites as well (not shown). Among the parameters compared, the relative humidity appears to be systematically under-predicted in all the monitoring sites. The underprediction of relative humidity is thought to have resulted from the very low humidity in the global input data sets over the Asia-Pacific region whereas the little differences in the diurnal variation in the other parameters are very local effects. Both the observation and the numerical simulations suggest

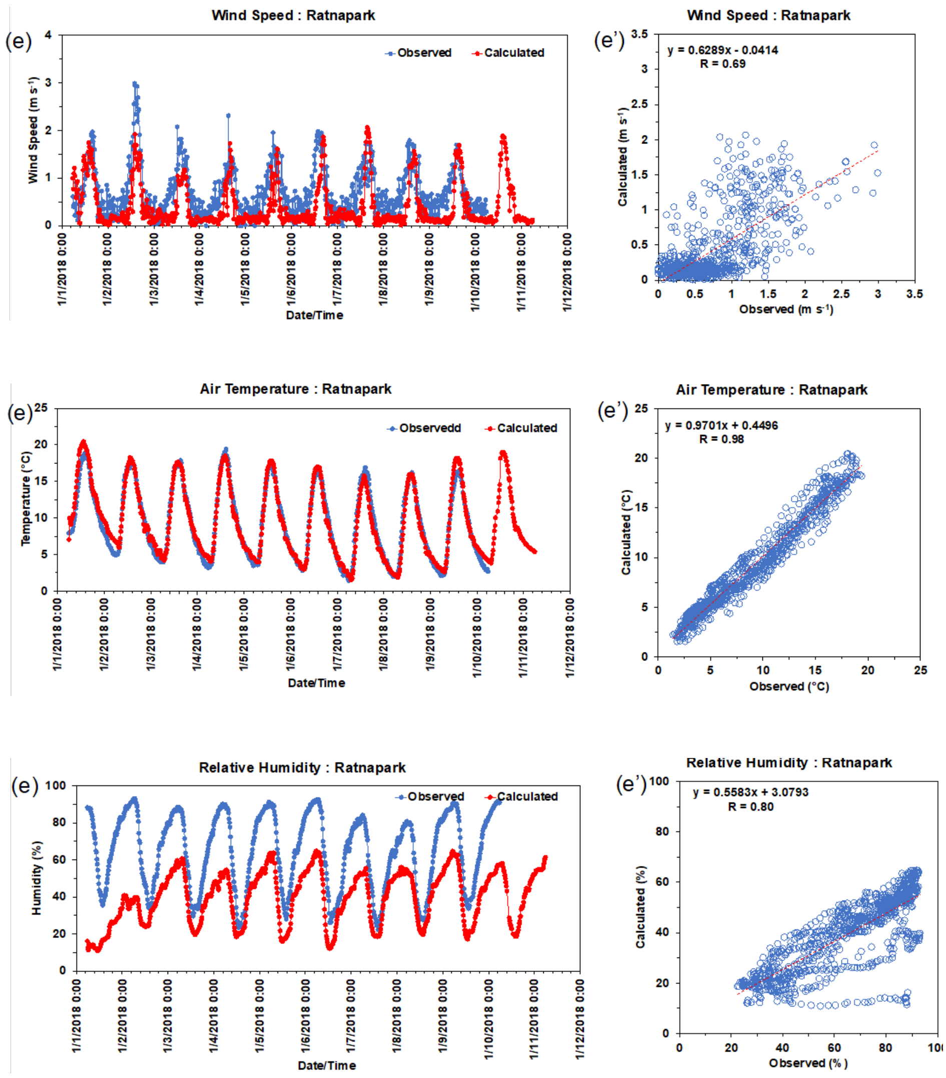



*Figure 3: Comparison of observed and simulated diurnal variation of wind speed, temperature and relative humidity at Ratnapark during 01 – 10 January 2018.*

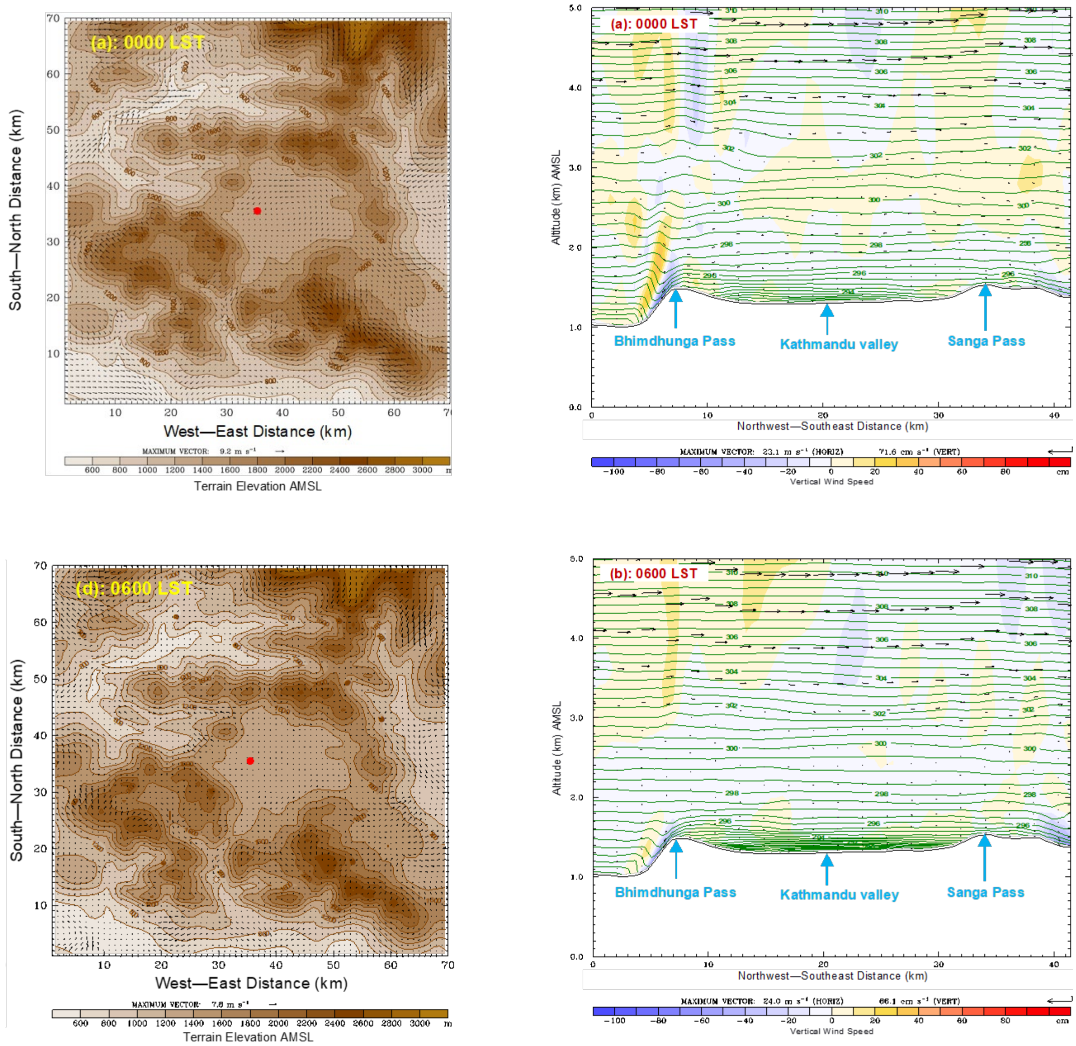
that very strong diurnal periodicity prevails in the meteorological flow fields over the Kathmandu Valley during the winter season, that is, there is little day-to-day variation in the meteorological flows in and around the Kathmandu Valley. The surface-level wind speed generally remains calm or windless from late evening (~20:00 LST) to late morning (~11:00 LST) the next day. The surface level maximum wind speed occurs in the late afternoon for a couple of hours that occasionally exceeds 5 m s-1 but generally remains less than 3 m s-1 in the central areas of the valley. The sharp increase in the speed close to the noontime and sudden drop in the evening, respectively, indicate the intrusion and the ceasing of the local flows over the valley.

## 3.2 Spatiotemporal Characteristics of the Immediate Atmosphere

In this sub-section, we discuss the spatiotemporal characteristics of the wind and thermal structure over the Kathmandu Valley by considering 05 January 2018 as the representative day of the winter season. Figure 4 shows the WRF simulated near-surface winds (left panel) and the vertical cross-sectional distributions of horizontal and vertical winds and the potential temperature (contours) (right panel) at some representative times. It can be seen that the near-surface atmosphere of the valley remains calm and highly stratified by accumulating cold air during the night and the early morning consistent with the observed diurnal patterns at different air quality monitoring stations (see Figures 4a-b and a′-b′). The depth of the accumulated cold air may reach up to the depth of ~300 m above the valley floor in the early morning. During the period, drainage flow prevails over the western and eastern mountain passes and along the Bagmati River Gorge situated on the southwestern rim of the valley. The western and the northeastern neighboring valleys also share much the same flow features but the eastern valley appears relatively windy. The formation of the highly stratified windless deep cold air pond over the Kathmandu Valley is of serious concern from the air pollution viewpoint as the air mass close to the valley floor remains strongly decoupled with the upper air and regional air masses. In such a situation, air pollutants released get trapped within the very shallow surface layer and hence their concentration may increase exponentially.

The nighttime strongly stratified situation over the Kathmandu Valley appears to break only in the late morning leading to significant changes in the flow fields. The downslope winds over the surrounding mountain slopes start to vanish and upslope winds in the surrounding areas tend to commence towards the valley. Winds over the whole calculation domain gradually decrease with the progressing morning and reach their minimum between 09:00—09:30 LST (see Figure 4c-c′). This particular period of time, thus, can be considered as the transient period during which the nighttime downslope flow regime switches into the daytime upslope/valley regime. The stable layer then lifts and reaches about the heights of surrounding mountaintops and caps the whole valley throughout the afternoon. This capping stable layer strongly prohibits the exchange of air masses across the layer and hence determines the mixing depth or boundary layer height over the valley in the afternoon. With the lifting of the nighttime stable layer two prominent wind systems, namely, the southwesterly and westerly/northwesterly winds developed over the surrounding areas intrude into the valley via the Bagmati River Gorge and the western low-mountain passes, respectively, close to the noontime. These two wind systems then merge as westerly over the central area of the valley and channel into the eastern valley.

In the afternoon, particularly, during the late afternoon, the northwesterly makes a hydraulic jump-like flow in the western part of the valley and converges with the southwesterly along the southwest—northeast line. The northwesterly while converging with the southwesterly lifts up and flows over the shallow (~250 m in depth) southwesterly (see Figure 4d-d′). The southwesterly appears rather cooler than the northwesterly by about a degree Celsius or so. The shallow and cooler southwesterly capped by the warm northwesterly leads to the development of thermal internal boundary layers over the central and eastern part of the valley. The western part of the valley is strongly influenced by the westerly/northwesterly wind whereas the eastern half part of the valley remains under the influence of the southwesterly wind. However, beyond 1900 LST, while the southwesterly vanishes, the northwesterly continues to penetrate the valley and generate a broad anticlockwise circulation over the valley floor (see Figure 4e-e') and gradually returns to almost the same situation of early morning (see Figure 4a-a' and b-b') demonstrating a strong diurnal periodicity of the wind over the valley.



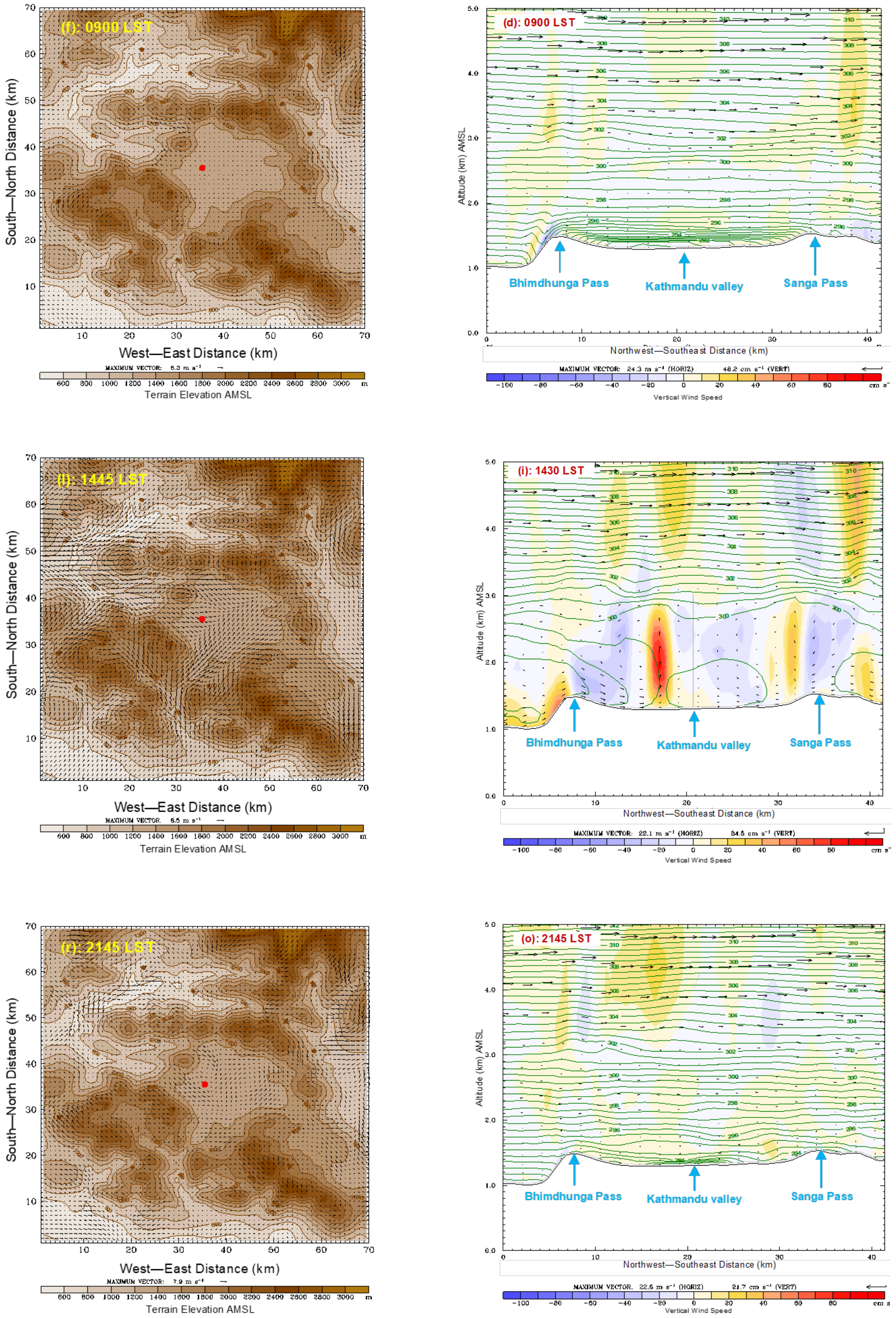



*Figure 4: Near-surface spatiotemporal distributions of horizontal wind (a-e) and vertical cross-sectional distribution of wind (vectors), vertical wind (raster color), and the potential temperature (contour), on 05 January 2018, along the A—B line (a'-e'). See Figure 4d for the orientation of line A—B.*

## 3.3 Visible Manifestations of Meteorological Implications

This sub-section discusses the meteorological implications for air pollution transport over the Greater Kathmandu Valley during the winter season. As we discussed earlier, the valley remains calm or windless from early evening to late morning forming a stably stratified cold air pond of about 300 m deep. This implies that during this long period, pollutants released are not dispersed or transported but remain trapped within a very shallow layer which is often visibly manifested over the valley into the immediate atmosphere (see Figure 5a).


*Figure 5: Visible manifestation of meteorological implications for air pollution transport over the Kathmandu Valley (a) nighttime trapped pollutants close to the surface, (b) vertically dispersed pollutants during the late morning, (c) vertical air motion generated at the front of the advancing regional cooloer airmass into the warm atmosphere of the valley close to the noontime, (d) horizontal transport of pollutants trapped in the afternoon time thermal internal boundary layers and (e) development of multiple layering of pollutants over the eastern part of the valley. Picture sources: (a) http://assets-cdn.ekantipur.com/images/kantipur/miscellaneous/ANG_2203-03012017070607-1000x0.jpg and (b-e) Ram P. Regmi.*

The night-time stable stratification begins to lift from the bottom between 08:30 to 09:00 LST. With the lifting of the surface level stable layer under a calm or windless situation, mixing activities are initiated at the ground level that gradually extends up to the height of about 900 m above the ground close to the noontime (see Figure 4c'-d'). As a result, the surface-level polluted air mass starts to disperse vertically with negligible horizontal transport until the two prominent winds of the valley, that is, south-westerly and north-westerly intrude into the valley (see Figure 5b). These winds are thought to be cool density flow intruding into the warmed atmosphere of the valley. As they advance into the warm air of the valley, the nose of the advancing cool air mass generates vertical wind, thereby lifting the night-time accumulated pollutants into the higher level, which lags behind the advancing cool air mass.

In effect, the level of pollutants at the surface decreases over the area soon they first come under the influence of south-westerly and north-westerly winds in the valley. This particular phenomenon of air pollution transport over the valley is also often manifested in the smoke released from the brick kilns (see sudden but limited upward motion and then bending back of smoke at the upper level in Figure 5c). Along with this lifting effect, the south-westerly and westerly/north-westerly sweep out the valley floor as well during the early afternoon.

The shallow and relatively cooler south-westerly capped by the warmer north-westerly and the presence of a stably stratified layer aloft at or generally below the surrounding mountaintops set the basic course of air pollution transport and formation of pollutant fields over the Kathmandu Valley during the afternoon. Under these afternoon time atmospheric conditions, the pollutants released over the areas that remain under the influence of south-westerly wind are vertically trapped within the shallow layer and tend to drift close to the surface along with the south-westerly (see Figure 5d) whereas the north-westerly picks up the pollutants released in the western part of the valley remain vertically trapped in between the south-westerly layer and the stably stratified layer at the level of surrounding mountaintops. As a result, the double layering structure of the pollutants develops over the central and eastern part of the valley close to the sunset (see Figure 5e).

## 3.4 Gridded Emission Fields

Figures 6a-d show the gridded spatial distribution of daily emissions of the Oxides of Nitrogen (NOx), Oxides of Sulphur (SOx), Carbon Monoxide (CO), and Total Suspended Particulates (TSP) over the Kathmandu Valley during the winter season at the horizontal grid resolution of 1 km × 1 km used to perform the CTM modeling for the particulate pollutant fields over the valley. The emission inventory (Regmi et al, 2018) suggests that the sum of about 0.83 kilotons of the four mentioned pollutants is emitted every day during the winter season with around 418.35 tons (50%) from transportation, 360.94 tons (43%) from domestic, and 55.65 tons (7%) from the industrial sector. Major emission sources have been identified as household cooking/heating, diesel generators, refuse burning, motorcycles, public vehicles, and most importantly road dust resuspension and cement factories.

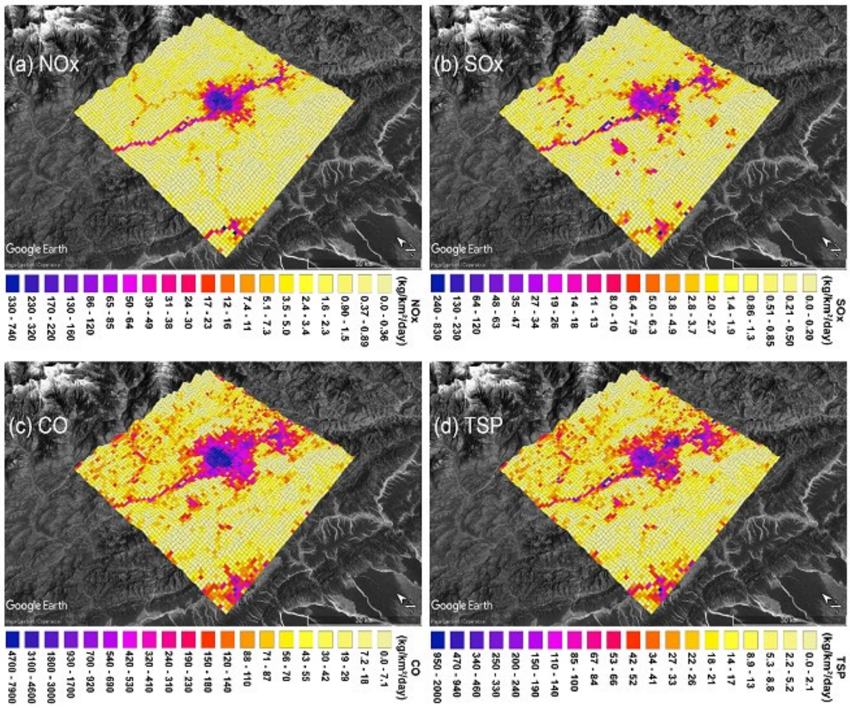



*Figure 6: Gridded emission inventories of (a) NOx, (b) SOx, (c) CO and (d) TSP of the Kathmandu valley overlaid on the Google Earth Terrain Map as per the year 2018.*

## 3.5 Rationale of the CTM Predictions

This sub-section examines the representativeness of the CTM simulated spatiotemporal distribution of PM2.5 by comparing its diurnal variation at four different monitoring stations distributed over the Kathmandu Valley. Figure 7 compares the diurnal variation of PM2.5 concentrations at Ratnapark, Shankhpark, Maharajgunj, and the Phoradurbar areas of the valley (left panel figures) and the corresponding regression analysis (right panel figures) for the period of 04 to 10 January 2018. The diurnal concentration patterns and the corresponding correlation coefficients suggest that the CTM prediction represents the spatiotemporal distribution of PM2.5 over the Kathmandu Valley with few understandable differences. Exact reproductions of observed sub-grid scale diurnal variations are not expected in a regional scale chemical transport modeling.

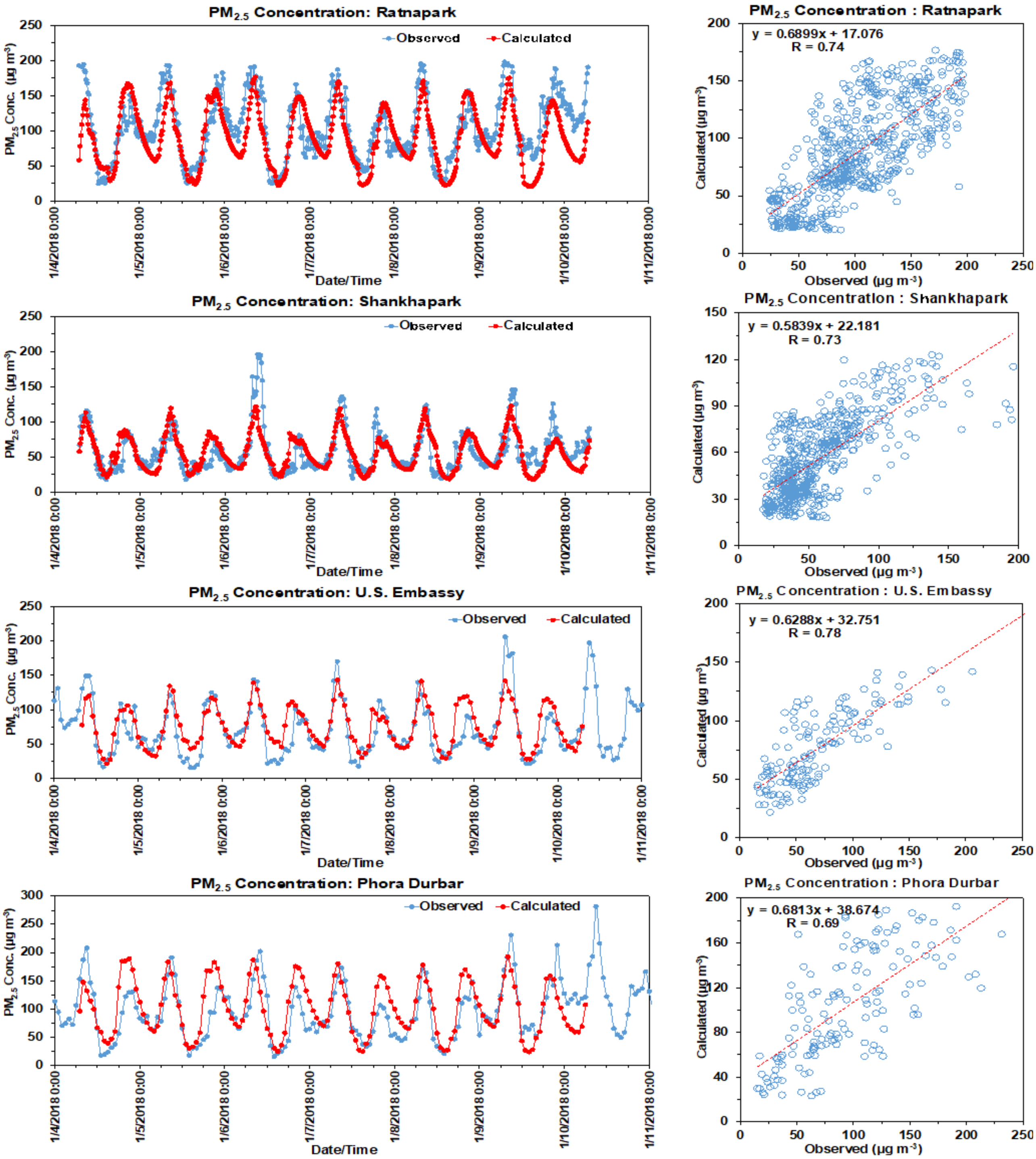
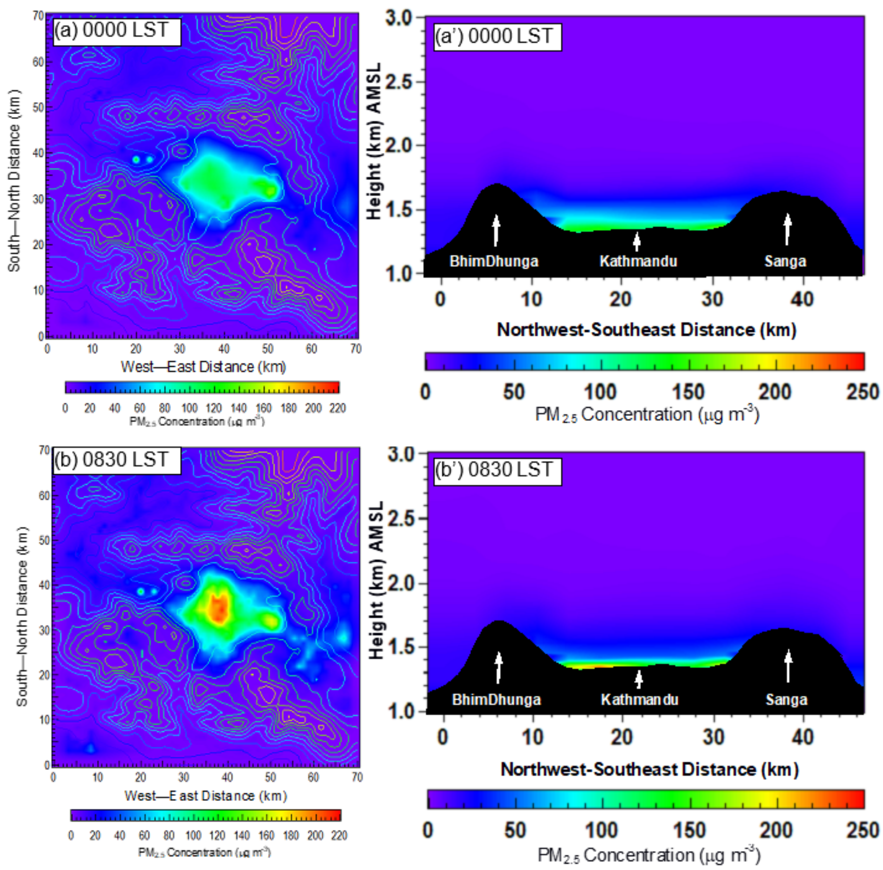



*Figure 7: Comparison of simulated diurnal variation of PM2.5 (left panel) and the corresponding correlation coefficient (right panel) at different air quality monitoring stations distributed over the Kathmandu Valley during 04—10 January 2018.*

### 3.6 Dynamics of Particulate Pollutants

In this sub-section, the spatiotemporal distribution of particulate pollutants (PM2.5) over the Kathmandu Valley is discussed in reference to the base state CTM simulation, that is, the simulation with a realistic emission inventory (see Figure 6) by considering the 05 January 2018 as the representative day of high air pollution winter season. The left panel of Figure 7 shows the horizontal distribution at 2 m height above the ground (AGL) and the right panel shows the vertical distribution of PM2.5 pollutant at some representative times on the day of 05 January 2018. The CTM simulation showed an effective accumulation of particulate pollutants within a shallow layer over the valley floor beginning from dusk leading to nighttime extreme concentrations close to midnight (see Figure 8a-a'). The almost uniform distribution of the PM2.5 concentrations over the valley floor resulted from the accumulation of downslope winds and the development of a weak anticlockwise circulation before the valley becomes calm or windless.

Beyond midnight, the concentration gradually decreases reaching its minimum in the early morning and before the resumption of domestic and transport activities around 04—05 LST (not shown). The near-surface concentration then rapidly increases until the nighttime inversion breaks up around 0830 LST (see Figure 8b-b') and the resumption of the convective dispersion. The near-surface concentration then gradually decreases until the prominent southwesterly and the northwesterly intrude into the valley close to the noontime (see Figure 8c-c').



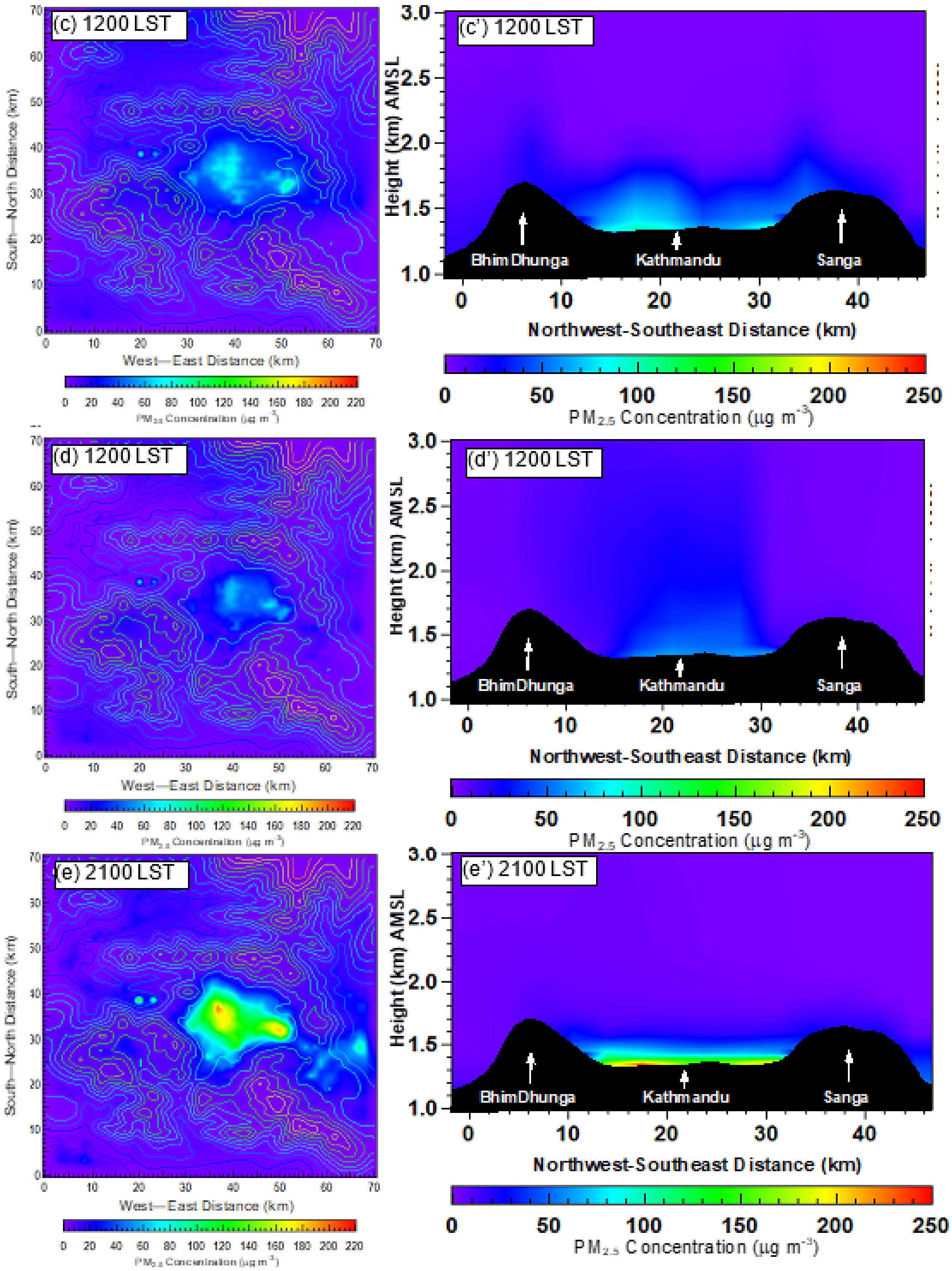
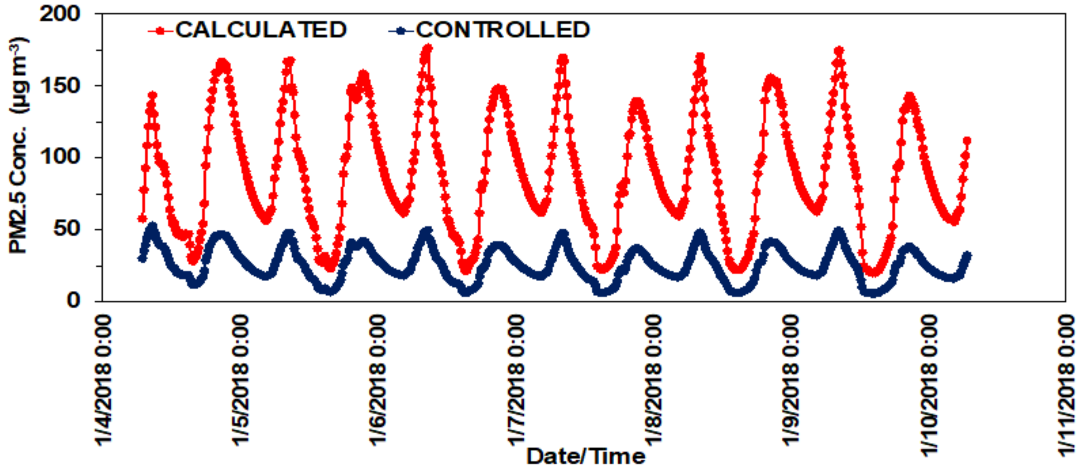


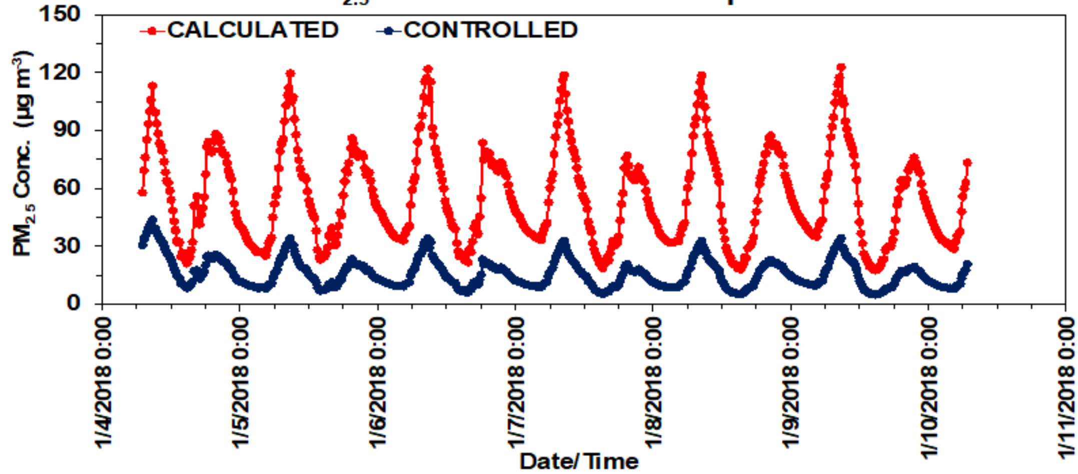

*Figure 8: The diurnal periodicity in the spatiotemporal distribution of PM2.5: Horizontal distribution at 2 m AGL (left panel) and northwest—southeast vertical cross sectional distribution (see A—B in Figure 4d) on 5 January 2018.*

The near-surface concentration over the whole valley suddenly decreases with the intrusion of the southwesterly and northwesterly winds that sweep out the valley floor flushing the dirty air mass of the valley into the eastern neighboring valley around the noontime and continue to do so until the later afternoon (see Figure 8d-d'). However, during the late afternoon as the northwesterly makes a hydraulic jump in the western part of the valley and flows aloft the shallow and relatively cooler southwesterly, the accumulation of pollutants begins in the lowest layer. The double-layered structure of the two wind systems appears to persist till the late evening which favours the building up of pollutants close to the surface. Meanwhile, nighttime domestic and transport activities resume at around 1600 LST and hence speedy increase in the concentration occurs in the late evening (see Figure 8e-e'). As the domestic and transport sector emissions exponential decreases from around 20:00 LST, the near-surface concentration then quickly decreases to resume the midnight situation discussed earlier (see Figure 8a-a') suggesting a strong diurnal periodicity in the dynamics of particulate pollutants over the valley consistent with the meteorological flow fields.

$PM_{2.5}$ Concentration: Ratnapark




$PM_{2.5}$ Concentration: Shankhapark




$PM_{2.5}$ Concentration: Phora Durbar

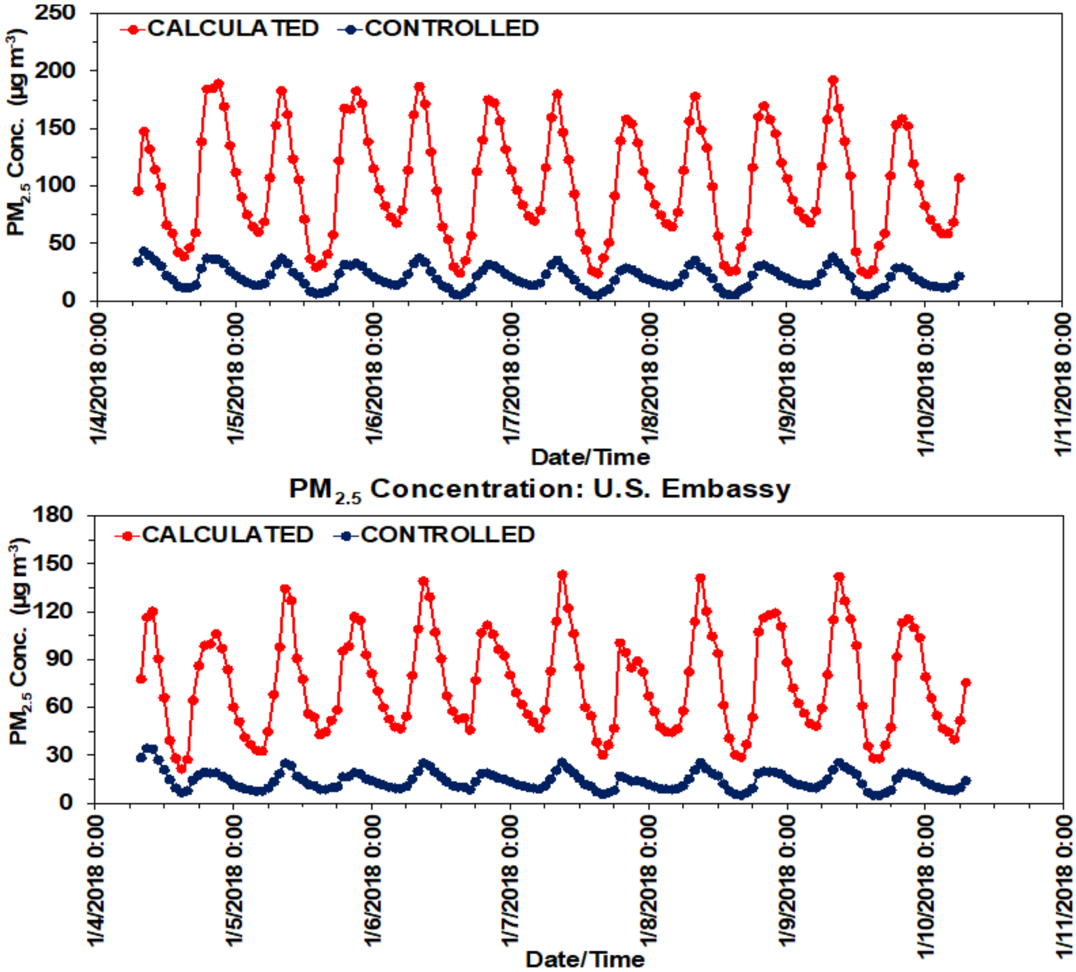



*Figure 9: Comparison of diurnal contribution for PM2.5 concentrations with uncontrolled (calculated) and controlled emission cases at different AQMS sites. The sites are mentioned at the top of each figures.*

## 3.7 Strategic Emission Control Measures

This sub-section discusses strategic emission control measures to improve the air quality over the Kathmandu Valley in reference to the case study of PM2.5. A series of control simulations were performed by reducing the sectoral emissions in different proportions and checking if they met the NAAQS at the air quality monitoring stations of the valley. Out of the several strategic emission control simulation that gave considerable positive outcomes (not shown), the emission control strategy, that is, 80, 70, and 60% reduction of emissions, respectively, in the domestic, transport, and industrial sectors appear most promising.

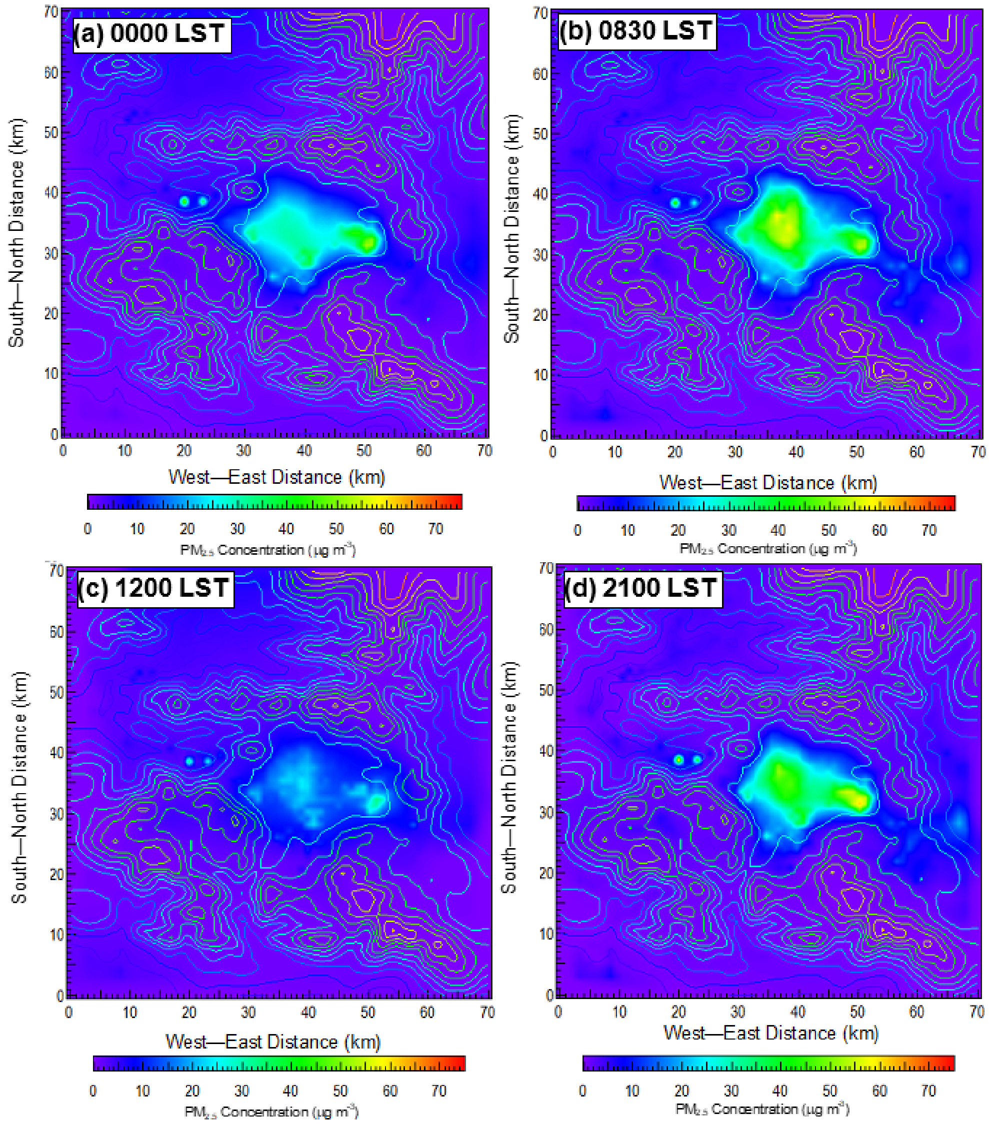



*Figure 10: Spatiotemporal distribution of PM2.5 concentration distribution at 2 m AGL with the reduction of emissions from the domestic (80%), transport (70%) and the industrial (60%) sectors at some representative times mentioned in the upper left corner of each figure.*

Figure 9 compares the CTM simulated base state (uncontrolled) diurnal variation of PM2.5 at the four air quality monitoring station sites with the strategic emission-controlled diurnal variation at the same site. The base state or uncontrolled simulation provides the current status of PM2.5 at different locations where it is monitored and the control simulation predicts the status of air pollution that would be after restricting emissions in the domestic, transport, and industrial sectors. As the base state simulated and the observed diurnal variation of PM2.5 concentration compares well (see Sub-section 3.5), the base state spatiotemporal distribution of PM2.5 concentrations is considered as prevailing concentration distribution over the Kathmandu Valley.

It can be seen that by limiting emissions from domestic, transport, and industrial sectors down to 20, 30, and 40% of the present domestic, transport, and industrial sectors, the NAAQS can be achieved.

Figure 10 shows the resulting spatiotemporal distribution of PM2.5 over the Kathmandu valley at 2 m AGL after implementing emission restrictions at some representative times. The concentration of PM2.5 remains well below the NAAQS over the whole valley for all times except over the Bhaktapur Brickfield areas, particularly, during the evening times when a large number of brickfields are in operation. Moreover, the PM2.5 concentrations may go beyond the NAAQS in the core city area of Kathmandu and Lalitpur around 08:30 LST. To bring the excess concentration over these areas down to the NAAQS, local emission sources need to be regulated.

## 4. Conclusions

The present study was conceived to develop a working level long-term solution to curb air pollution over the Kathmandu Valley. Efforts have been made to understand, model, and predict the current emission scenarios, dynamics, and formation of particulate pollutant fields with an improved understanding of meteorological implications for air pollution over the Greater Kathmandu Valley.

The gridded emission inventories of potential sources have been prepared that can enormously help understand the important sources and areas of emission hotspots where emission regulations are to be imposed effectively. The wintertime meteorological situation over the valley is highly adverse to air pollution. Very strong surface inversion builds up over the valley from the early evening to late morning and the daytime boundary layer height is also not much encouraging. The wintertime (high air pollution season) meteorological situation is likely to confine pollutants released during the night and morning times within a very shallow layer thereby building up the high level of pollutants that tends to disperse vertically from around 09:00 LST. The nighttime polluted air mass slowly starts to advect horizontally from around the noontime and continues to do so until the evening. The afternoon time boundary layer height, the height up to which pollutants can disperse vertically generally remains well below the surrounding mountain tops. The meteorological flow fields over the Kathmandu valley show a very strong diurnal periodicity during the winter season and can be exploited for the development of air pollution control.

The CTM simulation provided a detailed picture of air pollution transport and the formation of pollutant fields over the valley. Consistent with the expected meteorological constraints, the CTM predicted the air pollution transport and formation of pollutant fields over the valley. The CTM simulated concentration of PM2.5 compares well with the observed concentrations at AQMS scattered in the valley suggesting the CTM predictions are representative and do not deviate much from the ground realities. It provided the much-needed knowledge of air pollution transport characteristics and the formation of pollutant fields thereby revealing the affected areas. It showed the emission loadings over the valley have greatly exceeded the carrying capacity. In order to meet the NAAQS, heavy reductions in all the sectors is necessary. For the Kathmandu Valley, there is a need to limit the present emissions from domestic, transport, and industrial sectors down to 20, 30, and 40%, respectively.

Such a heavy reduction in the emissions from all three sectors is difficult but not impossible. For example, the domestic emission can be heavily reduced by supplying sufficient electricity at an affordable price, expected reduction in the emission from the transport sector can be realized by introducing metro-rails, trolly buses, monorails, and trams displacing the present time diesel power public transport system in the urban centers and major highways. Likewise, major industries in the valley are the brickfields, they can be regulated to use clean fuel or relocate to the areas outside the valley.  A few thousand Mega Watt of additional electricity production can meet all these requirements.

## 5. Acknowledgement

The authors would like to acknowledge the Department of Environment, Ministry of Forests and Environment, Government of Nepal for granting NARERL with the project entitled "Air Pollution Dispersion Modeling and Control System Development for Emissions over Kathmandu Valley and Lumbini Area" and providing the AQMS data for the validation of simulated meteorological and air quality fields over the Kathmandu Valley and Lumbini area.

## 6. References

CBS (2014). Statistical Pocket Book of Nepal, 2014.

Chen, F. and Dudhia, J. (2001). Coupling an advanced land surface–hydrology model with the Penn State–NCAR MM5 modeling system. Part I: Model implementation and sensitivity. Monthly weather review, 129(4), pp.569-585.

Collier, E. and Immerzeel, W.W. (2015). High-resolution modeling of atmospheric dynamics in the Nepalese Himalaya. Journal of Geophysical Research: Atmospheres, 120(19), pp.9882-9896.

DoTM (2017). Details of Registration of Transport up to Fiscal Year 2046/47-072/73. [online] https://www.dotm.gov.np/en/ vehicle-registration-record/ (Accessed: 17 December 2017)

Dudhia, J. (1989). Numerical study of convection observed during the winter monsoon experiment using a mesoscale two-dimensional model. Journal of Atmospheric Sciences, 46(20), pp.3077-3107.

Kitada, T. and Regmi, R.P. (2003). Dynamics of air pollution transport in late wintertime over Kathmandu Valley, Nepal: As revealed with numerical simulation. Journal of Applied Meteorology and Climatology, 42(12), pp.1770-1798.

Kitada, T., Lee, P.C. and Ueda, H. (1993). Numerical modeling of long-range transport of acidic species in association with meso-βconvective-clouds across the Japan sea resulting in acid snow over coastal Japan—I. model description and qualitative verifications. Atmospheric Environment. Part A. General Topics, 27(7), pp.1061-1076.

Kitada, T., Okamura, K., Nakanishi, H. and Mori, H. (2000). Production and Transport of Ozone in Local Flows over Central Japan-Comparison of Numerical Calculation with Airborne Observation—. In Air pollution modeling and its application XIII (pp. 95-106). Springer, Boston, MA.

Kitada, T., Sofyan, A. and Kurata, G. (2008). Numerical simulation of air pollution transport under sea/land breeze situation in Jakarta, Indonesia in dry season. In Air Pollution Modeling and its Application XIX (pp. 243-251). Springer, Dordrecht.

Kumar, P., Kotlarski, S., Moseley, C., Sieck, K., Frey, H., Stoffel, M. and Jacob, D. (2015). Response of Karakoram-Himalayan glaciers to climate variability and climatic change: A regional climate model assessment. Geophysical Research Letters, 42(6), pp.1818-1825.

Lee, J., Shin, H.H., Hong, S.Y., Jiménez, P.A., Dudhia, J. and Hong, J. (2015). Impacts of subgrid-scale orography parameterization on simulated surface layer wind and monsoonal precipitation in the high-resolution WRF model. Journal of Geophysical Research: Atmospheres, 120(2), pp.644-653.

Maussion, F., Scherer, D., Mölg, T., Collier, E., Curio, J. and Finkelnburg, R. (2014). Precipitation seasonality and variability over the Tibetan Plateau as resolved by the High Asia Reanalysis. Journal of Climate, 27(5), pp.1910-1927.

Mlawer, E.J., Taubman, S.J., Brown, P.D., Iacono, M.J. and Clough, S.A. (1997). Radiative transfer for inhomogeneous atmospheres: RRTM, a validated correlated-k model for the longwave. Journal of Geophysical Research: Atmospheres, 102(D14), pp.16663-16682.

NEEP/GIZ (2012). Baseline Study of Selected Sector Industries to Assess the Potentials for more Efficient use of Energy, PACE Nepal Pvt. Ltd., Kathmandu, pp.1-220.

Norris, J., Carvalho, L.M., Jones, C. and Cannon, F. (2015). WRF simulations of two extreme snowfall events associated with contrasting extratropical cyclones over the western and central Himalaya. Journal of Geophysical Research: Atmospheres, 120(8), pp.3114-3138.

Panday, A.K. and Prinn, R.G. (2009). Diurnal cycle of air pollution in the Kathmandu Valley, Nepal: Observations. Journal of Geophysical Research: Atmospheres, 114(D9).

Regmi, R.P. (2014). Aviation hazards over the Jomsom Airport of Nepal as revealed by numerical simulation of local flows. Journal of Institute of Science and Technology, 19(1), pp.111-120.

Regmi, R.P., Kitada, T. and Kurata, G. (2003). Numerical simulation of late wintertime local flows in Kathmandu valley, Nepal: Implication for air pollution transport. Journal of Applied Meteorology, 42(3), pp.389-403.

Regmi, R.P., Kitada, T., Dudhia, J. and Maharjan, S. (2017). Large-scale gravity current over the middle hills of the Nepal Himalaya: Implications for aircraft accidents. Journal of Applied Meteorology and Climatology, 56(2), pp.371-390.

Regmi, R.P., Kitada, T., Guenter, G., Kafle, G.C., Maharjan, S., Shrestha, S., Khadka, A.K., Adhakari, S. (2018). Air Pollution Dispersion Modeling and Control System Development for Emission over Kathmandu Valley and Lumbini Area, Department of Environment, Ministry of Forests and Environment, Government of Nepal, Kathmandu.

Regmi, R.P., Kitada, T., Maharjan, S., Shrestha, S., Shrestha, S. and Regmi, G. (2019). Wintertime boundary layer evolution and air pollution potential over the Kathmandu Valley, Nepal. Journal of Geophysical Research: Atmospheres, 124(8), pp.4299-4325.

Shrestha, P., Barros, A.P. and Khlystov, A. (2010). Chemical composition and aerosol size distribution of the middle mountain range in the Nepal Himalayas during the 2009 pre-monsoon season. Atmospheric Chemistry and Physics, 10(23), pp.11605-11621.

Skamarock, W.C., Klemp, J.B., Dudhia, J., Gill, D.O., Barker, D., Duda, M.G., Huang, X.Y., Wang, W. and Powers, J.G. (2008). A description of the advanced research WRF version 3 (No. NCAR/TN-475+ STR), University Corporation for Atmospheric Research. National Center for Atmospheric Research Boulder, Colorado, USA, https://doi. org/10.5065/D68S4MVH.

Thompson, G., Rasmussen, R.M. and Manning, K. (2004). Explicit forecasts of winter precipitation using an improved bulk microphysics scheme. Part I: Description and sensitivity analysis. Monthly Weather Review, 132(2), pp.519-542.

WECS (2014). Energy Consumption Situation in Nepal (Year 2011/12).

WHO (2016). Ambient air pollution: A global assessment of exposure and burden of disease, pp.131.

# *Urgency of National Ground Research Centre(N-GRC) in Nepal for Resilient and Sustainable Infrastructural Development*

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## Abstract

Poor infrastructure planning, design, construction, and operation due to poor management of ground risks are costing the country billions of rupees and hundreds of lives every year. Ground data collection, field and laboratory testing, data analysis, correct interpretation & design, and post construction performance monitoring & observations are key parts of engineering practice to manage the ground risks. It is often found that these various integral parts of engineering practices are seriously overlooked in Nepal. The country is lacking a ground database system, design guidelines, and code of practice to deal with various types of ground (soil and rock) prevailing within the national domain to manage the geo-hazards properly. There is rare practice of doing field monitoring and observation to investigate the performance of built or natural environment. The construction industry is in a need of leadership role to understand the ground risk and develop a necessary code of practice to build resilient and sustainable infrastructure. Therefore, there is an urgency of an establishment of a leading organisation at national level such as the National Ground Research Centre (N-GRC) to address these issues. Vision, mission, and objectives of N-GRC are presented in this paper. A brief discussion is also provided on organisational set up, operation model and financing.

*Keywords:* N-GRC, ground engineering, ground risks, built and natural infrastructure

## 1. Background

Poor management of ground risks directly impacts on infrastructure planning, design, construction and operation, which costs the country billions of rupees and hundreds of lives every year. One of the main reasons of the poor performance of physical infrastructure (lifelines) such as highways, bridges, irrigation canals, water supply projects of the country is due to poor understanding of the soils and geology. Ground Engineering is the most complex part of civil engineering since the ground is gifted by nature and not built in a controlled environment such as steel, concrete. Therefore, through understanding of ground and its behaviour are essential to manage the ground risks that allow to build safe and sustainable physical infrastructure.

Ground data collection, field and laboratory testing, data analysis, correct interpretation, field monitoring and observations are fundamental parts of engineering practice to manage the ground risks. However, there is widespread malpractice of ignoring necessary ground exploration to save the engineering design cost in Nepal. Ground hazards could create lots of uncertainty and introduce risks in construction project. These are not only geotechnical risk but also other risks such as programme risk, contractual risk, commercial risk, financial risk, health and safety risk, sustainability risk, and thus ultimately could lead projects to total failure.

Ground risk management is most effective when it started as early as possible in any project. In order to manage such risks, the public and private sector could play a pivotal role by building a ground database system bringing in historical ground explorations data of the whole country in one platform. So far, the country is lacking such initiatives. Thus, historical data are not available in public domain. Every project, therefore, has to scratch from a basic and invent the wheel again and again.

The country is lacking design guidelines, and code of practice to deal with various types of ground conditions (soil and rock) available in the country. There is rare practice of doing field monitoring and observation to monitor the performance of built or natural environment. Disaster risk management is very poor in the country. Geo-disasters such as landslide, earthquakes cause lot of human tolls and damage public and private assets. Ground risks are poorly understood, managed, and this is slowing down the development pace of the country.

With prospects of major complex infrastructure projects such as an underground metro rail system in the Kathmandu Valley, recent major damaged to the Melamchi Watershed (Water Supply project) due to flood and debris flow, dilapidated condition of major national highways, the country is in a need of initiatives and modern approaches to deal with the ground and associated ground risks for successful construction as well as operation of the infrastructure projects.

*Figure 1: Blocked the Narayangarh-Muglin road section due to landslide 2021 (My Republica, 2021)*

*Figure 2: Bridge failure (Jha and Chaudary 2021)*

To address the above issues from the grassroots level, the country is in a need of an establishment of National Ground Research Centre (N-GRC) with clear vision, mission, and objectives.

## 2. Vision of N-GRC

Build safe, resilient, and sustainable built (physical infrastructure) and natural environment through adequate understanding of the ground and associated ground risks.

## 3. Mission of N-GRC

Develop knowledge and expertise on soil and geology of the country and understand their engineering behaviour by academic/professional research and development, thus contribute on building safe, resilient, and sustainable physical infrastructure (Built and natural environment).

# 4. Objectives of N-GRC

Main objectives of the proposed N-GRC to achieve the above vision and mission would be as follow:

1. Establish a national geotechnical database centre
2. Develop experimental facilities for research on fundamental and advance engineering properties of soil and rock
3. Develop code of practice and guidelines to deal with various soils and geology, geohydrology prevailing in the country
4. Develop facilities for computer modelling of complex geotechnical problems
5. Develop expertise on field scale instrumentation and monitoring
6. Research on engineering geology and geo-environmental area

These are not exhaustive. Consultation with ground experts is recommended while establishing a comprehensive list of objectives. These key objectives are elaborated in detail below.

## 4.1 Establish a national ground database centre

The proposal is to build an online ground database system in GIS platform by collating all available historical ground investigation data in one place. Such system would be helpful in desk studies of prospective development projects, thus help saving time and cost of future development projects and accelerate nation building process.
To establish such database system, N-GRC would liaise with key government authorities such as DOR (Department of Roads), DORW (Department of Railways), Department of Mines and Geology and other related government bodies since such departments hold bundles of data of legacy projects of several decades. Collaboration with international organisations such as ICIMOD (International Centre for Integrated Mountain Development) would be helpful as this organisation has been actively working in the Himalayan region for sustainable mountain development and has also got own database system for landslide hazard mapping etcetera.

An expert team comprising geotechnical engineers, geologists, geohydrologists, GIS experts would be required to set up such database system. This would offer the N-GRC a capability to do 3D subsurface modelling and integration with Building Information Modelling (BIM).

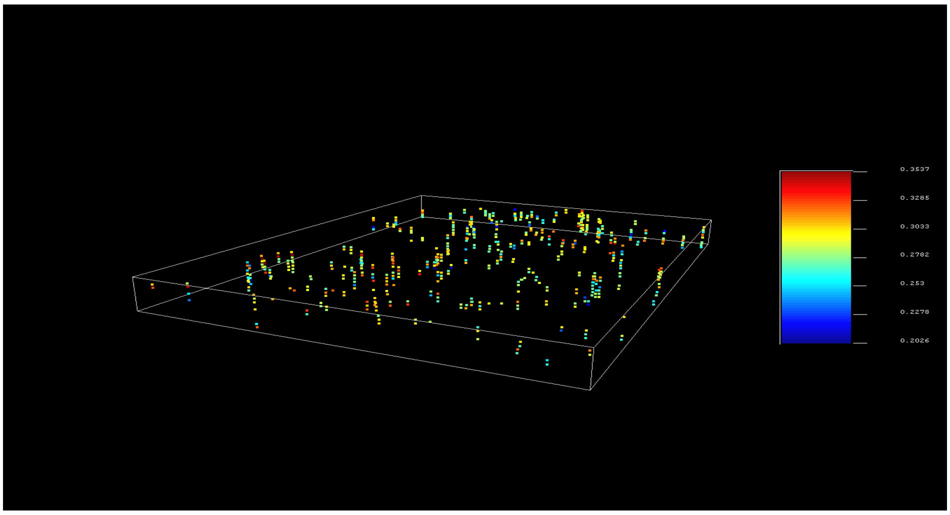


*Figure 3: Geo-data compilation to build ground models (Picture source: Ross Fitzgerald)*

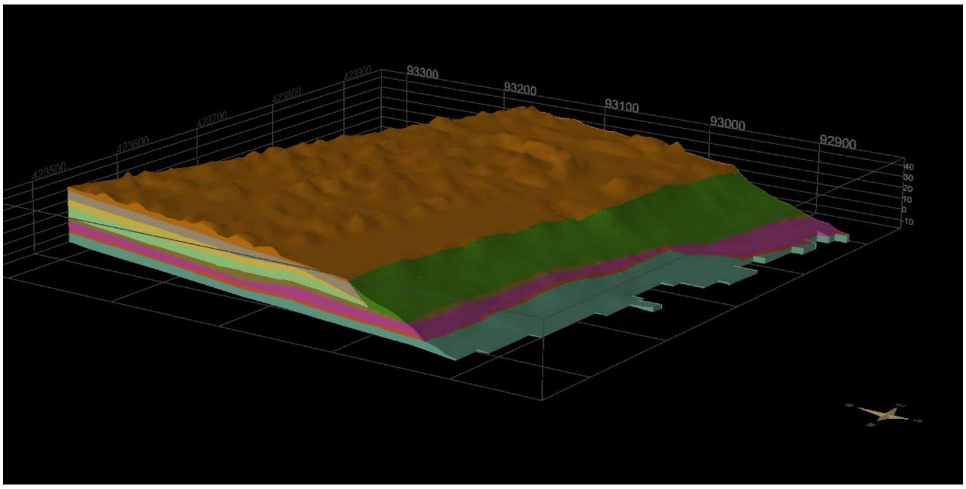


*Figure 4: A 3D ground model for an example (Picture source: Ross Fitzgerald)*

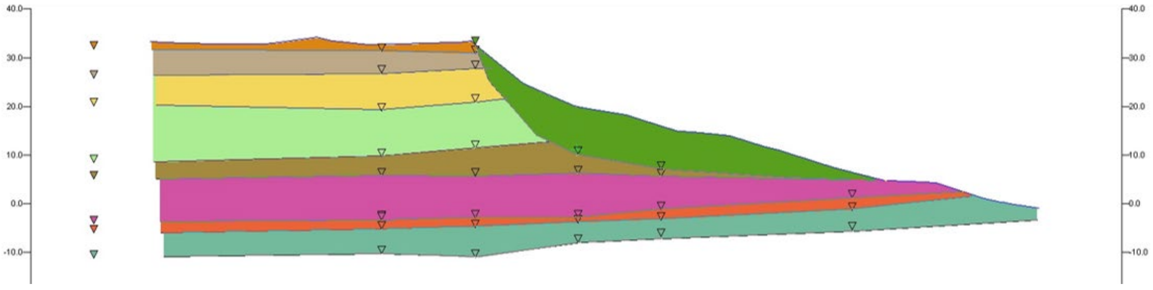


*Figure 5: A 2D ground model for an example (Picture source: Ross Fitzgerald)*

This would ultimately help in design optimization, ground risk assessment and mitigation in early phase of the major infrastructure projects. British Geological Survey (BGS) has developed such system for the UK soils and geology. See below a snapshot from BGS website. For more information, please browse using the following web-link:

https://mapapps.bgs.ac.uk/geologyofbritain/home.html?&_ga=2.243431745.539179664.1621594009-448297400.1614680371

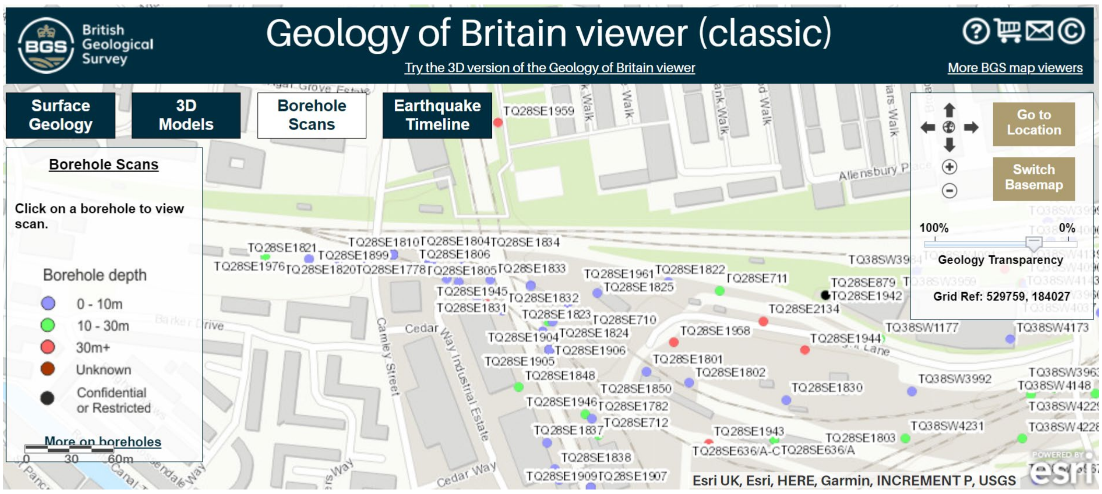


*Figure 6: Online Geo-database system developed by BGS (Source: British Geological Society (BGS))*

In 2018, Nepalese Consultant Multi-Disciplinary Consultant Pvt. Ltd developed such system compiling own data from Multi Soil Lab for a joint research collaboration on Kathmandu Underground Metro rail development at the University of Warwick (WU), UK. This has helped the WU students to explore ground details of the valley during their research works.

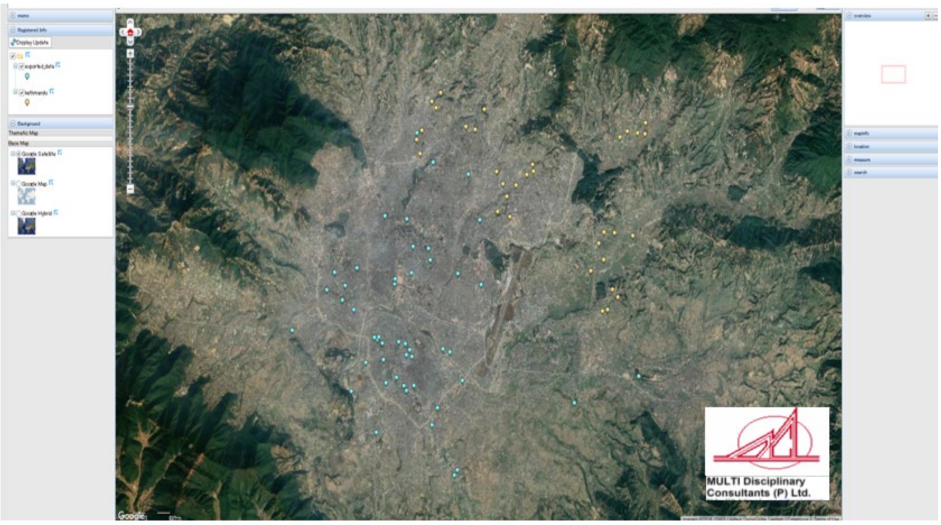


*Figure 7: Online Geo-database system developed by Multi Disciplinary in 2018*

## 4.2 Develop experimental facilities for research on fundamental/advance engineering properties of soil and rock

Nepal is in a need of establishing modern 21st century geo-laboratories for soil and rock testing. For this, a wide consultation with geo-experts having expertise on experimental research laboratory set up would be essential to establish national needs and gaps in the resource and facilities within the country. This would include both facilities for laboratory scale testing and field-testing. Few photographs of experimental laboratory set up and field-testing are presented below for a general impression on the extent of the facilities required.

*Figure 7: Online Geo-database system developed by Multi Disciplinary in 2018*

*Figure 9: Gotechnical lab testing (Source: website-2: gii.ie)*

*Figure 10: Field testing (Cone penetration testing) (Source:Website-3: sfc.com.sa)*

## 4.3 Develop Code of Practice, Guidelines on Ground Engineering

Nepal is in a need of having own code of practices and design guidelines those are relevant to the local context such as soil, geology, climate etcetera of various regions of the country.

Some recommended guideline documents that would be beneficial to the construction industry are below for examples. This list is not exhaustive and through the consultations with ground experts would be invaluable to develop a comprehensive list needing urgent attentions within the national context.

- Understanding soil and geology of the Kathmandu Valley for urban development
- Engineering in the Kathmandu soil
- Engineering in the Pokhara soil
- Popular rocks of Nepal and their engineering behaviours
- Guidance on design of pile foundation in Kathmandu soil
- Geo-chemical behavior of Kalimati clay

Professional societies and organisations such as Nepal Geotechnical Society, Nepal Geological Society, Nepal Engineers' Association (NEA), Nepal Electricity Authority, Nepal Academy of Science and Technology (NAST), Nepal Agricultural Research Council (NARC) could contribute to such exercise.

## 4.4 Develop facilities for computer modelling of complex geotechnical problems

Numerical modelling capacity is key for ground engineers while investigating or understanding complex soil-structure interaction problem. Commercial tools & software such as Praxis, Flac are available in the market for the purpose. Geotechnical engineers need training to build confidence on using such tool. N-GRC could play a pivotal role on solving complex ground related problems by building such workforce and setting up computing laboratory facilities.

## 4.5 Develop expertise on field scale instrumentation and monitoring

In order to validate design prediction and reduce the risk of uncertainty due to limited knowledge of the ground at the time of design and also advance the knowledge on the performance of geo-structure (built or natural), Instrumentation and Monitoring (I&M) is important. Some examples of field instrumentation work that could help advance knowledge and prevent risk of structural collapse and fatalities are presented below. Any major infrastructure project should have a dedicated unit of I&M. N-GRC could take a leadership role on helping the country on maintaining the performance of the major lifeline infrastructure by performance monitoring through I&M.

- Landslide prediction, monitoring, and assessment
- Understanding landslide in Jogimara (Prithvi Highway) and mitigation measures
- Ground movement due to deep excavation in Kathmandu clay
- Tunnelling and tunnel induced ground movement in Kathmandu clay
- Sinkhole mapping in Pokhara

### 4.6 Research on engineering geology and geo-environmental area

Further consultation with engineering geologists and environmental engineers is recommended to developed details under this heading.

## 5. Organisational Set-up and Responsibilities

As this concept paper is in a very early stage of N-GRC proposal, it is recommended that a public-private sector should take initiative on setting up such organisation through consultation with ground experts to find the best organisational set up and delineates its responsibilities. In general, the author perceives on a need of two parts within an organisational set up as below:

- Main operating body with a CEO
- Advisor panel of experts: for guidance, and check & balance

It is also recommended to figure out where such organisation would better fit in, such as within a government department or within an academic institution or as an independent body. For the success of such organisation, it would be essential to have a partnership with the relevant government bodies such as DOR, DORW, DOI as mentioned in the earlier sections.

It is also recommended to investigate on various possible operation models of the organisation and figure out a most appropriate one in the national context. It is important that the organisation remains self-sustainable financially. However, the government may need to take an initiative at the beginning and financially support the establishment of N-GRC. Such organisation should be set up with short-term and long-term goals.

## 6. Concluding remarks

Nepalese construction industry is in a need of leadership role to manage the ground risks for better performance of the existing and future infrastructure. This is key for disaster risk management as well. Management of ground risk is only possible through thorough understanding of the soil and geology and type of infrastructure to be built for delivering resilient, sustainable, and robust infrastructure. Therefore, establishment of the National Ground Research Centre (N-GRC) is an urgent need of the country. A wide consultation with ground experts is recommended while setting up such organisation to formulate organisational structure, operation model, and short-term and long-term goals.

## 7. References


My Republica (2021). Narayangarh-Mugling road section blocked by landslides again, 4th July 2021

Jha, P and Chaudary R. K., (2021). Bridge failures in Nepal: Diagnosis and solutions, The Himalayan Times, 20th July 2021

British Geological Society (BGS), Geology of Britain viewer (Classic) (https://mapapps.bgs.ac.uk/geologyofbritain/home.html?&_ga=2.243431745.539179664.1621594009-448297400.1614680371)

Website-1: gii.il
https://www.gii.ie/services/site-services/lab-testing/

Website-2: gii.il
https://www.gii.ie/services/site-services/lab-testing/

Website-3: sfc.com.sa
https://www.sfc.com.sa/services/topic/123

# *Development of a Low-Cost Aerial Research Platform for Addressing Current Limitations of Air Monitoring in Nepal*

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*(* Presented work is a volunteering effort not related to the author's institution of affiliation)*

## Abstract

Hyper-local mapping of atmospheric air pollution in the urban areas of Nepal has very limited available data. Present work presents our motivation and showcases our effort of developing a portable aerial research platform prototype for generating hyper-local maps of urban areas of Nepal with a custom-built air monitoring instrumentation platform based on a locally developed quadcopter drone. The air monitoring instrumentation consists of an Arduino board integrating an array of low-cost air sensors for monitoring NO2, SO2, O3, PM2.5, Temperature, Barometric Pressure, and Relative Humidity. Variants of locally developed electric quadrotor unmanned aircraft systems (UAS) are being developed which will be deployed as the aerial monitoring platform. The prototype UAS is envisioned to enable academics and researchers to collect atmospheric air pollution data by positioning the platform at any desired location for short durations, and within the limits of regulated airspace and telemetry range. Generation of vertical atmospheric profiles of air pollution variation at the measurement locations will enable the development of hyper-local three-dimensional air pollution maps of urban areas which can then guide the development of effective air pollution management and mitigation strategies. The current work discusses the background of the current air monitoring infrastructure in Nepal with associated challenges, the opportunities provided by the emerging low-cost sensor technologies, the technical aspects of the aerial platform prototype development process, and potential future avenues for its use.

*Keywords:* UAS, drone, air monitoring, sensors, low-cost

# 1. Introduction

Ambient or outdoor air pollution is recognized by the World Health Organization (WHO) as the leading cause of 4.2 million deaths worldwide. Air pollution has been attributed to health problems in humans including chronic and acute respiratory diseases, heart disease, stroke, and lung cancer. While almost all (99%) of the global population breathes air that exceeds the WHO guideline limits, people living in low- and middle-income countries are exposed to the highest levels of air pollution (Health impacts of air pollution, 2022).

Nepal is a developing South-Asian nation stretching along with the Himalayan range and is nestled between the two most populous countries of the world: India and China. India and China are also the two nations producing nearly 37% of the global emission of CO2 through the combustion of fossil fuel and industrial processes (Manisalidis et al., 2020). Although not being a heavily industrialized nation, significant amounts of air pollution emissions have been recorded in the country, an example is presented in Table 1 below.

*Table 1: Reported emissions of various air pollutants in Nepal in 2011 (Sadavarte et al., 2019)*

| Pollutant | Total estimated mass of emission in 2011 (Gg) |
|---|---|
| Carbon dioxide ($CO_2$) | 8900 |
| Methane ($CH_4$) | 110 |
| Nitrous oxide ($N_2O$) | 2.1 |
| Other oxides of nitrogen ($NO_x$) | 64 |
| Carbon monoxide (CO) | 1714 |
| Non-methanogenic volatile organic compounds (NMVOC) | 407 |
| Fine particulate matter ($PM_{2.5}$) | 195 |
| Black carbon (BC) | 23 |
| Organic carbon (OC) | 83 |
| Sulphur dioxide ($SO_2$) | 24 |

The Climate and Health Country Profile of 2015 by the WHO reported that with a population of roughly 28 million and a population growth rate of 1.2% but with a GDP per capita of 692 USD, Nepal is also one of the most vulnerable nations facing the dire impacts of both domestic and regional air pollution, and global climate change (Air Pollution | CDC, 2020). The same WHO report also highlighted the Government of Nepal (GoN)-reported values of spring and winter season mean ambient PM2.5 concentrations of over 70 and 80 μg/m3, respectively. For reference, the WHO annual mean PM2.5 guideline value is 10 μg/m3. In addition, the report also highlighted that over 91% of rural and 29% of the urban population in Nepal rely on solid fuels for cooking, creating dangerous levels of greenhouse gases and hazardous air pollutants, leading to roughly 54,900 total deaths attributable to household air pollution, based on 2012 data.

In recent years, the air pollution problem of Nepal has often put the country in the topmost ranks of the most polluted countries in the world. In 2019, the State of Global Air Report placed Nepal as the 2nd most polluted country in the world with a population-weighted PM2.5 annual average concentration of 83.1 µg/m3(State of Global Air 2020, 2020). One study even recorded the high average daily PM2.5 concentrations in the Kathmandu Valley of up to 160 µg/m3 (Pokharel et al., 2021). Nepal ranks 178th out of the 180 countries listed in Yale's 2020 Environmental Performance Index (DOR: SSRN, 2022). One past study has reported that about 44%, 15%, 52%, and 52% of the population in the Kathmandu are living in areas of higher than 40 µg/m3 of NO2, SO2, PM10 and PM2.5, respectively ('Air Pollution Health Impacts', 2022). The significance of the degree of contribution from the day-to-day air pollution generating activities in the urban centres of the country became clear during the multiple COVID-19 lockdowns faced by the country during the year 2020. One study recorded that there were statistically significant drops in PM2.5 concentrations in six major cities of Nepal ranging from 26% to 81% (Etyemezian et al., 2003).

Real-time monitoring of the various air pollutions of concern to the public health and environment is essential to be aware of the condition of the atmosphere and its potential impact so that appropriate response strategies can be formulated and enacted by the regulatory agencies as well as the public.

## 2. Current air monitoring situation in Nepal

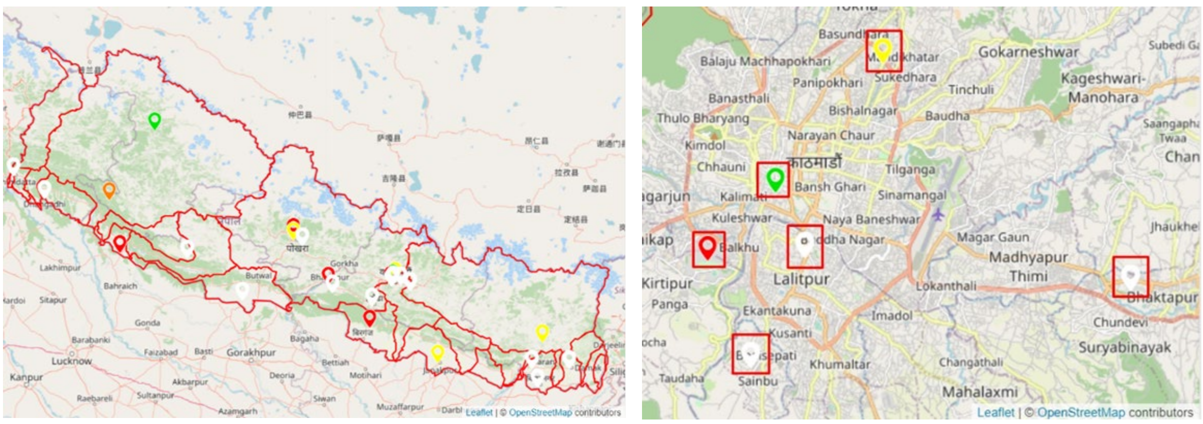
Many past studies conducted in Nepal have used air monitoring instrumentation as a one-time event, but consistent and continuous use of air monitoring instrumentation and stations are limited in number and scope. GoN started installing and operating ambient air monitoring stations in Nepal in the early '90s using high-volume and medium-volume samplers as campaign monitoring. In 2002, the Ministry of Population and Environment, with support from the Danish International Development Agency, established six air monitoring stations in Kathmandu Valley. These air monitoring stations collected continuous data on PM10 and PM2.5 but soon became dysfunctional in 2006 (Juginović et al., 2021). By the end of 2017, a total of 11 air monitoring stations were operating throughout the country (Neupane et al., 2020). Since 2012, GoN has also regulated the National Ambient Air Quality Standards (NAAQS) for various air pollutants. Table 2 below lists the nine pollutants regulated by the GoN NAAQS. However, not all the nine pollutants are monitored by the 11 air monitoring stations spread throughout the country. As a developing nation with one of the world's lowest GDP per capita, Nepal also suffers from a lack of resources to consistently operate and maintain many air monitoring stations and use many laboratory facilities capable of high-end environmental sample analysis capabilities. Even the operational air monitoring infrastructure has questionable data reliability, as the GoN-maintained website streaming the air monitoring data (Air Quality Monitoring | Nepal, 2022) provides no information regarding the instrumentation, calibration methods and schedules, data accuracy and data completeness about any of the publicly reported data. The NAAQS of Nepal is comparable to the NAAQS of the United States for the same average periods (US EPA, 2014).

*Table 2: National Ambient Air Quality Standards of different regulated pollutants in Nepal (Neupane et al., 2020).*

| Pollutant | Units | Averaging Time | Maximum Concentration | Approved Detection Methods |
|---|---|---|---|---|
| TSP† | µg/m³ | 24-hour | 230 | High-volume sampling and gravimetric analysis |
| $PM_{10}$ | µg/m³ | 24-hour | 120 | High-volume sampling and gravimetric analysis, TEOM‡, Beta attenuation |
| $PM_{2.5}$ | µg/m³ | 24-hour | 40 | $PM_{2.5}$ sampling gravimetric analysis |
| $SO_2$ | µg/m³ | Annual | 50 | Ultraviolet fluorescence, West and Gaeke Method |
| | | 24-hour | 70 | Same as annual |
| $NO_2$ | µg/m³ | Annual | 40 | Chemiluminescence |
| | | 24-hour | 80 | Same as annual |
| CO | µg/m³ | 8-hour | 10,000 | Non-dispersive infra-red (NDIR) spectrophotometry |
| Pb | µg/m³ | Annual | 0.5 | High-volume sampling followed by atomic absorption spectrometry |
| $C_6H_6$ | µg/m³ | Annual | 5 | Gas chromatographic technique |
| $O_3$ | µg/m³ | 8-hour | 157 | UV spectrophotometry |

† TSP = Total suspended particulates
‡ TEOM = Tapered element oscillating microbalance

The locations of the air monitoring stations operated by GoN are illustrated in Figure 1, as shown by the GoN Department of Environment website (Air Quality Monitoring | Nepal, 2022). The website currently shows 26 air monitoring stations spread throughout the country, but only 12 of the stations show live streaming data as of March 2022.




(a) (b)

*Figure 1. (a) Locations of air quality monitoring stations maintained by GoN throughout the country; and (b) Locations of air quality monitoring stations within the Kathmandu Valley (Air Quality Monitoring | Nepal, 2022). The pins in the maps are colour-coded according to the United States Environment Protection Agency-defined air quality index, and the white pins represent air monitoring stations that are not streaming live data (Credit: GoN website sourcing the base map from OpenStreetMap © contributors).*

In addition to the GoN air monitors, air monitoring stations are also operated and maintained by the US Embassy at two locations in Kathmandu (Phora Durbar Recreation Center in the Thamel area, and US Embassy grounds in the Lazimpat area (US Embassy, Kathmandu, 2022).

## 2.1 Limitations of the current air monitoring infrastructure of Nepal

There are some major limitations of such air monitoring network. Each air monitoring location can sometimes report extremely high values resulting from very localized events which may not be representative of the general air quality of the region. A past study by Li et al. (Lawrence and Lelieveld, 2010) concluded that in many urban areas, more than one or two measurement locations per km2 is essential to quantify the air pollution spatial patterns with high enough fidelity (such as <2 ppb NO2 or <1 μg/m3 PM1). The failure of some air monitoring stations in a sparsely located air monitoring network will also obscure the scenario of air pollution impacts within a certain region which makes it hard for researchers and regulators to forecast future trends that can be expected regarding air pollution temporal patterns. It is also very hard to assess the number of people affected by a certain source of air pollution such as a single stationary source such as an industrial stack, or fugitive road dust emanating from a single busy road due to vehicular movement.

## 2.2 Need for higher geospatial resolution monitoring

A huge portion of the population living in the major cities may be subject to hazardous levels of air pollution. Kathmandu Valley, for example, has an estimated average population density of approximately 2800 individuals per km2 (2011 estimate) (Juginović et al., 2021), the majority of who live near very busy and under-maintained roads. Schools, offices and hospitals are also often located right next to residential buildings in major cities like Kathmandu. Other building types besides the residential ones can also be expected to suffer the same levels of exposure to air pollutants. The degree of impact on their health due to both local and regional air pollution cannot be reasonably quantified and assessed without measurement of different air pollutants at a high geospatial resolution, such as at the neighbourhood level. While large-scale atmospheric dynamics and advection of various air pollutants have been extensively studied in the South Asian region, hyper-local scale studies have hardly been conducted with reusable and low-cost instrumentation in the urban settings of Nepal. If air pollution data is available at such a hyper-local geo-spatial scale, it can also guide future urban planning efforts. Future research can also help to identify the human exposures to various air pollutants because of the infiltration of outdoor air pollutants into indoor built environments if the spatial distribution patterns of air pollutants can be mapped at a high enough resolution.

More localized data availability can help address some of these shortcomings of stationary air monitoring stations. However, an increase in the number of air monitoring locations also means a drastic increase in the associated resources and cost. Hence, a more distributed air monitoring system capable of providing hyper-local data at a neighbourhood-scale resolution should also be low-cost and affordable.

## 3. Low-cost sensors and citizen science

Air monitoring stations maintained by government-level regulatory agencies (often called "reference grade instruments") are often very expensive, bulky, and require dedicated skilled operators for their timely maintenance and calibration. An example is the reference-grade instrument suite used by an air monitoring station maintained according to the European CSN EN 12341 Standards for standard gravimetric measurement of PM10 and PM2.5 mass concentrations (European Standards CSN EN 12341, 2014). In the United States, Federal Reference and Equivalence Methods are used as the "gold standard" for air pollution monitoring and ensure data quality through standardized instrumentation and calibration processes as per the federal law of the United States (40 CFR § 53.1) that implements the U.S. Clean Air Act requirement of monitoring six "criteria pollutants" (CO, O3, SO2, NO2, Pb and PM) (US EPA, 2016). The typical cost for each reference monitor used by the US EPA is between $15,000 to $40,000 (USD).

Emerging low-cost sensor technologies can provide a promising alternative solution to the need for a high number of real-time air monitors at a reasonable cost for hyper-local air monitoring. Hundreds of brands of low-cost air quality sensors (<300 USD) are now available in the market and have been used in many countries to improve the spatial granularity of collected data and supplement the network of reference monitors maintained by regulatory agencies. Internet of things (IoT) architecture is often utilized to collectively assess various types of air pollutants using a distributed network of low-cost sensors (LCS) that are either fixed at a certain location or are used on mobile platforms. The use of LCS also enables the public without a high degree of technical knowledge and skills to engage in air quality monitoring and reporting activities. Such involvement of the general public is commonly known as citizen science.

The LCS can consist of various types of sensor technologies to continuously monitor different types of pollutants. Generally, electrochemical sensors and metal oxide sensors are used for the measurement of various gaseous air pollutants such as CO, O3, SO2 and NO2. The electrochemical sensors may have temperature and humidity sensitivity along with cross-sensitivities with other gaseous compounds but require low power to operate. On the other hand, metal oxide sensors generally consume higher power due to the need to heat the sensor element from to 200 to 500 °C to increase its sensitivity to the measured gas and the response time. Metal oxide sensors also have low humidity sensitivity but may still show cross-sensitivities with other compounds present in the measurement environment, just like the electrochemical sensors (Clements and Vanderpool, Robert, 2019). For PM concentration measurements, optical sensors using light scattering are commonly used by LCS (Karagulian et al., 2019). In general, the performance characterization and evaluation of the LCS are performed through the "collocation" method, which means the LCS are placed near reference grade monitors and their data are simultaneously collected and later compared (Conner et al., 2018). For their general usability to monitor local air quality, LCS being used needs to show a good level of agreement with the reference grade air monitors with a coefficient of determination (R2) > 0.75 and a slope close to 1.0 (Karagulian et al., 2019).

Besides continuous air monitoring, passive sampling techniques can also be used as low-cost methods to quantify time-weighted average values of different air pollutants such as NOx, SOx, O3, ammonia, formaldehyde, hydrogen cyanide, elemental mercury, benzene, toluene, xylenes, ethylbenzenes, and many other VOCs and semi-volatile organic compounds (SVOCs). Air sampling using such passive samplers uses a sorbent-laden sampling media that is exposed to the air to be analysed for a specified period. Deployment of such samplers can be done for several days to several months at a time. Evacuated canisters and bags can also be used to collect samples of air. The passive samplers or canisters containing collected air samples are then taken to a laboratory and analysed using standardized analysis methods. Passive samplers have been used in numerous past studies since the 1970s and are known to yield results equivalent to other established methods for many VOCs and other pollutants. The advantage of the passive sampling technique is its simplicity and low cost associated with sample collection. However, once the samples have been collected, sample handling must be done with extreme care, conforming to the temperature, humidity and storage time requirements that are unique to each type of sample collected. Also, an infrastructure of analytical laboratories capable of providing standardized analytical services should be available along with a fast enough transportation and courier service so that samples can be properly and accurately analysed within the time frame required by the analytical methods, depending on the compounds being analysed. Although in limited numbers and capabilities, some commercial laboratories are emerging in Nepal that can provide some analytical services for environmental samples, including air samples (Soil Water and Air Testing Laboratory Pvt. Ltd. - SWAT Lab, Bagmati (9851002006), 2022; Ecoconcern, 2022; 'Environmental Laboratory -', 2022).

## 4. Use of UAS for air monitoring in Nepal

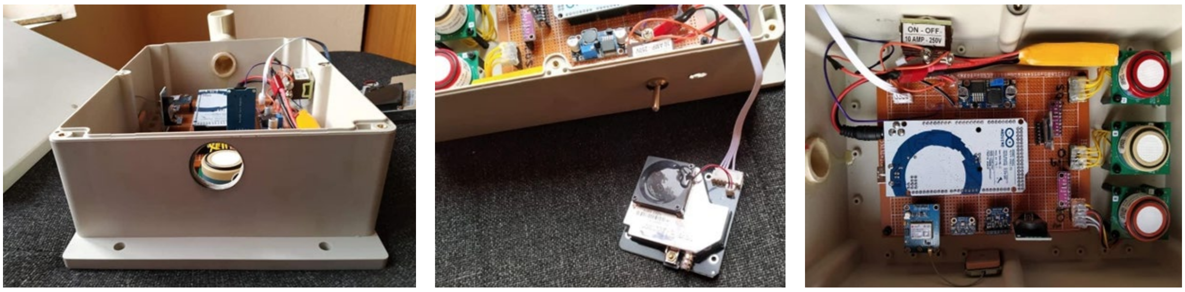
Remotely piloted aircraft, drones, and Unmanned Aerial Vehicles (UAVs) – also referred to as Unmanned Aerial Systems (UAS) are increasingly being considered in the recent decades as aerial platforms for remote sensing payloads and generating hyper-local maps of air pollution dispersion. UAV systems overcome the limitations of cost and complexity associated with manned aircraft and offer greater versatility, flexibility, and can be deployed with minimal planning and scheduling. They can fly at low altitudes, slowly, with the ability to acquire high Spatio-temporal resolution data from often hazardous environments without endangering the safety of people operating the UAV or people on the ground. There are several variants of UAVs that can be utilized for air quality monitoring, such as fixed-wing drones and Vertical Take-Off and Landing (VTOL) drones (these include rotorcraft such as quadcopters, hexacopters, octacopters, and helicopters). Depending on the size, weight and the technology used, the flight time and horizontal travel distance of these platforms can vary greatly, between a few minutes to several hours. Each type of configuration and design (fixed wing/VTOL) has its benefits and limitations.

The fixed wing configuration is easy to construct and can carry remote sensing instrumentation payloads to longer distances with lower energy consumption. However, VTOL configurations with hovering capabilities can position themselves in any desired point in a three-dimensional space, enabling the researchers to collect the desired data from the desired location. Maintaining a scheduled operation system of drones can supplement ground-based air monitoring systems. The hyper-local data gathering capability of the UAVs can not only fulfil the data gaps between the physically distant air monitoring stations on the ground but also provide information on the variation of the concentration of different air pollutants at various altitudes as well as horizontal distances from major roads. The use of drones in Nepal is currently limited to tourism and commercial videography applications. However, the Civil Aviation Authority of Nepal has recently developed regulations for operating UAVs that also apply to the drones being used for scientific research (CAAN - Drone, 2022).

## 5. UAS development project

To bridge the gap between the limitations of current air monitoring capabilities and the opportunities available through low-cost sensor technologies for hyper-local air pollution mapping, a small-scale effort was undertaken as a pilot project to develop a prototype UAS for air monitoring using low-cost sensors. A prototype quadcopter drone was developed at Orion Space Pvt. Ltd. (Sanothimi, Kathmandu).

The first step in the aerial platform development effort was to create a sensor box that could house the low-cost sensors along with the Arduino microcontroller board. This effort was successfully completed in 2019 and preliminary testing data were obtained through the sensors and logged on the onboard SD card integrated with the sensor box. Figure 2 illustrates the fabricated sensor box and Table 3 lists the different sensors along with their purchase prices in US Dollars.



(a) (b) (c)

*Figure 2. (a) The sensor box; (b) The optical particulate matter sensor (c) Top view of the sensor box and circuit layout*

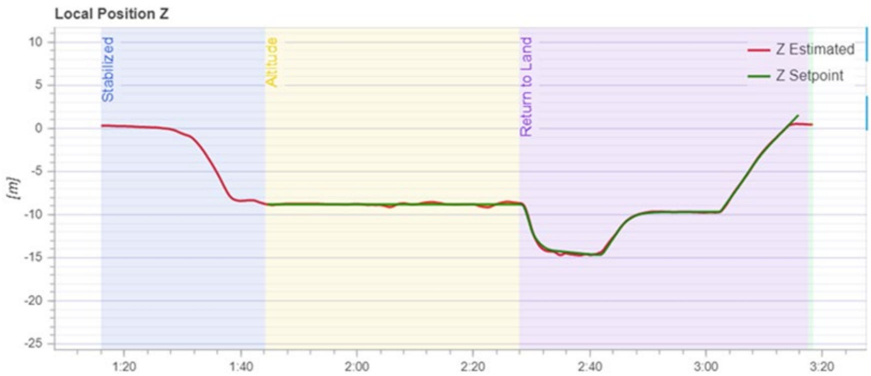
Once the sensor box was built and tested (without calibration), the next step was to identify a suitable aerial platform capable of flying the sensor box. A research group from the Department of Mechanical and Aerospace Engineering at Tribhuvan University, Institute of Engineering, Pulchowk Campus (IoE, Pulchowk) joined the research effort in 2020 with an already underway quadcopter that was locally designed and fabricated in Kathmandu, Nepal. Figure 3 below illustrates the workbench along with the quadcopter drone, the remote control and telemetry data visualization on a laptop computer at IoE, Pulchowk. Variants of locally developed electric quadrotor UAS, made of polymer frames, with a wheelbase of 600 mm and payload capacity of up to 3 kg, will be deployed as the aerial monitoring platform. The UAS is capable of manual as well as autonomous flights. The platform is powered by a single Lithium-Polymer battery, which also supplies power to the air monitoring instrumentation through a battery eliminator circuit.

At the current stage, the data telemetry system integrated with the quadcopter drone is yet to be integrated with the air monitoring sensor box but can report the time series data of the flight path coordinates and sideslip conditions (example shown in Figure 4). The initial integration of the sensor box with the drone resulted in excessive vibration and poor flight control characteristics. Hence, it was decided to miniaturize the sensor box and reduce its weight further. This effort is currently underway at Orion Space Pvt. Ltd.

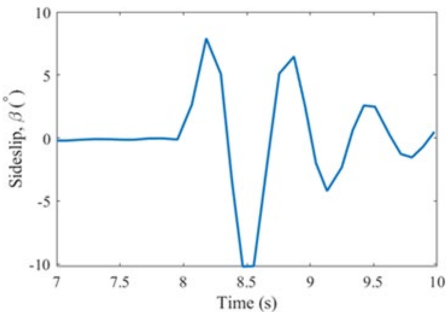
*Table 3: Sensors used in the prototype drone*

| **Model** | **Description** | **Price (USD)** |
|---|---|---|
| NO2-B43F | Nitrogen doxide sensor | 63.00 |
| SO2-B4 | Sulphur dioxide sensor | 63.00 |
| OX-B431 | Ozone sensor | 69.00 |
| *Sensirion* SHT31-D | Temperature & Humidity sensor | 13.95 |
| BMP280 | Pressure sensor | 9.95 |
| 000-0ISB-00 – SO2 | Board for $SO_2$ | 85.00 |
| 000-0ISB-02 – NO2 | Board for $NO_2$ | 92.00 |
| 000-0ISB-02 – O3 | Board for $O_3$ | 92.00 |
| Nova PM sensor SDS011 | $PM_{2.5}$ | 39.00 |
| | ***Total =*** | ***526.90*** |

*Figure 3. The laboratory workbench shows the prototype quadcopter drone, remote controller, telemetry data receiving laptop and associated system parts and accessories*




*(a)*




*(b)*

*Figure 4. Example time series data produced by the aerial quadcopter drone platform showing (a) time series of the setpoint and estimated-through-measurement altitudes of the drone with respect to the take-off point during a test flight; (b) the time series data of the recorded sideslip angle (an aerodynamic state of flight when the drone is moving somewhat sideways as well as forward relative the oncoming airflow – an indicator of inefficient flight conditions).*

## 6. Challenges and future efforts

Sensor calibration is a challenge for the development and deployment of the aerial air monitoring platform in Nepal due to the limited availability of laboratory and reference grade instrumentation facilities. An active effort is underway to identify pathways to calibrate the sensors to ensure reliable and accurate data acquisition and interpretation. Sensor box optimization is also underway, as mentioned earlier, to reduce the size and weight of the instrumentation assembly to enhance the flight time and performance of the aerial platform. An effort is also underway to upgrade the telemetry module for smooth real-time data logging and to provide redundancy to the collected data both on board the aerial platform and on a ground station-based laptop computer. Funding for the continuation of this research and development effort has been a challenge and future avenues of tapping into national and international research grants are being explored. Finally, the scalability of this development effort is a challenge as of now until further funding is ensured and supporting laboratory facilities and resources have been identified.

# 7. References

Air Pollution | CDC (2020). Available at: https://www.cdc.gov/climateandhealth/effects/air_pollution.htm (Accessed: 26 March 2022).

'Air Pollution Health Impacts' (2022) Global Clean Air. Available at: https://www.globalcleanair.org/air-pollution-health-impacts/ (Accessed: 26 March 2022).

Air Quality Monitoring | Nepal (2022). Available at: https://pollution.gov.np/portal/#/home?_k=8pm0mu (Accessed: 26 March 2022).

CAAN - Drone (2022) Civil Aviation Authority of Nepal - Operating UAV (drone) in Nepal. Available at: https://caanepal.gov.np/drone (Accessed: 26 March 2022).

Clements, A.L. and Vanderpool, Robert (2019) 'EPA Tools and Resources Webinar FRMs/FEMs and Sensors: Complementary Approaches for Determining Ambient Air Quality, 18 December. Available at: https://www.epa.gov/sites/default/files/2019-12/documents/frm-fem_and_air_sensors_dec_2019_webinar_slides_508_compliant.pdf.

Conner, T. et al. (2018) 'How to Evaluate Low-Cost Sensors by Collocation with Federal Reference Method Monitors'. Available at: https://www.epa.gov/sites/default/files/2018-01/documents/collocation_instruction_guide.pdf.

DOR: SSRN (2022). Available at: http://ssrn.aviyaan.com/road_network/getNationCategoryAndPavement (Accessed: 26 March 2022).

Ecoconcern (2022). Available at: https://ecoconcern.com.np/enpho_lab (Accessed: 26 March 2022).
'Environmental Laboratory -' (2022). Available at: http://nesspltd.com/company/environmental-laboratory/ (Accessed: 26 March 2022).

Etyemezian, V. et al. (2003) 'Vehicle-based road dust emission measurement: I—methods and calibration', Atmospheric Environment, 37(32), pp. 4559–4571. doi:10.1016/S1352-2310(03)00528-4.

European Standards CSN EN 12341, E. (2014) EN 12341, https://www.en-standard.eu. Available at: https://www.en-standard.eu/csn-en-12341-ambient-air-standard-gravimetric-measurement-method-for-the-determination-of-the-pm10-or-pm2-5-mass-concentration-of-suspended-particulate-matter/ (Accessed: 26 March 2022).

Health impacts of air pollution (2022) Environmental Defense Fund. Available at: https://www.edf.org/health/health-impacts-air-pollution (Accessed: 26 March 2022).

Juginović, A. et al. (2021) 'Health impacts of air pollution exposure from 1990 to 2019 in 43 European countries', Scientific Reports, 11(1), p. 22516. doi:10.1038/s41598-021-01802-5.

Karagulian, F. et al. (2019) 'Review of the Performance of Low-Cost Sensors for Air Quality Monitoring', Atmosphere, 10(9), p. 506. doi:10.3390/atmos10090506.

Lawrence, M.G. and Lelieveld, J. (2010) 'Atmospheric pollutant outflow from southern Asia: a review', Atmospheric Chemistry and Physics, 10(22), pp. 11017–11096. doi:10.5194/acp-10-11017-2010.

Manisalidis, I. et al. (2020) 'Environmental and Health Impacts of Air Pollution: A Review', Frontiers in Public Health, 8. Available at: https://www.frontiersin.org/article/10.3389/fpubh.2020.00014 (Accessed: 26 March 2022).

Neupane, P.R. et al. (2020) 'Estimating Emission Load from Road Transportation within the Bhaktapur Municipality, Nepal', Journal of Environmental and Public Health, 2020, p. e2828643. doi:10.1155/2020/2828643.

Pokharel, R. et al. (2021) 'Spatio-temporal evolution of cities and regional economic development in Nepal: Does transport infrastructure matter?', Journal of Transport Geography, 90(C). Available at: https://ideas.repec.org/a/eee/jotrge/v90y2021ics0966692320309819.html (Accessed: 14 April 2022).

Sadavarte, P. et al. (2019) 'Nepal emission inventory – Part I: Technologies and combustion sources (NEEMI-Tech) for 2001–2016', Atmospheric Chemistry and Physics, 19(20), pp. 12953–12973. doi:10.5194/acp-19-12953-2019.

Soil Water and Air Testing Laboratory Pvt. Ltd. - SWAT Lab, Bagmati (9851002006) (2022). Available at: https://vymaps.com/NP/Soil-Water-And-Air-Testing-Laboratory-Pvt-Ltd-Swat-Lab-280253629150480/ (Accessed: 26 March 2022).

State of Global Air 2020 (2020). Special Report ISSN 2578-6873. Boston, MA: The Health Effects Institute and the Institute for Health Metrics and Evaluation's Global Burden of Disease project, p. 28. Available at: https://www.stateofglobalair.org/resources.

US Embassy, Kathmandu, T.W.A.Q.I. (2022) US Embassy, Kathmandu, Nepal Air Pollution: Real-time Air Quality Index, aqicn.org. Available at: https://aqicn.org/city/nepal/kathmandu/pulchowk (Accessed: 26 March 2022).

US EPA, O. (2014) NAAQS Table. Available at: https://www.epa.gov/criteria-air-pollutants/naaqs-table (Accessed: 26 March 2022).

US EPA, O. (2016) EPA scientists develop and evaluate Federal Reference & Equivalent Methods for measuring key air pollutants. Available at: https://www.epa.gov/air-research/epa-scientists-develop-and-evaluate-federal-reference-equivalent-methods-measuring-key (Accessed: 26 March 2022).

# *Sustainable and Integrated Transport in the Kathmandu Valley*

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## Abstract

In the Kathmandu valley (KV), cities are rapidly growing (25% in 30 years 1978-2011), with more houses, peoples (population 37% will grow by 2050), vehicles (growth @ 13% and 90% more cars, 1/3 of total vehicles in KV) but with limited utilities and services. Open spaces and lands are occupied for building constructions (high rises and private houses). Public transports i.e., buses, mini/micro buses, tempos, all are competing, occupying already congested (by cars) road spaces bringing the city traffic nearly to the halt. Numbers of vehicles plying in the congested roads produced more pollutions, externalities are residents' health is deteriorated (health cost) and travel time increased (delay cost) – the economic cost is very high, and peoples are paying for all these externalities. Annual economic cost of traffic congestion in the Kathmandu Valley was above Rs 116 billion in 2018.Public transport (PT) is not coordinated with multiple uncoordinated operators. Transportation institutional commitment does not match with their objectives and policies. Motorcycles dominate urban mobility. Infrastructure provision for NMT (cycling and pedestrian transports) is not proportionate to its modal trip (42%). Since 1993, public transport studies of KV, are scoped for improvement of urban public transport, data collection, traffic survey, travel demand forecasting and new mass rapid transit (MRT) system in KV. Two studies based MRT systems indicate the feasibility of rail transport. Recently, a new enthusiast has proposed underground and elevated metro rails in the Kathmandu Valley, which is extended up to Banepa city. New rail transport, integrated with other public transports (surface) including sustainable transports (waking/ cycling) along with travel demand management (TDM) techniques & PT routes restructuring, will improve traffic congestion and increase in urban mobility.

*Keywords:* Public Transport, Traffic, Congestion, MRT, Metro Rail, NMT, Pedestrian, Cycling

# 1. Introduction

In the Kathmandu valley (KV), cities are rapidly growing with more houses and population, private vehicles increased exponentially especially motorcycles. Urban mobility has become a rare commodity with increased travel time as valley public transports are not managed properly and coordinated. It has resulted more pollutions, health is deteriorated and travel time increased – the economic cost is very high, and peoples are paying for all these externalities.

Various transport studies have recommended many useful measures to rectify the transport problems. Among them mass transit systems – with underground and elevated metro rail would share fraction of private vehicle trips. However, transport authorities need to develop infrastructure for integrated and sustainable transports - waking and cycling (NMT trips). Only with underground and elevated metro rail system with improved public transports and NMT provision will improve traffic congestion in the Kathmandu Valley.

# 2. State of Traffic and Transport in KV

Nepal is one of the top five fastest urbanizing countries in the world (UN DESA, 2018) and Kathmandu Valley (KV) is among the rapidly urbanizing agglomerations in South Asia.

## 2.1 Growth of KV

Built-up area in the Kathmandu valley has increased from 2.94% in 1967 to 24.7% in 2011 (Figure 2.1). The urban growth caused by many factors among all economic opportunity, conversion of rural space into urban space is an important contributor to urban growth. and public service accessibility are most.

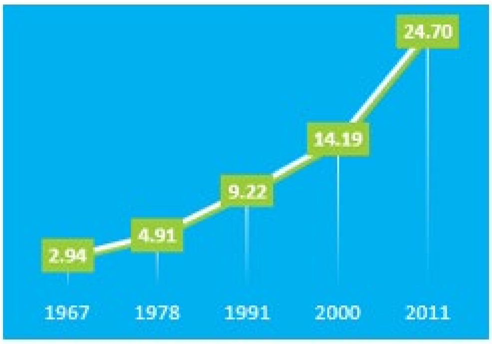



*Figure 2.1 Built up area increased (%) in Kathmandu valley (UTIKV, 2017)*

A spatial modelling process generated the perspective urban landscape for the projection of future growth of KV for the period 2010 to 2050. This analysis suggests that urban development will continue through both in filling in existing urban areas and in the fringe areas (Thapa & Murayama, 2011).

## 2.2 Urban Population Growth

According to UN Population Division, urban population of Nepal will increase from 2.7% (1950) to increase to 37% (2050). A population growth rate of Kathmandu Metropolitan City (KMTC) has recorded over 4 percent since the late 1970s (WB, 2013) and its population for the period 1950-2025 was illustrated in the Figure 2.2.

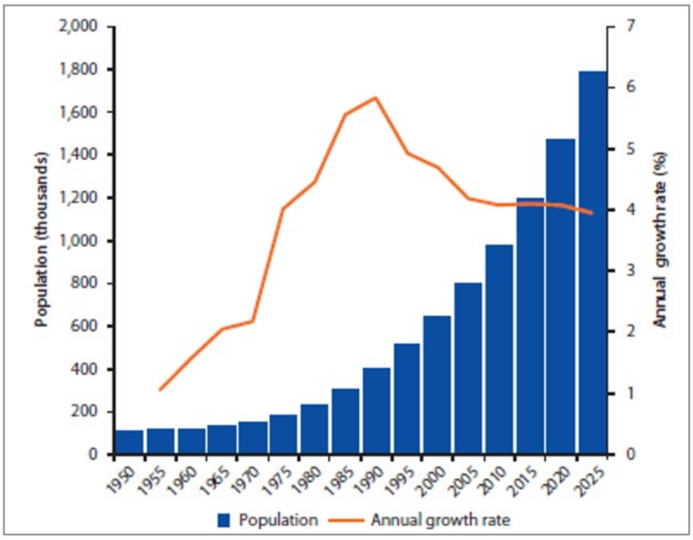



*Figure 2.2 Population and Annual Population Growth Rate of KMC 1950-2025 (UN DESA 2012 & WB 2013)*

Below is the projection of population of three districts in the Kathmandu Valley (KV) and Kavre Palanchok district by CBS in 2014 with the base year 2011 (Table 2.1).

*Table 2.1 Estimated Future Population in GKV Districts (CBS, 2021 & KMRTS 2012)*

| | 2011 | 2021 (preliminary CBS) | 2031 (KMRTS) | 2041 (KMRTS) |
|---|---|---|---|---|
| Kathmandu | 1,744,240 | 2,017,532 | 2,784,194 | 3,647,294 |
| Lalitpur | 468,132 | 548,401 | 729,373 | 1,006,535 |
| Bhaktapur | 304,651 | 430,408 | 606,875 | 934,588 |
| Kavre Palanchok | 381,937 | 366,879 | 487,949 | 673,370 |
| Total (GKV) | 2,900,971 | 3,363,220 | 4,608,392 | 6,261,787 |

Further, in the report of 2018 MRT study report (ADB), it is mentioned that to include the floating population it has agreed to adopt 2031 CBS data plus 30% (assumption made by KV Water Supply and Wastewater System Improvement project, 2011). On this assumption, 2031 population for GKV is extrapolated to 2041.

## 2.3 Road Network in GKV

Road networks in Greater Kathmandu Valley (Table 2.2), consist of Strategic Roads (SRN) and Local Roads including urban roads, are managed by two jurisdictions viz. Department of Roads (DOR) and Ministry of Federal Affairs and Local Development (MoFALD – previously DoLIDAR).

Further, 'Strategic Roads' are classified into highways, ring road, feeder roads, and urban roads, similarly, category of Local Roads includes district roads, urban roads, and other roads.

*Table 2.2 Greater Kathmandu Valley: Road Lengths (LRN, 2016 & SRN, 17/18)*

| Jurisdiction | Network | Kathmandu | Bhaktapur | Lalitpur | Kavre Palanchok | Total (GKV) |
|---|---|---|---|---|---|---|
| | | Districts | | | | Km |
| DOR | Strategic Roads, SRN (2017/18) | 229.99 | 111.59 | 131.39 | 149.12 | 622.09 |
| | Urban Roads | 97.26 | 0 | 0 | 0 | 97.26 |
| DOLIDAR | Local Roads, LRN (2016) | 804.9 | 21.15 | 290.38 | 212.06 | 1328.49 |
| Total | | 1132.15 | 132.74 | 421.77 | 361.18 | 2047.84 |

Functional category of roads corresponds to different design standards, width, lanes, traffic volume and speed. Different categories of roads are illustrated in the GIS map (Figure 2.3).

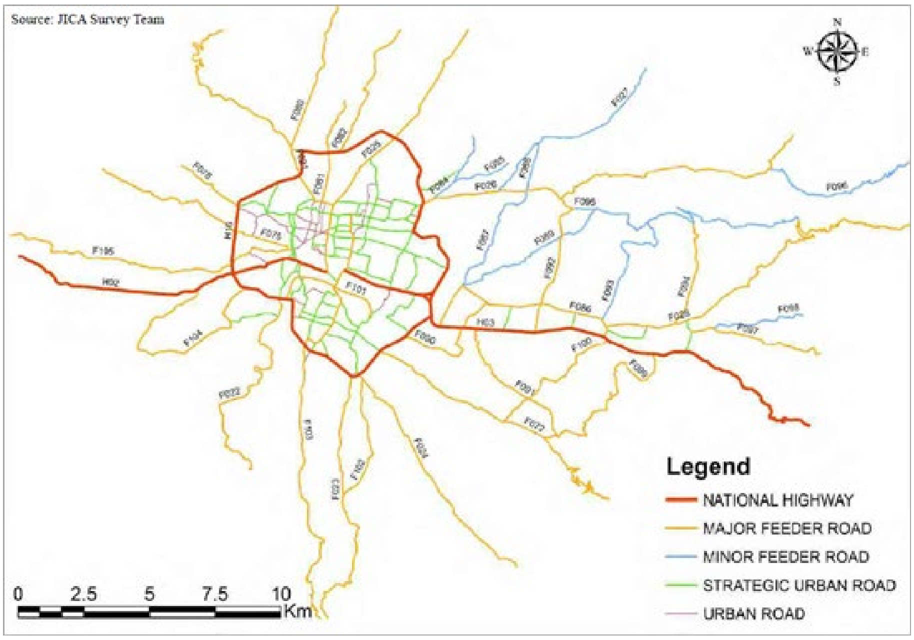



*Figure 2.3 GIS Map of Road Network in KV (JICA, 2012 & DOR)*

## 2.4 Vehicle Growth in GKV

According to Department of Transport Management (DOTM) until 2016/17, 37% of all vehicles in Nepal, registered in Bagmati Zone (Figure 2.4).

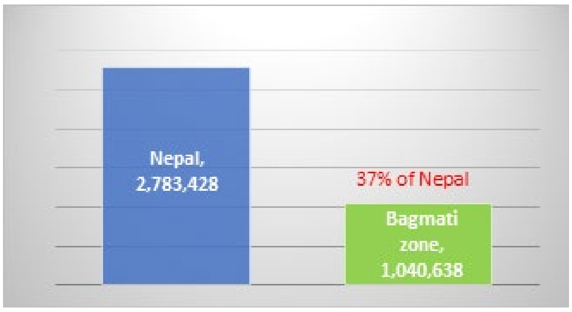



*Figure 2.4 Registered Vehicles in Bagmati Zone & Nepal (DOTM 2016/17)*

Similarly, another data (DOTM, 2018/2019) shows, almost 1.1 million of vehicles are plying in the Kathmandu valley roads. This means there are more than one third of total vehicles (34%) are inside Kathmandu Valley, remaining 66% (2.1 million) in outside the valley (Figure 2.5). The vehicles mostly comprise of motorcycles, cars, buses and smaller Public Transport vehicles (mini/micro buses, three wheelers, Safa Tempo) and others.

Motorization in the Valley has been increasing by 30.41% in fiscal year 2015/16 and 26.64% in fiscal year 2016/17.

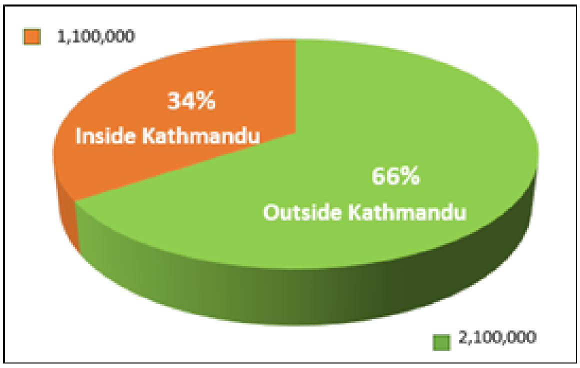



*Figure 2.5 Share of Vehicles Inside & Outside Kathmandu Valley (DOTM, 2018/19)*

## 2.5 Vehicle Fleet Characteristics

2019/20 vehicle data (Figure 2.6) shows out of 3.82 million vehicles, 3 million are motorcycles, which are huge numbers (79 %), their numbers have increased year by year. Numbers of public transports including buses, mini/micro buses & tempos are less than 192,784 (5.04%), which are less than numbers of car/jeep/van and pick up together were 341,669 (8.94%). It should be noted that if taxis are counted in the category of 'Car' then its number should be discounted from the car numbers and should be added to category 'Public Transport'.

In absence of proper public transports, for urban and rural middle/low-income population, motorcycles are only mode and reliable transport vehicle to reach the short destinations in less cost and time, hence, its growth is a lot higher than other vehicles.

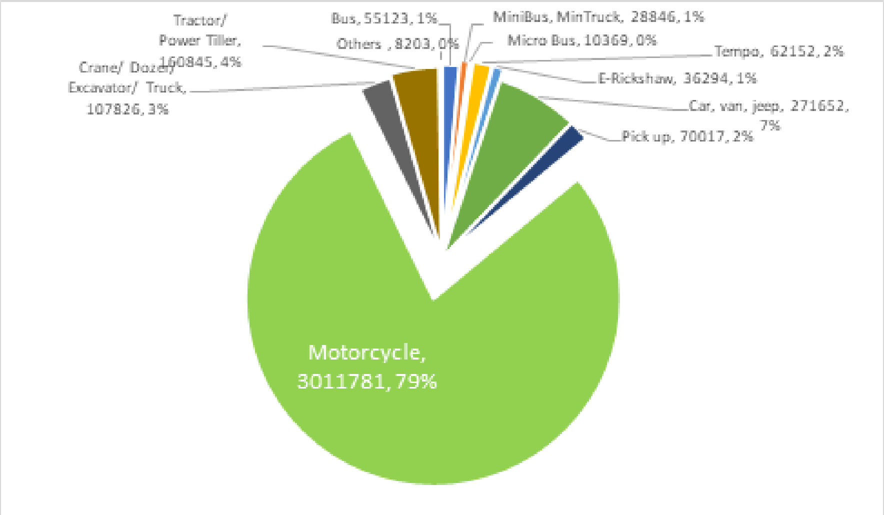



*Figure 2.6 Share of vehicles (%) registered in Nepal until 2016/17*

In 2014, a survey was conducted to count vehicle for 12 hours for estimating vehicular emission in the Kathmandu Valley, which shows private vehicles - 85% (motorcycle – 77.5%), PT vehicles - 12.5% (taxi – 8%) and other utility vehicles - 2.5 %. Increased in number of motorcycles (77.5%) indicates there is dire need of modal shift from private to public transport facility in the valley.

## 2.6 Modal Trip Share in KV

According to trip distribution (2011) by various travel modes (Figure 2.7), category 'Walking' is highest share – 40.7% followed by Bus & Motorcycles (27.6% & 26%), whereas category 'Car' & 'Bicycle' are bare minimum (4.2%, 1.5%). 'Bus' category include trips by Tempo, Microbus, Minibus, Medium-bus and Large-bus and 'Car' category includes car, Taxi and Truck.

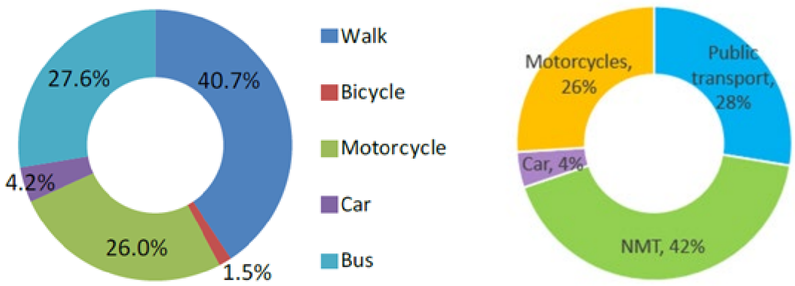



*Figure 2.7 Modal Trip distribution in KV (2011)*

## 3. Public Transport (PT) in KV

There are more than 200 existing public transport routes on road network in the Kathmandu Valley. Majority of urban public transport services (Figure 3.1) include a mix of 26-56 seat buses, 15-25-seat minibuses, 6-14 seat microbuses and 11-seat three-wheel tempos.


*Figure 3.1 Public Transport vehicles and seat capacity (JICA 2012)*

Department of Transport Management (DOTM) is responsible for issuing route permits, route planning, and route ownership. Transport operators' associations have very strong hold on route permits to some companies. DOTM has planned for a GPS based Vehicle Tracking System for PT Vehicles, similar to London's buses automatic vehicle location system – iBus, for real time information on PT, mobile apps to provide on routes, schedules, fares, real time update of all PTs.

Few private bus companies such as Sajha yatayat, Mahanagar Yatayat, and Metro Yatayat Bus, have introduced with big size buses in the Valley roads. Any size of buses including smaller vehicles ply in the wider roads and duplication of routes by mix of all PT vehicles along with cars and motorcycles, are causing traffic congestion in the valley (KSUTP 2018).

Intermediate Public Transport (IPT), sometimes it is called informal transport, sector comprises mostly small PT vehicle, low-performance services (micro-bus, tempo) that are privately operated (Bhattarai & Shahi 2021). These vehicles serve individuals making non-work/work trips mostly for feeder services and individual destinations. Many of small PT vehicles have no access on route licences. Hence, routes are not properly regulated and managed - run informally. There are web-based transports: ridesharing and taxi services available in the KV. They include Motorcycle Taxis & Car Companies (Tootle and Pathao). It is not clear whether they are regulated under DOTM.

There is no clear plan and programme for coordination with Public Transport (PT) owners, route structuring, providing PT infrastructures (bus layby/stops, bud lanes).

There is a need of improvement of bus based public transport in Kathmandu valley.

## 3.1 Non-motorised Transport in KV

Modal trips are schematically compared with the infrastructure provision for various travel modes (Figure 3.2 a). It clearly indicates NMT (walking and cycling) trips are significantly high (42%) compared to other travel modes, but it has been ignored in the planning and provision of infrastructure such as footways and cycleways (Figure 3.2 b).

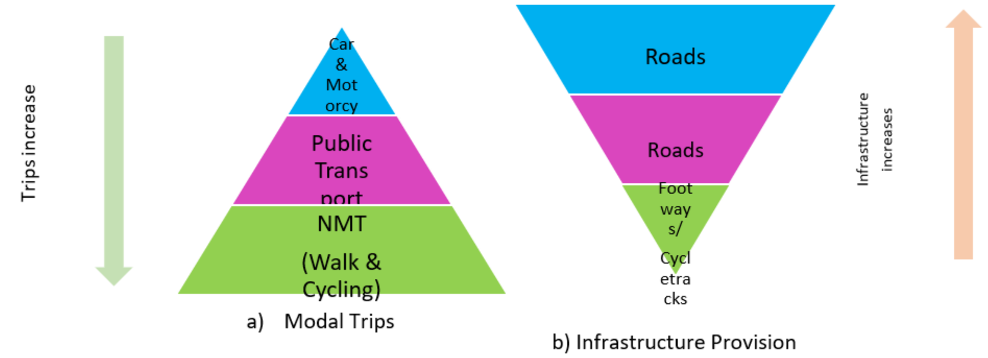



*Figure 3.2 a) Modal Trips & b) Infrastructure in KV (JICA 2012)*

Pedestrians are forced to walk on narrow and poorly maintained footways and even on roads. For most low-income commuters, walking and cycling are the only affordable mode of transport, but there is no NMT focused urban transport planning. Lalitpur Metropolitan City has initiated a cycle lane. There are few components of pedestrianisation schemes (e.g. heritage walking) that have been implemented in Kathmandu under ADB supported transport projects.

### 3.2 Electric mobility in KV

In 1973, 1st electric vehicles – Trolley buses were run from Bhaktapur to Kathmandu, but it is abandoned in 2009 (Figure 3.4 a). Electrically powered 3-wheeler e-Tuk-Tuk/e-rickshaw (Safa Tempo) is a successful example of public EV in Kathmandu since 1996 (Figure 3.4 b). In fact, the technology of electric version of the three-wheeler was bought by the Nepal Electric Vehicles Industries (NEVI), whose founder, Bijay Man Sherchan, is a mechanical engineer who had previously established Nepal's first car assembly workshop.


*Figure 3.4 a) Electric Trolley Bus, b) Safa Tempo*

A target of 20% reduction in transport sector emissions with a vision of sustainable and environment-friendly transport system has been set in 15th Five-Year Plan (2019-24), National Climate Change Policy (2019) and Government's transport mitigation policy (2019). Global Green Growth Institute (GGGI, 2018) with MOFE/MoPIT has launched the 'Electric Mobility Program' to support sustainable transportation, which will contribute to reduce fossil fuel consumption (50% by 2050) and reduce emissions in the transport sector (WB 2017, NOC 2016). Under the GGGI component, the government will procure 300 more Electric Buses for Sajha Yatayat. 39% cheaper to run Electric buses than Diesel Buses (GGGI 2018).

## 4. Traffic and Transport Studies

Since 1993 JICA has been substantially involved in the studies of urban transport of Kathmandu Valley e.g.: junction surveys, traffic counting, data collection, urban transportation systems – mass rapid transport/transit (MRT) and many others. All these study reports and data are essential references for any public transport issues of the Kathmandu Valley.

The following studies are carried out by different agencies:
- JICA 1993: A Study on Kathmandu Valley Urban Road Development.
- JICA 2000: Kathmandu Junctions survey.
- JICA 2012: Data Collection Survey on Traffic Improvement in Kathmandu Valley.
- KMRTC 2012: Feasibility Study of Mass Rapid Transit (Underground and Elevated Railway) System in Kathmandu Valley.
- WB 2013: National Transport Management Strategy 2070, Draft Version.
- JICA 2014: The Project on Urban Transport Improvement for Kathmandu Valley.

- ADB 2014: Public Transport Restructuring, Kathmandu Sustainable Urban Transport Project.
- JICA 2017: The Project on Urban Transport Improvement for Kathmandu Valley.
- ADB 2018: Mass Transit Options and Prioritisation Study (KSUTP).
- JICA 2019: Data Collection Survey on Urban Transport in Kathmandu.

## 5. Mass Transit in Policy Documents

In Nepal, mass transit or metro rails are usual subject, when one talks on Transport issues. Below are some policy documents (Pokharel, R. and Acharya, S.R. 2015) in Table 5, where needs of mass transportation systems are addressed.

*Table 5: Mass Transit in Policy Documents (Source: Varius sources)*

| Documents | Main issues of transport |
|---|---|
| Kathmandu Valley Master Plan (2015-2035) | ❖ Inclusive & accessible Public Transport<br>❖ Mass rapid transit (MRT), bus rapid transit (BRT), automated guided transit (AGT)<br>❖ Walking and cycling network<br>❖ Operate (under BOOT model) transportation system |
| National Urban Development Policy (2017) | ❖ Promote sustainable Public Transport<br>❖ Prepare transportation management plan |
| Strategic Plan for Transport Infrastructures (2073 - 2078) | ५. काठमाडौं उपत्यका भित्रको पूर्व-पश्चिम तथा उत्तर-दक्षिण लामा रुटहरू फर्पिङ-बूढानिलकण्ठ, थानकोट- धुलिखेल तथा चक्रपथ जस्ता संभाव्य रुटहरूमा मेट्रो रेल संचालनका लागि १ वर्षमा विस्तृत अध्ययन सम्पन्न गरी निर्माण कार्य आरम्भ गरिनेछ। |
| National Environmentally Sustainable Transport Strategy (2014) | ❖ Provision of mass transit in Kathmandu (high-capacity bus, LRT)<br>❖ Invest for pedestrian and NMT infrastructure in Kathmandu and other cities |
| 13th Plan Policy paper | ❖ Private investment will attract through PPP to construct Metro rail in KV |
| The Fifteenth Plan (Fiscal Year 2019/20 – 2023/24)<br>` | ❖ Kathmandu Metrorail Project: 77km metro rail by F/Y 2030/31<br>❖ Estimated Cost: Rs 470 bln<br>❖ As a National Pride Project to develop electric Railways as secure, reliable, fast and environment-friendly public transport in an urban area. |

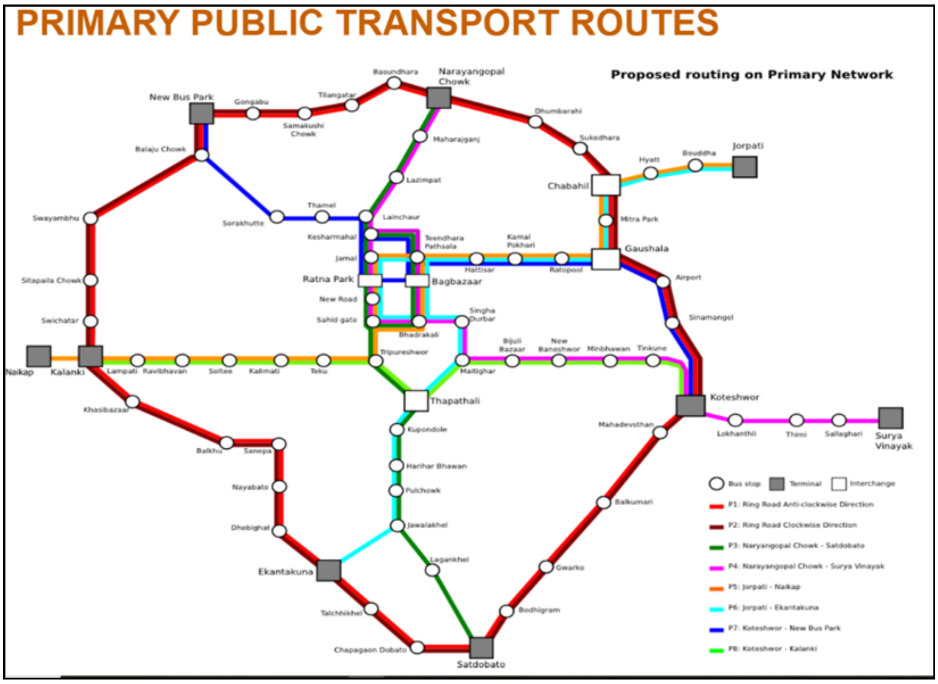
Electric mass transit system targets on dual objectives: reduce use of fossil fuel and modal shift from motorcycle and cars, it should be noted that number of motorcycles are increasing exponentially. Working policies of transport system emphasize on mass transit and promotion of electric mobility along with mass transit and address need of NMT (cycling and footway) infrastructure.

## 6. Restructuring Public Transport Routes (KSUTP, 2018)

There are several problems in existing public transport system (KSUTP, 2018). Following are main issues of PT in KV: duplication of routes, with multiple uncoordinated operators, large numbers of low-capacity vehicles operating on high volume routes causing traffic congestion and environmental degradation, congestion in the city centre from the multitude of PT terminals/ stops and loading areas, poor quality of service to users, inadequate passenger facilities, weak regulation and poorly maintained vehicles. A separate division as 'Public Transport' is proposed for public transport inside DOTM's organisation according to KSUTP.

Public transportation improvement is one of the four components of the KSUTP, which is supported by the ADB. The project has proposed three-tier hierarchy of public transport routes based on the demand and width of the road infrastructures (KSUTP, 2018). The project has proposed 8 primary routes, 16 secondary routes and 40 tertiary routes plus 2 in historic areas (Figure 6). It has envisaged to operate higher capacity buses with 12 meter or 18 meter, 9-10 meter buses in secondary routes providing feeder service to primary routes and low occupancy vehicles such as tempos, microbus and minibus in tertiary routes.

Part of two routes were tested under pilot scheme of operation: pilot route New Bus Park via Samakhusi and the CBD to Sinamangal. The projected traffic for with project situation is estimated by replacing 388 trips of microbuses and 682 trips of Safa tempos by 160 trips of buses (ADB, 2020).




**Primary Routes (8nos./131km)**
- ✓ High demand corridors 100k pass/day
- ✓ High-capacity buses – 12m or articulated
- ✓ Major roads, Priority for PT vehicles
- ✓ Provision for walking & cycling

**Secondary Routes (16nos./178km)**
- ✓ Medium demand 50k- 100k pass/day
- ✓ Medium capacity buses – 9-10m
- ✓ Urban roads, No priority – mixed traffic
- ✓ Provision for walking & cycling

**Tertiary Routes (40nos./246km)**
- ✓ Low volume
- ✓ Small vehicles, Tempo, Micro & minibuses
- ✓ Narrow urban roads

*Figure 6: Introducing 3 tier route hierarchy of Public Transport (KSUTP, 2018)*

This PT routes restructuring is a part of travel demand management (TDM) for a PT based transportation system.

## 7. Travel demand analysis

Travel demand forecasting and future ridership volume has been estimated based on System for Traffic Demand analysis (STRADA)'s four-stage travel demand model for two new transport study projects 'Feasibility Study of Mass Rapid Transit (Underground and Elevated Railway) System in Kathmandu Valley' (KMRTC, 2012) and 'Mass Transit Options and Prioritisation Study' (KSUTP/ADB, 2018). A trip-based travel demand forecast has been modelled in the Window based STRADA package. Below 'Table 7' outlines input parameters and stage outputs involved in the four-stage modelling framework.

*Table 7: Four Step Trip-based travel demand model (STRADA & JICA 2012)*

| Input | Four Steps Method | Output |
|---|---|---|
| Socio-economic framework<br>Trip survey<br>Traffic survey<br>Population growth | Trip Generation | Number of trips (generated by and attracted to each zone) |
| Traffic Analysis Zone<br>Traffic count, modal trips<br>Gradient technique<br>Road network/GIS map | Trip Distribution | OD Matrix (estimate the number of trips travelling between zones) |
| Vehicle classification<br>Vehicle ownership<br>Public transport | Modal Split | OD Matrix by modes (estimate the number of trips made using different transport modes) |
| Future Network Volume<br>GIS transport analysis network<br>Analysis Assumption<br>Population forecast<br>Forecasting MRT Ridership | Traffic Assignment | PT/MRT Ridership (estimates the number of trips on the road or MRT by different transport modes) |

In transport modelling framework (KSUTP, 2018), it included JICA transport model master plan (2017) with extended land zone plan, restructured PT routes (feeder), forecast of future road, rail and new satellite towns, and population forecasts (2040) including "floating population".

## 8. Congestion and its economic Cost

The result of traffic jam is frustration, time lost to traffic, and more air pollution and greenhouse gases. Numbers of vehicles plying in the congested roads produced more pollutions, externalities are residents' health is deteriorated (health cost) and travel time increased (delay cost) – the economic cost is very high, and peoples are paying for all these externalities.

*Table 8: One day time delay in minutes (Chand, 2018)*

| S.No. | Particulars | Time delay (minutes) |
|---|---|---|
| 1 | Walking | 7 |
| 2 | Motorbikes | 21 |
| 3 | Cars/Taxi | 27 |
| 4 | Taxi | 28 |
| 5 | Bus/minibus/microbus | 33 |

Annual economic cost of traffic congestion in the Kathmandu Valley was above Rs 116 billion in 2018 (Table 8) according to a survey carried for the research (Chand, 2020). A study suggests traffic congestion increase the amount of carbon emission by 28% in KV.

# 9. Timing of Metro Development

Below are urban transport policy recommendations for the development of transport infrastructure (Figure 9.1 a &b) for the country's development stage and city population size. For the Kathmandu valley population size is medium and Nepal is categorised as least developed country (Figure 9.1 b) although now it is candidate for developing country. Three of four transport policy recommendations assuming Nepal lies in least developed and developing countries (Figure 9.1 a).

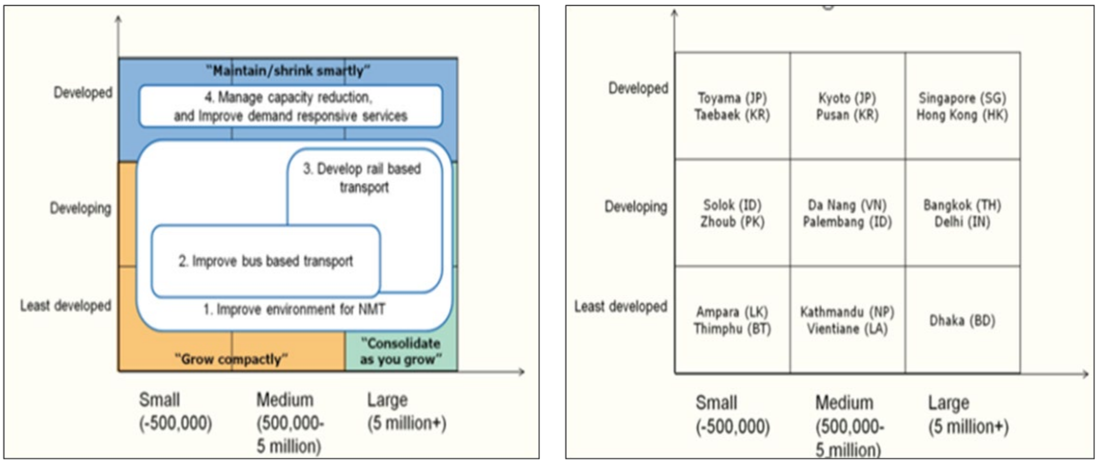



*Figure 9.1 a) Four Priorities for Asia & Pacific (UN ESCAP), b) Countries & City size*

Year of metro opening for Kathmandu is BS 2030, which has been established for various Asian cities according to GDP per capita and urban population (Table 9). Currently experts and planners are in discussion with the need of MRT or metro rail in the KV.

*Table 9 Timing of Metro Development in Other Asian Countries (JICA 2012)*

| Cities | Metro Opening Year | GDP per capita (US $, constant 2010) | Urban Population |
|---|---|---|---|
| Manila | 1999 | 1573 | 9,846,621 |
| Delhi | 2002 | 802 | 16,891,671 |
| Bangkok | 2004 | 4190 | 7,096,699 |
| Mumbai | 2014 | 1645 | 18,104,072 |
| Chennai | 2015 | 1759 | 9,667,072 |
| Dhaka | 2021 | Estimated 1220 | Estimated 21,375,261 |
| ***Kathmandu*** | ***2030*** | ***Estimated 1380*** | ***Estimated 4,924,467*** |

The development of a metro system for the Kathmandu valley, takes long time to complete the project cycle of planning, design, and construction before to reach the stage of operating a metro system in the future, the lead time requires starting initial preparations now (JICA, 2011).

# 10. Studies on Mass Rapid Transit (MRT) System in Kathmandu Valley

Many studies are carried out on mass rapid transit options for the Kathmandu Valley. Among them are two Mass Rapid Transit (MRT) study in KV, which have been discussed in this Chapter:

- KMRTC 2012: Feasibility Study of Mass Rapid Transit (Underground and Elevated Railway) System in Kathmandu Valley
- ADB 2018: Mass Transit Options and Prioritisation Study (KSUTP)

Other options of MRT studies in Kathmandu Valley are:

- FASEP Systra: Feasibility Study for a Cable Car Transport in Kathmandu Nepal.
- Investment Board Nepal (IBN): Metro from Dhulikhel – Nagdhunga (East-West)
- IBN/ Scomi Group, Malaysia: Monorail on Existing Ring Road (Circular)
- KMC/ China Railway CC: Monorail on Existing Ring Road (Circular)
- KMC/CIMEX: Sky Rail/AGT from Naya Naikap to Bhaktapur (East-West) with links from Tinkune to TIA airport & Tilganga Eye hospital.

## 10.1 KMRTC MRT Feasibility Study (2012)

First feasibility study of Mass Rapid Transit (underground and elevated railway or metro railway) System in the Kathmandu Valley was carried out by Kathmandu Mass Rapid Transit Consortium (KMRTC) project (JICA, 2012) with the option of underground and elevated railway systems.

KMRTC proposes 5 Lines of MRT route with 57 stations and 5 depots (Figure 10.1). It is believed construction of MRT will decrease in road traffic volume. It is found that high volume of traffic in North-South & East West corridors. MRT ridership was forecasted with the two scenarios of construction of all 5 lines in one go and 2 lines (phased) with MRT charge at NRs 20 and 30 per person per km.

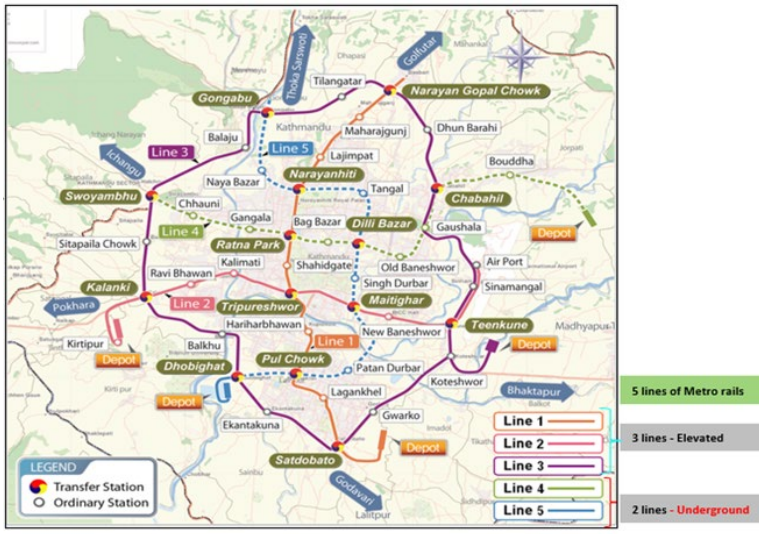



*Figure 10.1 Mass Rapid Transit System (Underground and Elevated Railway) In Kathmandu Valley (KMRTC, 2012)*

## 10.1 KMRTC MRT Feasibility Study (2012)

Another study of Mass Rapid Transit System in the Kathmandu Valley was carried under Kathmandu Sustainable Urban Transport (KSUTP) project (ADB, 2018), with proposed 5 lines of underground and elevated railway systems (Table 10.1 and Figure 10.2 b).

*Table 10.1 Future Mass Transport Network for KV (2018 KSUTP)*

| Lines | Mass Transit Routes (2018 KSUTP) | Length (Km) |
|---|---|---|
| 1 | Budanilkantha to Godawari | 19.60 |
| 2 | Bhaktapur to Naya Naikap | 20.30 |
| 3 | Jorpati to Gongabu | 9.10 |
| 4 | Ring Road | 27.40 |
| 5 | Tokha – Chobhar | 15.20 |

Combination of metro rail and AGT (Automated Guide Transit) are proposed at grade or elevated with high demand (3 lines in Red) MRT lines (Figure 10.2 a & b) in Phase I (BS 2030) and medium demand (2 lines in Blue) MRT lines (Figure 10.2 b) in Phase II (BS 2040).

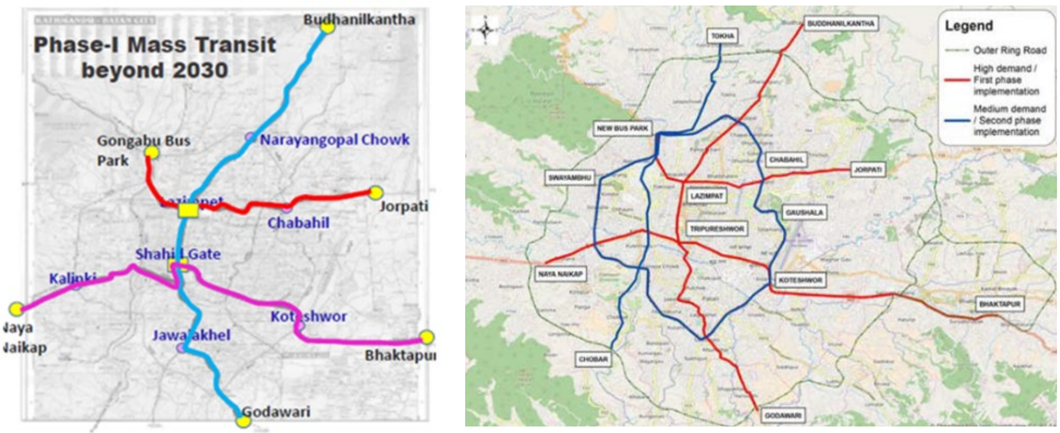



*Figure 10.2 a) MRT lines and b) Prioritisation (high/medium demand) (KSUTP, 2018)*

## 10.3 MRT Ridership (KSUTP, 2018)

MRT ridership was forecasted with the 6 options of MRT corridors out of 5 lines with MRT charge at NRs 6.4 per person per km. Passenger peak hour peak duration (PPHPD) for all 5 lines is given in Table 10.2.

*Table 10.2 Traffic Forecasts on Mass Transit Routes (2018 KSUTP)*

| Lines | Mass Transit Routes (2018 KSUTP) | Passenger peak hour peak duration (PPHPD) |
|---|---|---|
| 1 | Budanilkantha to Godawari (19.6km) | >25000 |
| 2 | Bhaktapur to Naya Naikap (20.3km) | >30000 |
| 3 | Jorpati to Gongabu (9.1km) | >20000 |
| 4 | Ring Road (27.4km) | 15000 - 20000 |
| 5 | Tokha – Chobhar (15.2km) | 10000 - 20000 |

MRT ridership for north south and east west line has been given in Table 10.3 for comparison.

*Table 10.3 MRT Ridership (KSUTP,2018)*

| Line | 2020 | 2024 | 2026 | 2030 |
|---|---|---|---|---|
| 1 North-South (19.60 Km) | 743,918 | 775,254 | 806,589 | 848,370 |
| 2 (East-West) (20.30 Km) | 1,400,388 | 1,564,133 | 1,727,879 | 1,946,206 |

Multi-criteria evaluation (MCE) has been used for 6 options of corridors out of 5 lines. MCE includes the following parameters: use of existing capabilities, cost effectiveness, mitigate adverse impact on people, efficiency of service, mitigate adverse impact on city and safety.

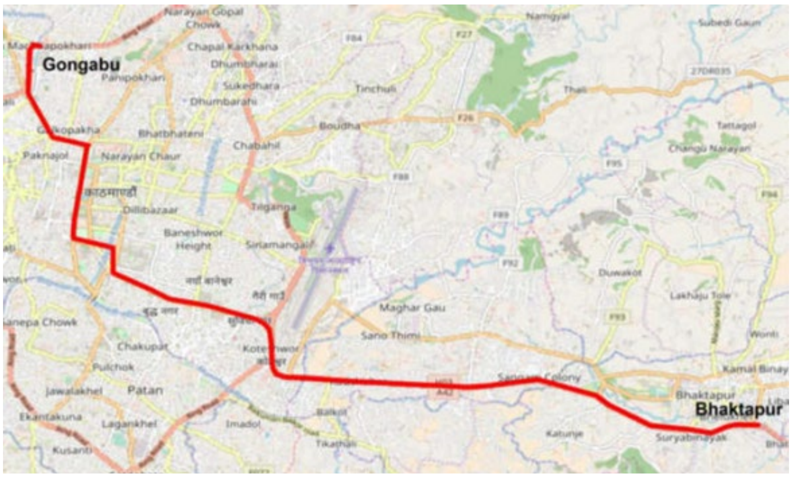



*Figure 10.3 Highest Ridership on East West Corridor Option # 1 (KSUTP, 2018)*

Modelling results for evaluation of 6 MRT corridor options include system ridership levels, mass transit modal share, road congestion levels, vehicle-km by transport mode, average journey speed, total passenger–km and total generalized transportation cost. MRT daily ridership for East West line - corridor option # 1 (Figure 10.3) is higher than other 5 corridor options (Table 10.4).

*Table 10.4 MCE Output of Corridor option (KSUTP, 2018)*

| Multi Criteria Evaluation (MCE) options | Veh-km per day (2040) | Total Transport generalised cost per trip (2040) | Total MRT Network Daily Ridership (2040) | Modal share (%) - 2040 | % Reduction in GHG Emissions from Do Nothing |
|---|---|---|---|---|---|
| Do Nothing | 18,489,772 | NRs 123.90 | 0.00 | 0.00% | - |
| Option 1 (corridor) | 12,486,212 | NRs 82.70 | 8,239,349.00 | 28.40% | 13.80% |

## 11. GKV Metro Rail

Greater Kathmandu Valley (GKV) Metro Rail Promotion Group has been working on MRT transport for the extended Kathmandu Valley up to Banepa / Dhulikhel of Kavre district. Conceptual plan of GKV metro rails (Figure 11.1) has been created by Dr. Binod Lal Amatya.

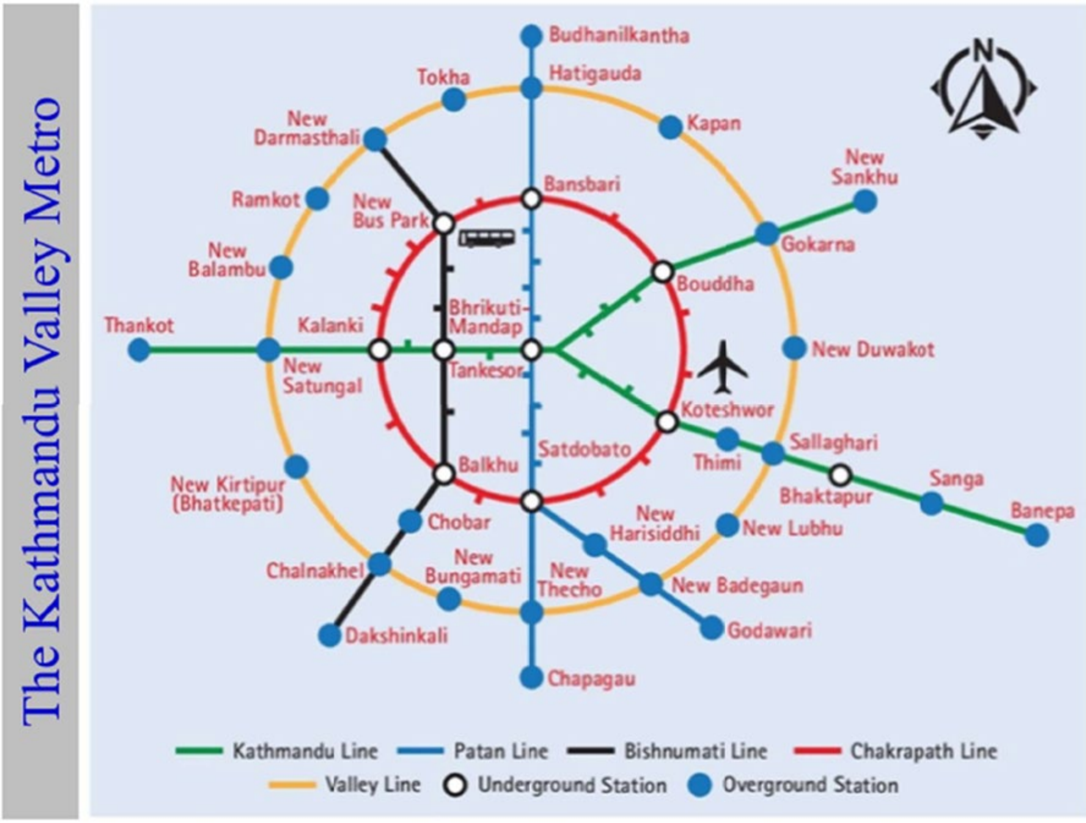



*Figure 11.1 Schematic plan of Greater Kathmandu Valley Metro Rail (Amatya et al., 2020)*

GKV Metro rail has proposed of 5 main lines (+ 2 branches) and 103 numbers of stations with the route length of 192.5km, of which 85km underground and 107.5km elevated (Table 11.1). Metro alignment will be scrutinised with the consideration of sensitive areas with heritage and other landmark buildings.

In 2020 (2019), GKV Metro Rail Promotion Group with Warwick University, UK and Muti disciplinary Consultants, Nepal, has carried out a geotechnical investigation of Patan Line (Blue), which suggests feasibility of metro rail tunnelling in the Central Business District (CBD) area inside the Chakrapath.

*Table 11.1 Kathmandu Valley Metro Rail (Amatya et al., 2020)*

| S No. | Route Name | Route Location | Length (km) | Underground UG (km) | Elevated OG (km) | Stations UG, OG |
|---|---|---|---|---|---|---|
| 1a (Blue) | Patan Line (NS Cross Rail) | Godawari-Satdobato-Bhrikuti Mandap- Budhanilkantha | 26 | 14.5 | 11.5 | 11, 9 |
| 1b (Green) | Patan Line (Branch) | Chapagaun-Satdobato | 8 | 2 | 6 | 0, 4 |
| 2a (Green) | Kathmandu Line (EW Cross Rail) | Thankot - Kalanki- Bhrikuti Mandap -Koteshwar-Bhaktapur - Banepa | 36.5 | 15.0 | 21.5 | 9, 12 |
| 2b (Green) | Kathmandu Line (Branch) | Bhrikuti Mandap -Bouddha-Gokarna-Sankhu | 17.5 | 7.5 | 10 | 4, 6 |
| 3 (Yellow) | Valley Line - Orbital Rail (Outer) | Naya Satungal -Dharmshala Kapan-Gokarna-Sallaghari-New Bhadgaon-Bungamati-Kirtipur | 53.5 | 5.5 | 48.0 | 0, 16 |
| 4 (Red) | Chakra path Line, Orbital Rail (Inner) | Kalanki-New Bus Park-Bansbari -Koteshwar-Satdobato-Balkhu | 30.5 | 30.5 | - | 18, 0 |
| 5 (Black) | Bishnumati Line | Dakshinkali-Chobar-Tankesor-New Bus Park-Dharmsthali | 20.5 | 10 | 10.5 | 6, 8 |
| | Total | Five (5) Metro Lines + Two (2) Branches | 192.5 km | 85 km | 107.5 km | 48 UG 55 OG (Total 103) |

GKV Metro Rail Promotion Group claims that GKV metro rail will absorb 25% of total trips as per their high-level estimate. Scenario of without and with GKV metro rail has been illustrated in Figure 11.2 (Shrestha, et al., 2021). GKV metro rail will attract 10% and 1 % trips of private vehicles: motorcycles and cars.

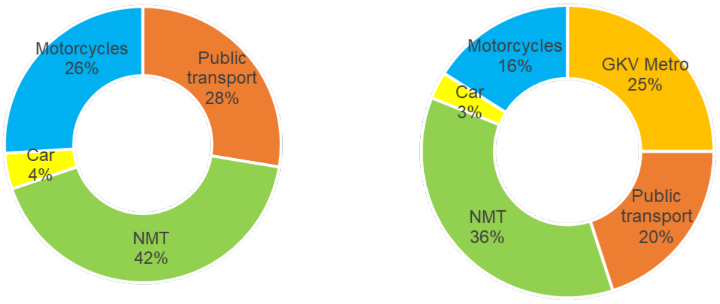



*Figure 11.2 Modal Trip distribution a) without and b) with GKV Metro Rail*

# 12. Integrated and Sustainable Transport

## 12.1 Integrated Transport

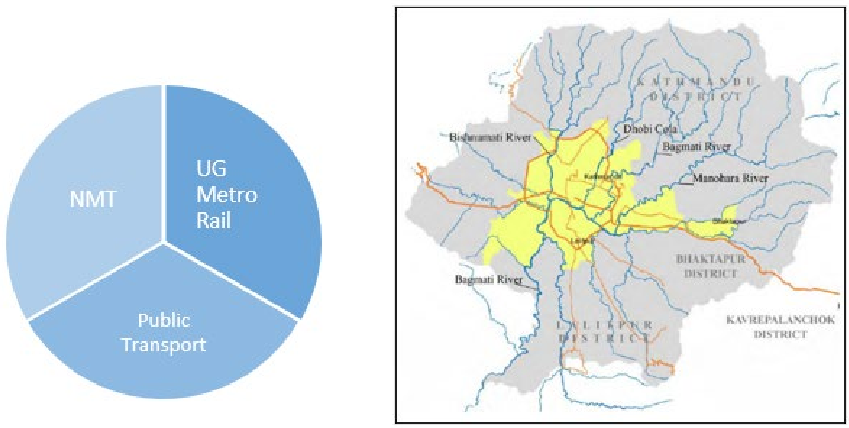
Integrated transport involves the combining of different modes of transport. A successful integrated transport system should result in higher demand for public transport, with a knock-on reduction in congestion and pollution (https://www.designingbuildings.co.uk). In the Kathmandu Valley, all modes of transport are partially integrated, no coordination with each other in terms of timetables, ticketing and other factors. Most importantly modal shift infrastructure are not planned and even neglected. Provision of infrastructure ie. bays/stops for buses, tempos, taxis, car/motorcycles parking bicycles stands; passenger waiting areas and safer pedestrian crossings is very essential for transport integration. Investment in traffic technology required for control and safety is virtually nil in the KV transport system.

## 12.2 Sustainable Transport

A sustainable urban transportation system can be achieved through land use planning, opportunities for walking and cycling (NMT) transport by reducing adverse impact on the environment with balanced integrated transport system (UN ESCAP, 2012). Sustainable transport in GKV involves existing PT based transport with few provisions for non-motorised transports (NMT), which should be improved to reduce traffic congestion.

All three components of GKV transports ie walking and cycling (NMT), buses, tempos, taxis (PT) and underground metro rail could be integrated to reduce dependencies on private vehicles - cars and motorcycles (Figure 12.1 a).

To achieve this, cities should start diverting from designing car-oriented cities to pedestrian and bicycle friendly non-motorized transportation system (UN ESCAP, 2012). It is possible to build dedicated walkways and cycleways along the banks of rivers/streams in KV. Also, more river crossing bridges for NMT should be built to develop NMT network (Figure 12.1 b). It is noted that roads are already built along the banks of some rivers in KV.




a) b)

*Figure 12.1 a) Sustainable Transport Components and b) Walkway along Rivers in KV (JICA)*

# 13. Conclusion

Transportation issues are addressed in many of policy documents, but plans and programmes don't match with the vision, often overlapped between multiple agencies. Multiple PT studies have been shelved without the use of their recommendations. At present, there are a couple of piecemeal approaches for green transport (e.g. electric mobility), which have been implemented for the improvement of PT issues in KV. Traffic congestion and air pollution have a negative impact on GDP as it imposes a significant cost in terms of both health and productivity (UN ESCAP, 2012). Authorities aware for the consequence but it is very slow to act.

Five major areas are identified for the improvement of transportation system in the Kathmandu Valley, the following measures are suggested.

1) Institutional reform:

- Establishment of Kathmandu Valley Public Transport Authority (MoPIT)
- Creation of PT Division in DOTM (KSUTP/ADB)

2) Improvement in PT management

- PT route re-structuring (wider road for larger buses) - KSUTP
- London & Seoul experiences on PT management reform (Harnis & Mizokami, 2011) to be introduced in PT management:
  - Partnership between authority & operator
  - Separation of planning & operation
  - Planning done by authority & operation undertaken by operator
- Creation of Transport database and PT studies to be reviewed
- Transport policy to emphasize on mass rapid transit (MRT) - Metro Rail policy
- Traffic Management with ICT solutions

3) TDM (Travel demand management) measures:

- Promotion of electric mobility
- Reserved lane for public transports
- Junction improvement considering pedestrian and cycling
- More crossing on the Bagmati River and other rivers
- More new bypass roads and river corridor roads
- Provision of intermodal facilities
- Coordination and optimisation of timetables
- Fair integration with PT
- Public policies to discourage automobile use

4) Development of urban railway system

- Greater Kathmandu Valley Metro Rail (Underground Metro Rail inside the Ring Road and Elevated rail on open areas)
- Consideration of changes in Traffic scenario after Metro construction
- Intermodal transfer

5) Pedestrian and cycling (NMT transport) - Promoting walking and cycling

- At least 10% of total infrastructure budget on NMT for initial five years
- Development of pedestrian and cycling (NMT) networks - as primary travel mode
- Walkways/Cycleways along Rivers in KV
- Priority to Pedestrian Traffic
- More river crossing bridges for pedestrians and cyclists (JICA)
- Latent possibility of bicycle uses in the Kathmandu Valley

Above mentioned measures and findings are the way forward referred from various transport studies in Nepal and international transport publications. If we set underground/elevated metro rail as a backbone of the Kathmandu valley transport network, integrating surface public transports (as feeder) with provision non-motorised transports, it would be possible to free up space for surface transports due to 'Modal shift' at 20 to 25% (KSUTP, 2018) as a result 'Traffic congestion' will be reduced at 28% (KSUTP, 2018). The public will benefit from reduced travel time and increased urban mobility.

## 14. References

Amatya, B.L. et al., 2020. GKV Metro Rail concept paper, Greater Kathmandu Valley (GKV) Metro Promotion Group.

Bhattarai, D.K. and Shahi, P.B., 2021. Integrated Multi-Modal Transportation System: A Sustainable Approach for Urban Transport in Kathmandu, Journal of Mechanical and Civil Engineering.

CBS, 2014. Population Statistics. Central Bureau of Statistics (CBS).

Chand, S.J.B. PhD, 2018. Research study - Estimation of Time Delay Cost (One day).

Dalkmann, H. and Sakamoto, K., TRL, 2012. Urban Transport Policy Recommendations for the Development of Eco-efficient Infrastructure, ESCAP, KOICA.

DOR, 2017/18. Department of Roads (DOR), Statistics of Strategic Roads Networks (SSRN).

Dorina, P. and Dominic, S., 2015. 'Sustainable Urban Transport in the Developing World', The University of Queensland, Delft University of Technology.

DOTM, 2016/17. Registered Vehicles in Bagmati Zone & Nepal.

DOTM, 2018/19. Registered Vehicles in Nepal & Kathmandu Valley.

GGGI, 2018. Global Green Growth Institute (GGGI) with MOFE/MoPIT, Accelerating Implementation of Nepal's Nationally Determined Contribution National Action Plan for Electric Mobility.

KVDA: Kathmandu Valley Master Plan (2015-2035).

GON: National Environmentally Sustainable Transport Strategy (2014).

GON: Strategic Plan for Transport Infrastructures (2073 - 2078).

GON, NPC Fifteenth Plan (Fiscal Year 2019/20 – 2023/24), National Planning Commission.

Ghimire, K.P. and Shrestha, S.R., IJE, 2014. Estimating Vehicular Emission in Kathmandu Valley, Nepal, International Journal of Environment.

Harnis, J.E. & Mizokami, S., 2011. Some Valuable Learning of London's and Seoul's Experience in Public Transport Reform. Proceedings of the Eastern Asia Society for Transportation Studies, Vol.8, 2011.

ITS: https://www.designingbuildings.co.uk/wiki/Integrated_transport_system

JICA, 2011. Research on Practical Approach for Urban Transport Planning, Study by JICA & ALMEC Corporation.

JICA, 2012. Final Report: Data Collection Survey on Traffic Improvement in Kathmandu valley. Japan International Cooperation Agency (JICA).

JICA 2019. Data Collection Survey on Urban Transport in Kathmandu Valley.

JICA, STRADA. System for Traffic Demand analysis (STRADA), Four Step Trip-based travel demand model, https://www.vmi.co.jp/strada/en/

KMRTC, 2012. Kathmandu Mass Rapid Transit Consortium (KMRTC), Final Report on Feasibility Study of Mass Rapid Transit (Underground and Elevated Railway) System in Kathmandu Valley.

KSUTP, 2018. Kathmandu Sustainable Urban Transport Project (KSUTP), Mass Transit Options and Prioritisation Study, Asian Development Bank (ADB).

KSUTP, 2020. ADB completion report - Kathmandu Sustainable Urban Transport Project. Field Survey and Feasibility Study of Pilot Route, Asian Development Bank (ADB).

Maya Fact Sheet # 3, 2003. Clean Energy Nepal (CEN), Electric Vehicles in Kathmandu.

Maya Fact Sheet # 4, 2014. Public Transportation in Kathmandu Valley: Restructuring and Reforming the System.

MaYA (Manav-kendrit Yatayat Abhiyan.

MoFALD, 2016. Ministry of Federal Affairs and Local Development (MoFALD): Statistics of Local Road Network (SLRN).

MoUD, 2017. National Urban Development Policy (2017), Ministry of Urban Development.

Pokharel, R. and Acharya, S.R., 2015: Sustainable Transport Development in Nepal: Challenges, Opportunities and Strategies. Journal of the Eastern Asia Society for Transportation Studies, Vol.11.

Shrestha, K.K. et al., 2020. GKV Metro Rail concept paper, Greater Kathmandu Valley (GKV) Metro Promotion Group.

Thapa, R.B. and Y. Murayama, Y., 2011. Scenario based urban growth allocation in Kathmandu Valley, Nepal, Landscape and Urban Planning 105(1-2):140-148.

UN DESA, 2012. UN Population Division, Department of Economic and Social Affairs.

UN ESCAP, 2012. Sustainable Urban Transportation System, CITYNET.

UTIKV, 2017. Project on Urban Transport Improvement for Kathmandu Valley (UTIKV), Final Report, Volume I, Present Conditions.

WB, 2013. Urban Growth and Spatial Transition in Nepal: An Initial Assessment.

WB 2013: National Transport Management Strategy 2070, Draft Version.

WB, 2017 & NOC, 2016. Petroleum consumption and CO2 emissions from the transport sector.

# *Project SPEED Initiative and PACE Approach for delivering UK Railway Infrastructure Projects*

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## Abstract

The Rail Project SPEED (Swift, Pragmatic and Efficient Enhancement Delivery) framework was initiated by Network Rail in 2020 with support from the Department for Transport (DfT) of the UK Government to find a new way of delivering rail projects. It provides great opportunities by removing barriers and inefficient processes that have long hindered transformation of the rail industry. Network Rail has used the GRIP (Governance of Railway Investment Projects) framework to govern its capital delivery of projects for over a decade. It has eight stages of project lifecycle to manage its corporate risks from project initiation to implementation and to project close or handover to asset owner. Having too many such sequential stages as well as inefficient governance and processes in them has caused project delays and has resulted in more than necessary costs. In order to tackle these issues and hence deliver railway infrastructure projects considerably more quickly and at lower cost, GRIP has been replaced with a new streamlined project lifecycle framework called PACE (Project Acceleration in a Controlled Environment). PACE has only four core project lifecycles as opposed to the eight in GRIP and is a more flexible way of delivering projects that can be tailored to the needs of each individual project, making improved trade-offs between cost, time, and scope constraints. It reduces non-value add governance activity and project processes while providing effective and efficient assurance regimes. This paper discusses the Project SPEED initiative and PACE lifecycle framework and compares them to the GRIP project lifecycle. The effectiveness of its implementation in railway infrastructure projects is also demonstrated with some examples of recently completed projects by Network Rail.

*Keywords:* Project SPEED, Infrastructure projects, Governance, PACE lifecycle

## 1. Introduction

Governments and industries around the world have been facing tremendous economic pressure due to multiple factors such as the rise of fuel and energy prices, the impact of the COVID pandemic, among others. It has become necessary for industries to find better ways of delivering projects and providing greater value for their clients, customers, and taxpayers. The UK rail industry is under unprecedented economic pressure because of the impact of the pandemic and other national and international crises. These industries also face the perception of being inefficient and not providing better value for money. They need to think differently and adjust their mindset, working practices and provide an emotional drive to do things in a more efficient ways (Rail SPEED | Network Rail, 2021; Bhandari, N., 2019). In order to provide greater flexibility in delivering projects and removing inefficient processes and barriers, Network Rail has initiated a new project delivery framework, called Rail Project SPEED (Launch of Project SPEED, 2021).

The aim of the Project SPEED is to half the time and slash the cost associated with the delivery of capital investment onto the rail network and improve outcomes for all stakeholders. It presents an opportunity to drive efficiency and transform the way we deliver projects in the rail industry. Its initiative, principles and benefits are explained in following sections.

## 2. Rail Project SPEED Initiative

Project SPEED is one of the UK government's strategies to "Rebuild Britain" under the government's theme of building back better, greener and faster by streamlining governance, assurance and processes when delivering infrastructure projects. Rail Project SPEED was jointly developed by Network rail and the Department for Transport (DfT) in 2020 to focus on reducing the costs and time required for delivering rail infrastructure projects (Rail SPEED | Network Rail, 2021; Launch of Project SPEED, 2021).

The Rail Project SPEED initiative was launched to see how the costs of railway infrastructure projects could be reduced by streamlining processes and implementing good practices. The purpose of this approach is to restore the confidence in rail industry to deliver projects at an affordable cost on time and within budget, for the benefit of users and value for money for taxpayers. The key aim of this initiative is to focus on halving the project time and significantly reducing the costs of delivering rail infrastructure projects through a new approach of working and the simplification of processes from project initiation to implementation and close out. This can be presented in a simple graphical representation as shown in Figure 1, which shows the performance of project delivery and its relationship with cost spend and time duration.

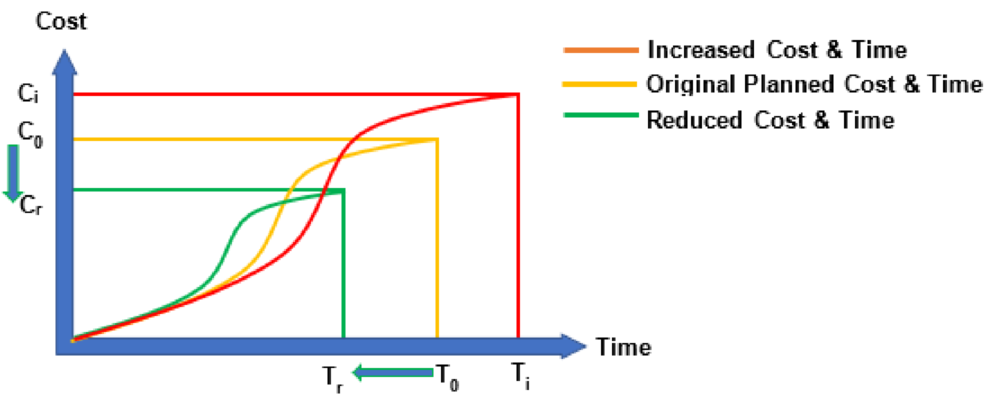


*Figure 1: S-Curve of project performance between costs spend vs time duration*

The overall aim of this approach is to deliver the project with reduced cost and timescale (Cr, Tr) than the originally planned cost and programme (C0, T0). However, experience from recently delivered UK railway major schemes such as Crossrail and the Great Western Electrification Programme (GWEP) show that their cost and time had significantly increased (towards Ci and Ti) than originally planned (C0 and T0) (RIA Electrification Cost Challenge, 2019; Crossrail: The project at a glance, 2021). The SPEED initiative has been launched for new railway schemes to tackle these issues faced by the railway infrastructure projects.

## 2.1 SPEED Principles

The Network Rail's SPEED principles are guided by its four values: Safe, Care, Teamwork and Empowerment. Values bind people together and remind them of what they collectively believe to be important and guide them on how to act and make decisions. Network Rail values exist to empower their people to always be safe, care about the railways, its users and each other and put teamwork at the heart of everything they do. Building on these values, the Network Rail Project SPEED team has developed principles to guide their day-to-day working and make sure that everyone plays a part in building a modern, affordable, and efficient railway. The key principles of SPEED and their outcomes are listed in Table 1.

*Table 1: The Project SPEED principles (Rail SPEED | Network Rail, 2021)*

| Principle | Expectation/outcomes |
|---|---|
| Be Bold | • Challenge and encourage others to challenge you<br>• Do things better and smarter<br>• Keep learning, act promptly and share experience |
| Outcomes focused | • Change the way to deliver the best outcome for passengers |
| Accountable and empowered | • Take ownership to help others and passengers more |
| Integrity and trust | • Work together better to improve the passenger experience |
| Service focus | • Support each other and the passenger experience |
| Be curious | • Take more control of the situation<br>• Empower and be empowered<br>• Do the right thing for passengers |

### 2.2 SPEED Benefits

The key benefits of implementing the SPEED framework for rail project delivery is the simplification of governance decisions and the streamlining of assurance processes. In successful implementation of its core principles, the benefits from this approach will be far reaching, and can be listed as below:

- Economic stimulus: through investment in infrastructure projects by reducing the cost of project delivery
- Earlier release of benefits: through reduced project delivery timescales and ensuring passengers experience better journey and more quickly
- Greater value for taxpayers: with more benefit delivered for every pound invested in the railway industry
- Simplification of processes: through removal of barriers that have long hindered industry transformation
- Securing the long-term viability: making the railway industry as an attractive investment opportunity

As explained above, Project SPEED is to provide a framework to the project delivery team which aims to half the timescale and slash the cost associated with the delivery of capital investment onto the railway infrastructure projects and improve outcomes for their stakeholders. In order to achieve this, Network Rail has recently replaced its inefficient and inflexible GRIP project lifecycle with an efficient and more streamlined project lifecycle tool, called PACE (Project Acceleration in a Controlled Environment (PACE) | Network Rail, 2021), a new project management process, which will be described in more detail in the subsequent section.

## 3. Network Rail's PACE Approach

PACE describes how Network Rail manages and controls investment projects on the rail networks and provides a more flexible control framework to the project sponsors and managers, enabling them to tailor controls and deliverables to reduce the reputational and financial risk related to project delivery. PACE is designed to maximise value and minimise bureaucracy by empowering project teams to make better decisions on their projects with an increased focus on achieving improved outcomes in the most efficient way for funders, customers, users, and other stakeholders.

### 3.1 The PACE Lifecycle

In the rail industry, investments can be funded, procured, and delivered in a number of ways. Network Rail has an important role to play, regardless of the approach. It has an obligation to make sure that all schemes or projects are compatible and integrated with existing railway operations, and at the same time when schemes are completed, they can be operated and maintained safely, reliably, efficiently, and cost-effectively.

In order to manage its corporate risks and govern its capital delivery for projects, Network Rail had implemented the GRIP process approach for over a decade. GRIP has eight stages of project lifecycle from project initiation & development to delivery and to handover to asset owner and maintenance. It has recently been realised by Network Rail and DfT that too many sequential stages and inefficient governance and processes within them has caused project delays and has incurred more than necessary costs. To address these issues and to deliver railway infrastructure projects considerably more quickly and with better value for money, GRIP has been replaced with a new streamlined project lifecycle, PACE, which has only four core project lifecycles i.e., four phases of the project.

Figure 2 illustrates PACE lifecycle timeline in relation to GRIP lifecycle. It is a more flexible way of delivering rail projects compared to GRIP, which reduces overall governance activity and project processes throughout the project lifecycle.

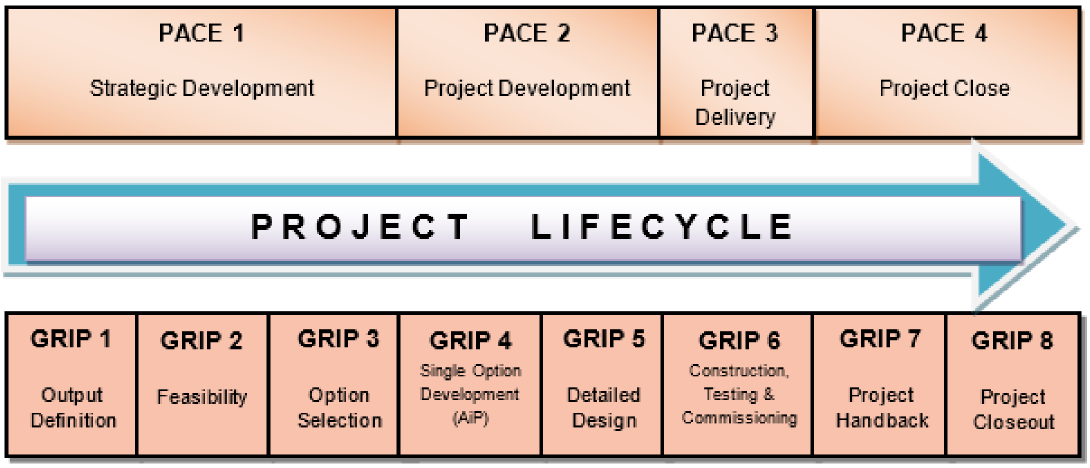


*Figure 2: PACE project lifecycle and relationship with GRIP*

## 3.2 The PACE Milestones and Phase Readiness Review

As explained in previous section, PACE reduces the project lifecycle stages. This has been done by consolidating a number of old GRIP stages in each phase of the PACE lifecycle. The old GRIP stages have been replaced by the PACE milestones as shown in Table 2 (Project Acceleration in a Controlled Environment (PACE) | Network Rail, 2021). The purpose of which is to make sure the project focuses mainly on key requirements throughout the lifecycle. The benefit of this approach is that it enables the project to more effectively schedule activities required for delivery of critical outcomes. The PACE milestones are normally delivered in sequential order; however, this is not mandated in PACE. It is allowed for the project to deliver milestones in a non-sequential order within a phase and it is permitted to overlap activities required to deliver individual milestones.

*Table 1: Import of petroleum products 2019 – 2020 (NOC,2020)*

| Phase | Milestone | Description |
|---|---|---|
| Strategic Development & Project Selection | ES1 | Client requirement defined and baselined. |
| | ES2 | Constraints identified and project feasibility confirmed. |
| | ES3 | Single option identified and endorsed. |
| Project Development & Design | ES4 | Design standards approved and Approval in Principle. |
| | ES5 | Construction ready design approved. |
| Project Delivery | ES6 | Construction complete. |
| Project Close | ES7 | Project demobilised and handed back to Sponsor. |
| | ES8 | Contractual accounts settled, warranties transferred to maintainer, formal closeout. |

PACE phases may be overlapped or combined where there is not the requirement for a mandatory Phase Readiness Review (PRR) between the phases, which further reduces the timescale of project delivery. PRR's are critical control points in the project lifecycle to confirm that a sufficient level of deliverables has been completed to meet the scope and requirement of the project and that risk has been identified and managed or controlled before the project moves to the next phase of the lifecycle. Figure 2 and Table 3 show that a maximum of four governance-controlled review points of project lifecycle is required under PCAE as opposed to eight in the GRIP process. Furthermore, not all projects are required to undertake a PRR at the end of each phase (Table 3) (Project Acceleration in a Controlled Environment (PACE) | Network Rail, 2021). The minimum requirements are determined by the Project Level of Control (LoC), which is mainly determined by the complexity and novelty of the project, which is assessed and approved by an independent Safety Review Panel (SRP) or a similar body.

*Table 3: Minimum Phase Readiness Reviews*

| end of phase ↓ | Including milestones | LoC 1 | LoC 2 | LoC 3 | LoC 4 |
|---|---|---|---|---|---|
| Strategic Development & Project Selection | ES1/2/3 | Required | Recommended | Optional | Optional |
| Project Development & Design | ES4/5 | Required | Required | Required | Recommended |
| Project Delivery | ES6 | Required | Required | Recommended | Optional |
| Project Close | ES7/8 | Required | Required | Required | Required |

# 4 Case Study: Okehampton Station, Dartmoor Railway Line

Several rail projects have already been started that implement Project SPEED principles and PACE lifecycles. Some example projects of those that have already been delivered or planned are listed in Table 4 for the purpose of providing an insight of the benefits of implementing SPEED principles. More detailed analysis is also provided below for Okehampton Station and Dartmoor Line reinstatement (Rail SPEED | Network Rail (2021; Project Acceleration in a Controlled Environment (PACE) | Network Rail, 2021). Okehampton and White Rose Station projects have already been completed (in 2021 and 2022). The other projects or schemes listed in Table 4 are either in development or planning stage.

*Table 4: Cost and Timescale saving on rail projects using SPEED principles*

| Projects | Original Cost, £m | Cost saving, £m | Timescale saving, months |
|---|---|---|---|
| Okehampton, Dartmoor Line (completed) | 56 | 10 | 24 |
| White Rose Station, Leeds (completed) | 22 | 1.21 | 9 |
| Northumberland Line (on-going) | 166 | 50 | 9 |
| York Station Capacity Programme (on-going) | 90 | 14 | 36 |
| Anglia Access for All (AFA) Station upgrade schemes (up to Scheme design) | 1.7 | 0.36 | 2 |
| Croydon Area Remodelling Scheme (planned) | 4300 | 326 | 24 |

Okehampton Station, Dartmoor Line: Okehampton is the first of the UK Government's "Restoring Your Railway" schemes to return to service, which has now reopened to passengers for regular service after 50 years. This project has reopened the Dartmoor Line, enabling regular passenger services between Exeter and Okehampton in Wales & Western Region. If the conventional approach to delivery had been applied, the earliest the line could reopen would have been the second quarter of 2023. However, by developing the programme with Project SPEED principles, a 24-month saving from the originally planned schedule has been achieved, and the project was completed in November 2021, saving £10m from the original cost of just over £50m.

The cost and time savings on the Okehampton project was achieved by doing following key approaches that align with SPEED and PACE:

- Using in-house delivery for key works and existing Network Rail frameworks contracts to shorten the procurement process.
- Utilising a high-street environment for construction activities with complete blockade (no trains being run on the line during the construction).
- Carrying out enabling works early on to support the main works.
- Agreement with DfT (the funder) to move the project straight to Final Business Case (FBC) instead of producing a staged business case, hence avoiding layers of inefficient NR/DfT governance.
- Using phased funding to allow the project to continue with key delivery activities while awaiting a Final Investment Decision.
- Challenging the NR standards on asset quality that are suitable for track on a branch line to reduce the scope of work required.

- Agreement with the Network Rail Assurance Panel (NRAP) and Safety Review Panel (SRP) for the scheme as "non-interoperable" and "non-significant", thereby avoiding the requirement of rigorous Interoperability Regulations.
- Using risk-based self-assurance engineering reviews and approvals.
- Combining the outline and detailed design, thereby overlapping PACE phases to reduce assurance and approval process.

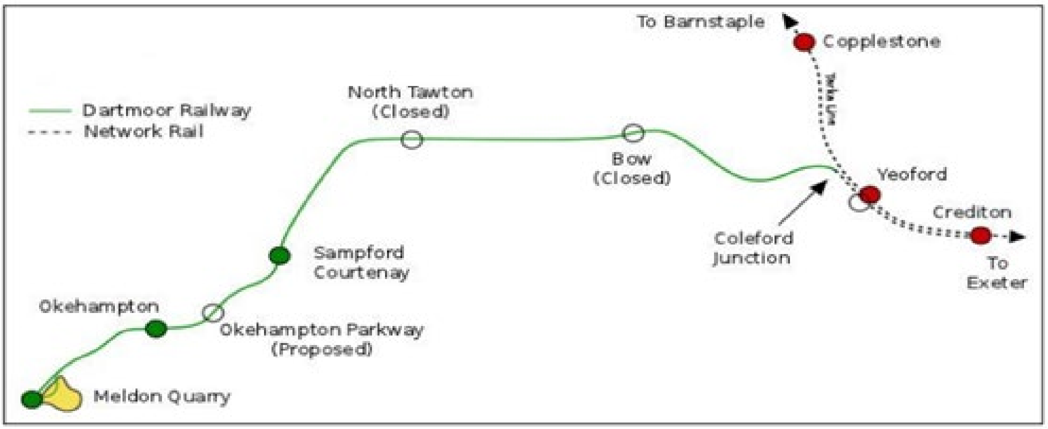


*Figure 3: Dartmoor Railway Line reinstatement (Network Rail, 2021, PACE)*


*Figure 4: Rebuilt Okehampton Station reopened to passenger for regular service (Network Rail, 2021, PACE)*

# 5 Challenges and Opportunities for implementing SPEED & PACE

The main challenge of implementing the Project SPEED principles and PACE project lifecycle is balancing the quality of the delivery of projects with the lowest possible cost and reduced timescale. There are other challenges as highlighted in Figure 5 such as the lack of competent resources including critical workforce, onerous company and industry standards, access & logistic availability to carry out actual physical works, lack of support from stakeholders due to their mindset, etc. However, the author believes that each challenge can be converted into opportunity by adapting new ways of working, effective engagement with stakeholders, driving efficiency through innovation and technology and a delivering minimum viable product (MVP) rather than sticking within comfort zones and over-specified sub-optimal solutions.

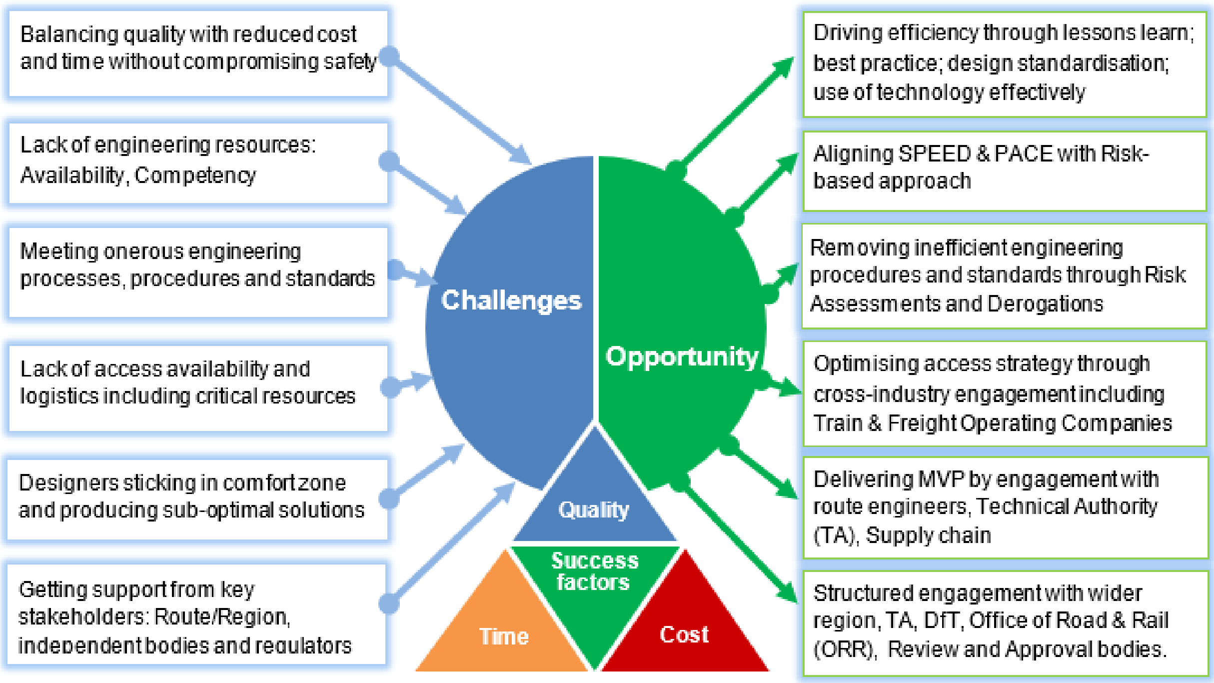


*Figure 5: Challenges & Opportunities in Project SPEED & PACE while balancing quality with reduced cost & time*

## 6 Conclusions and implications

It has been recognised that because of major cost and programme overruns on recently delivered projects (GWEP, Crossrail), the reputation of delivering major railway infrastructure projects in the UK had suffered massively, and thus there is a necessity to explore new ways of delivering them to gain confidence from the Government and taxpayers. Network Rail, in collaboration with DfT, has developed a new project delivery mechanism – the Project SPEED framework and PACE project lifecycle, aiming to streamline governance and assurance processes, thereby reducing the cost and timescale of project delivery. Network Rail has already demonstrated cost and programme efficiencies by delivering a number of projects under Project SPEED and PACE and is planning to make them mandatory for new railway infrastructure projects and hence commit to deliver more affordable and value for money for funders, passengers and freight users.

The Project SPEED principles and PACE lifecycle governance and assurance processes can be implemented in any engineering infrastructure projects, including infrastructure development in Nepal.

## 7. References

*Rail SPEED | Network Rail (2021). Available: https://www.networkrail.co.uk/industry-and-commercial/supply-chain/existing-suppliers/rail-speed/*

*Launch of Project SPEED (2021), Available at: https://www.gov.uk/government/news/launch-of-project-speed-challenges-rail-industry-to-cut-time-and-costs-of-rail-upgrades.*

*RIA Electrification Cost Challenge (2019). Available at: https://www.riagb.org.uk/RIA/Newsroom/Stories/Electrification_Cost_Challenge_Report.aspx*

*Crossrail: The project at a glance (2021). Available at: https://www.london.gov.uk/sites/default/files/crossrail_-_project_at_a_glance.pdf.*

*Getting project right, Rail Engineer (2021). Available at: https://www.railengineer.co.uk/getting-projects-right/*

*Project Acceleration in a Controlled Environment (PACE) | Network Rail (2021). Available: NR/L2/P3M/201 - Project Acceleration in a Controlled Environment (PACE) | Engineering360 (globalspec.com)*

*Bhandari, N. (2019). Importance of a Robust Engineering Assurance Process and iELC for Railway Infrastructure Projects. Proceedings of 3rd SONEUK Conference on Innovative Technologies and Practices for Nepal.*

# Assessment of the Impact of Metro Rail on Improving Air Quality of the Kathmandu Valley

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## Abstract

The Kathmandu Valley suffers a disastrous level of air pollution every winter. Culturally, historically, and the aesthetically rich valley is randomly urbanized housing millions of unmanaged floating populations. Recent studies suggest that the local emission loadings of the valley, categorically from the domestic, industrial, and transportation sectors, are far greater than its carrying capacity. Managing its air pollution is a challenge. A massive reduction in emission loadings would be necessary to bring the air quality to the national ambient air quality standard. Clean mass transit like Metro Rail could be a key to the sustainable and environment-friendly development of the Kathmandu Valley, transforming the unmanaged transportation system- a significant contributor to the valley's emission. In this paper, authors present the emission status and air pollution scenario in the greater Kathmandu Valley at present and a possible reduction scenario of the same after the introduction of the proposed Metro Rail. Availability of precise and updated emission data and development-specific projected emission data would help realize the impact and sustainability of any development activity before implementation and maximize its benefit ensuring the air quality, economy, health, and environment.

*Keywords:* Kathmandu Valley, Gridded emission inventory, Metro Rail.

# 1. Introduction

Every winter, the air quality of the Kathmandu Valley severely degrades securing top positions in the most polluted city rankings, time and again. The observation at the seven Air Quality Monitoring Stations installed in the valley, by the Department of Environment, Government of Nepal, suggests that the daily mean concentration of the Fine particulate matter (PM2.5) crosses the National Ambient Air Quality Standard (40 µg m-3) and World Health Organization air quality health guideline value (15 µg m-3) by multiple folds (Regmi et al, 2018). Acknowledging the socio-dynamics and other complexities associated with air pollution, sustainable solutions have been essential to tackle this level of pollution in the valley.

The meteorological condition of the Kathmandu Valley and the excessive local emissions are mainly responsible for air pollution in the valley. The local emission activities from the domestic, industrial, and transportation sectors aided by the adverse meteorological conditions like nighttime and daytime thermal inversions and low mixing layer heights, cause the Kathmandu Valley atmosphere to quickly saturate even with fewer emission loadings (Regmi et al, 2003; Regmi et al, 2018; Kitada and Regmi, 2003). The current local emission loadings to the valley are much greater than its carrying capacity. In wintertime, daily emission of the criteria pollutants like Total Suspended Particulates (TSP), Carbon Monoxide (CO), Oxide of Nitrogen (NOx), and Sulphur Dioxide (SO2) are estimated around 126.01 Ton, 656.26 Ton, 33.90 Ton, and 18.74 Ton, respectively. The transportation sector solely contributes around 50% of NOx and CO, 21% of SO2, and 16% of TSP (Regmi et al, 2018).

The transport sector in the Kathmandu Valley, where more than 1.1 million (myRepublica, 2017) big and small, private, public, and freight vehicles that are seldom maintained and monitored ply in rather narrow, dusty, mostly damaged, and under construction roads, is very complex. A massive traffic diversion from small and fossil fuel-based services to environment-friendly Mass Rapid Transit (MRT) systems like Metro Rail is highly desired to tackle traffic congestion and air pollution. The strategic development and effective implementation of the Metro Rail as major alternative transportation could be a viable and effective option for MRT in the Kathmandu Valley.

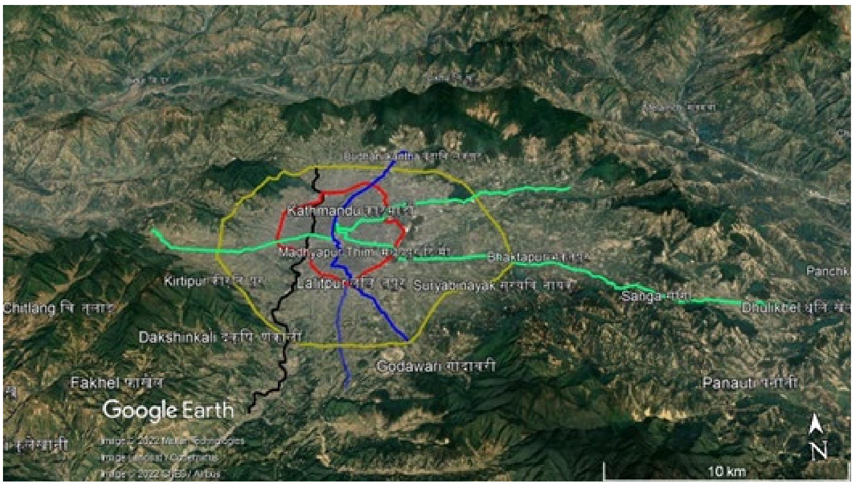


*Figure 1: The routes of the proposed Kathmandu Metro Rail (Amatya 2020) overlaid on Google Earth.*

The introduction and expansion of Metro Rail in the major cities in neighboring countries have been found very effective to reduce the concentration of air pollutants and carbon emissions. It is seen that the extension of the Delhi Metro reduced CO concentration by 34% at the traffic intersections in the Indian Tax Office in Delhi (Goel and Gupta, 2017). Similarly, NO2 concentration was also found to decline. Likewise, after the Metro Rail extension in Bangaluru under the "Namma Project", at 6 monitoring stations in Bangaluru Metro Rail Corporation Limited, the PM2.5 concentration remained below 60 μg m-3 between 2017-2020, and the coarse particulate matter (PM10) concentration decreased after 2018. In addition, the estimated carbon emission by commuters reduced between 19.6 and 120.4 Gigagram (Gg) during 2017-2022 (Thakur, 2022). Similarly, in ridership discontinuity analysis by Chen and Alexander (2012) in Taipei Taiwan, the opening of Taipei Metro reduced the concentration of CO by 5 to 15 percent and also reduced NOx. These studies show the positive impact of Metro Rail on the environment, provided the electricity source to drive them is from renewable sources.

The efforts and workouts in planning to materialize the Metro Rail implementation in the Kathmandu Valley have been made for more than a decade by both the Government and private sectors. Feasibility studies and possible Metro Rail routes have been suggested (Investment Board Nepal and Department of Railways, 2020; Amatya, 2017). The figure shows Metro Rail routes based on Amatya (2020) overlaid on the Google Earth imageries (see Figure 1). However, the possible environmental benefits of the Metro Rail have not yet been realized.

In this paper, the authors present the current emission scenario from the transportation sector and possible reduction in emission loadings in the valley with the introduction of the proposed Metro Rail.

## 2. Methodology

To get detailed insight into the emission loadings in and around the Kathmandu Valley, a gridded emission inventory of the criteria pollutants from the transportation sector was prepared at a 1 km × 1 km resolution grid net over 70 km × 70 km domain centred at the valley (See Figure 2). Vehicular activities and their intensities were estimated through data from the Department of Transport Management and Surveys. Computation of the emission strength at each grid was carried out adopting the procedure presented in Figure 3 and the formulation in Equation 1 (Kitada and Regmi, 2003) in ESRI's ArcGIS 10.3.

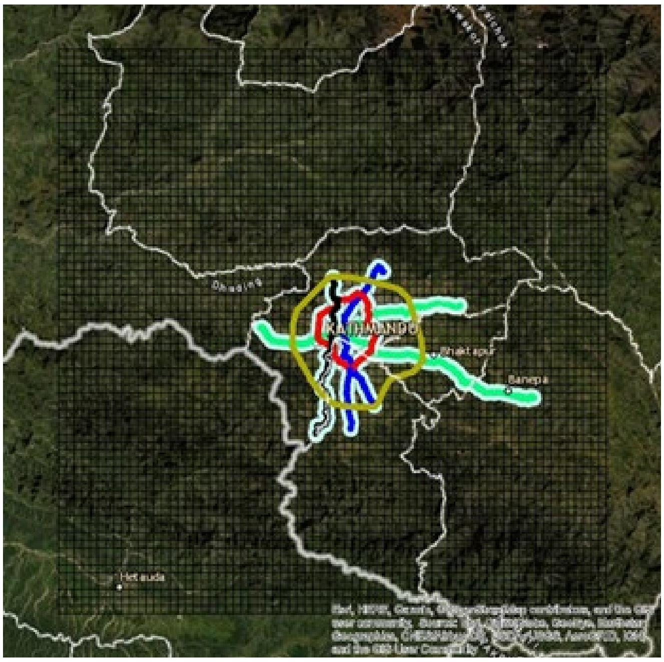


*Figure 2: The gridded study domain over the Kathmandu Valley and surrounding area, and 2 km buffer region around the proposed Kathmandu Metro Rail route (Amatya, 2020) overlaid on Esri Map imageries.*

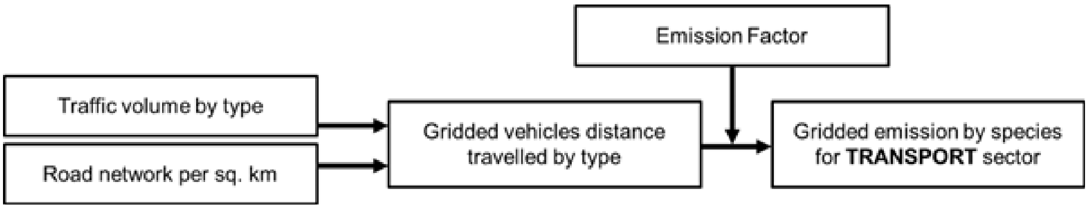


*Figure 3: The flow chart depicting the procedure followed to prepare the gridded emission inventory of the transport sector of the Kathmandu Valley.*

$$\text{Transport emission} = \sum_{vehicle\ type}(number\ of\ vehicles) \times (grid\ vehicle\ kilometer\ travelled) \times (emission\ factor\ per\ kilometer\ of\ travel) \quad \text{......... (1)}$$

Emission factors for vehicular emission were adopted from Shrestha and Malla (1996) and Atmospheric Brown Clouds (ABC) emission inventory manual (Shrestha et al, 2013).

During estimation, emissions from the transportation sector were segregated into emissions from heavy-duty vehicles (trucks, tippers, tankers, etc.), two-wheelers (motorcycle, scooters), taxi, private light passenger and duty vehicles such as cars, vans, pickup, etc. and public vehicles. Here, public vehicles included buses, mini-buses, vans, three-wheelers, etc.
For the assessment of the impact of the Metro Rail on vehicular emission, a buffer zone of 2 km width around the proposed routes based on Amatya (2020) was taken. The transport activity and thus the emission from the buffer region was reduced with the assumption that the Metro Rail would be able to shift 50 % of traditional public vehicles, 40 % of the Motorbike, 30 %

of Car, and 50 % of Taxi riders in the region to the metro system. The assumption is around two times the anticipated modal shift as per studies by the Kathmandu Sustainable Urban Transportation Project (KSUTP, 2018). The controlled gridded emission was, thus, estimated following the assumptions. As there is very less vehicular activity around the Greater Ring Road, the area was not considered. However, for the future scenario, the traffic creation in the region due to the introduction of Metro Rail in Greater Ring Road may not be ignored.

## 3. Results and Discussion

The Kathmandu Valley houses three major cities or metropolis, viz. Kathmandu, the capital city of Nepal, Lalitpur, and Bhaktapur and has experienced a population boom and haphazard urbanization in recent decades. With its ever-increasing population and subsequent increase in industries, construction, and commercial activities, transport demands have parallelly surged up. A large share of energy consumption in the transport sector is fulfilled by traditional and fossil fuel. In addition, the traffic congestion has resulted in an increase in air pollution to an unacceptable level, affecting the life of the people, the beauty of the city, and its heritages.

The gridded spatial distribution of the criteria pollutants from the transport sector, presented in Figure 4, appear almost similar. In the distribution map, transport emissions are confined in the valley, especially in the core city areas like Ratnapark, Pulchowk, Balkhu, Kalanki, Baneshwor, Koteshwor (see Figure 4 for location) where traffic volume and congestion are the largest. A maximum of 274 kg (TSP), 6834 kg (CO), 281 kg (NOx), and 58 kg (SO2) has been estimated to be emitted per square km per day inside the valley. Similarly, the neighboring Banepa Valley in the east also appears equally polluted. Besides, significant emission is distributed in major highways like Prithivi Highway in the west, Araniko Highway in the east, East-West highway in the south-west of study domain in Hetauda, Kathmandu-Trishuli Road in the north-west. These highways serve as a major land route for people and goods to get in and out of the valley. Currently, the estimated total emissions of TSP, CO, NOx, and SO2 from the transportation sector in the study domain are 19620, 375129, 19115, and 3821 kg per day (see Figure 5). The high emission in the valley is particularly attributed to private-owned vehicles like two-wheelers and cars that share a total of around 68%, 91%, 50%, and 68 % contribution of TSP, CO, NOx, and SO2, respectively. Until 2019/2020, the total bike and car registration share 79% and 7% of the total vehicle registration in Nepal (DOTM, 2020).

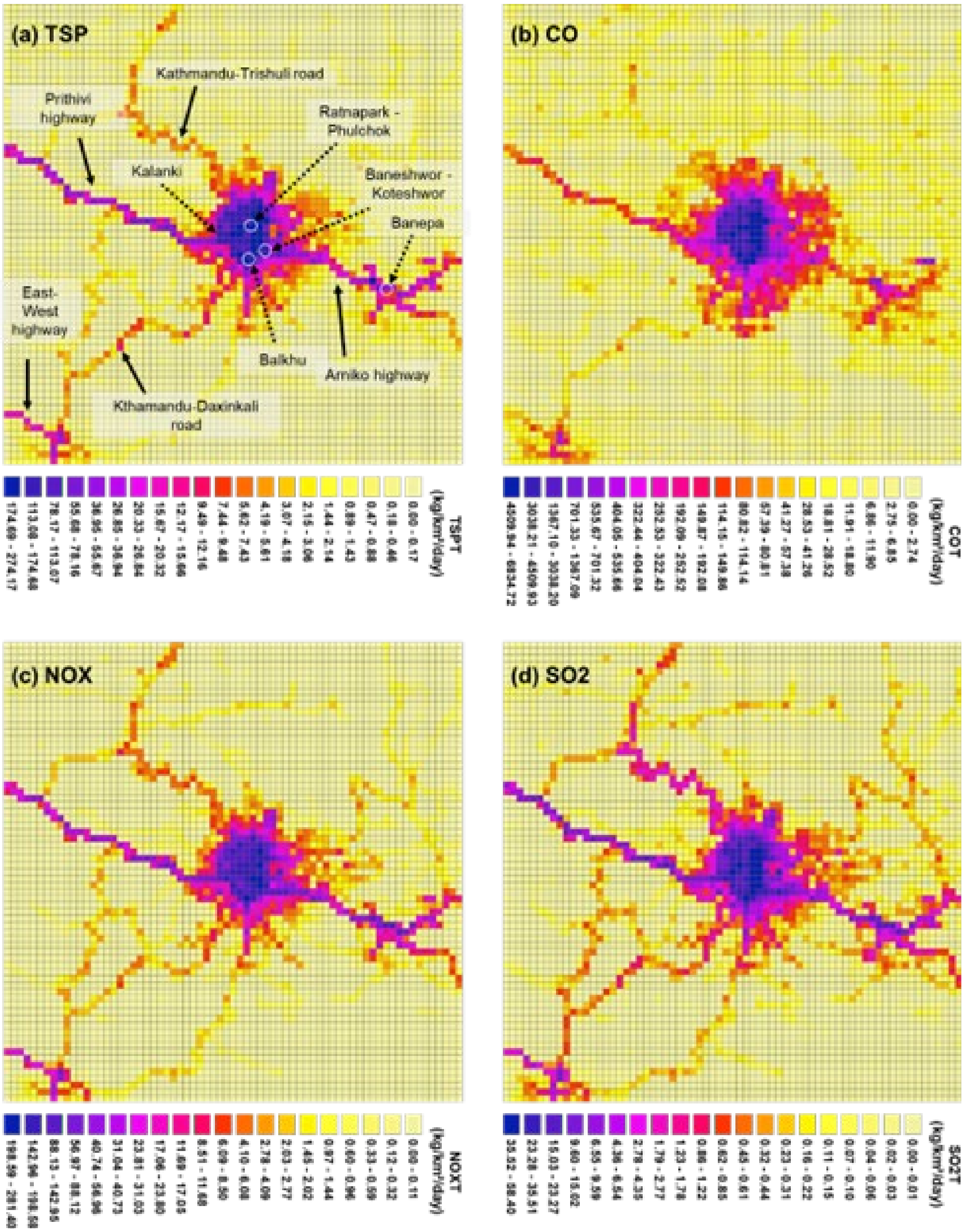


*Figure 4: Spatial distribution of the (a) TSP, (b) CO, (c) NOx, and (d) SO2 emisison from vehicular emission over the study domain covering the Kathmandu Valley.*

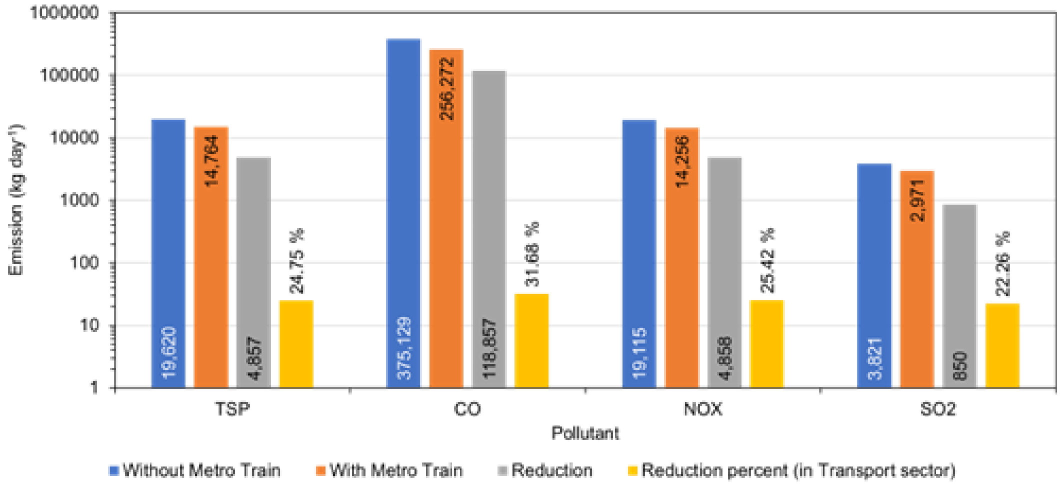


*Figure 4: Spatial distribution of the (a) TSP, (b) CO, (c) NOx, and (d) SO2 emisison from vehicular emission over the study domain covering the Kathmandu Valley.*

Another important component of transport-based air pollution is road dust. The poor road condition and dust collected at roadside and tires are blown away by vehicles plying on the road. Road dust alone contributes around 19.6% of total TSP emissions in the Kathmandu Valley.

On applying assumed reduction on each subsector (see Section 2), as much as 4857, 118857, 4858, and 850 kg of TSP, CO, NOx, and SO2 emission respectively are estimated to be reduced in the study area every day. The reduction accounts for 24.75%, 31.68%, 25.42%, and 22.26 % of the total emissions of these four pollutants from the transportation sector. The spatial distribution of the reduction of the pollutants appears similar and maximum reduction, as expected, is in major city centers within the Ring Road area. The maximum, up to 95.37, 273.30, 98.61 and18.03 kg of TSP, CO, NOx, and SO2 respectively are reduced per square km per day under the assumption.

Encouraging though it is, this reduction under the assumption may not be sufficient to bring a remarkable drop in the valley's pollution. The emission remains is still large enough to degrade the air quality in the valley to an unacceptable limit. Besides, the addition of the transport-based pollution due to new traffic creation as a by-product of Metro Rail development is also evident. As most of the emissions are from private vehicles, greater work may have to be performed to encourage a larger percentage of private-vehicle owners to use Metro Rail. It is to be noted that these alternative means of transportation ought to ensure greater mobility, comfort, and safety to ensure its sustainable impact.

This study is based on the emission estimation of year 2018. An updated and more precise emission data would help better realize the recent emission scenario and the impact and sustainability of development activity like Metro Rail before implementation.

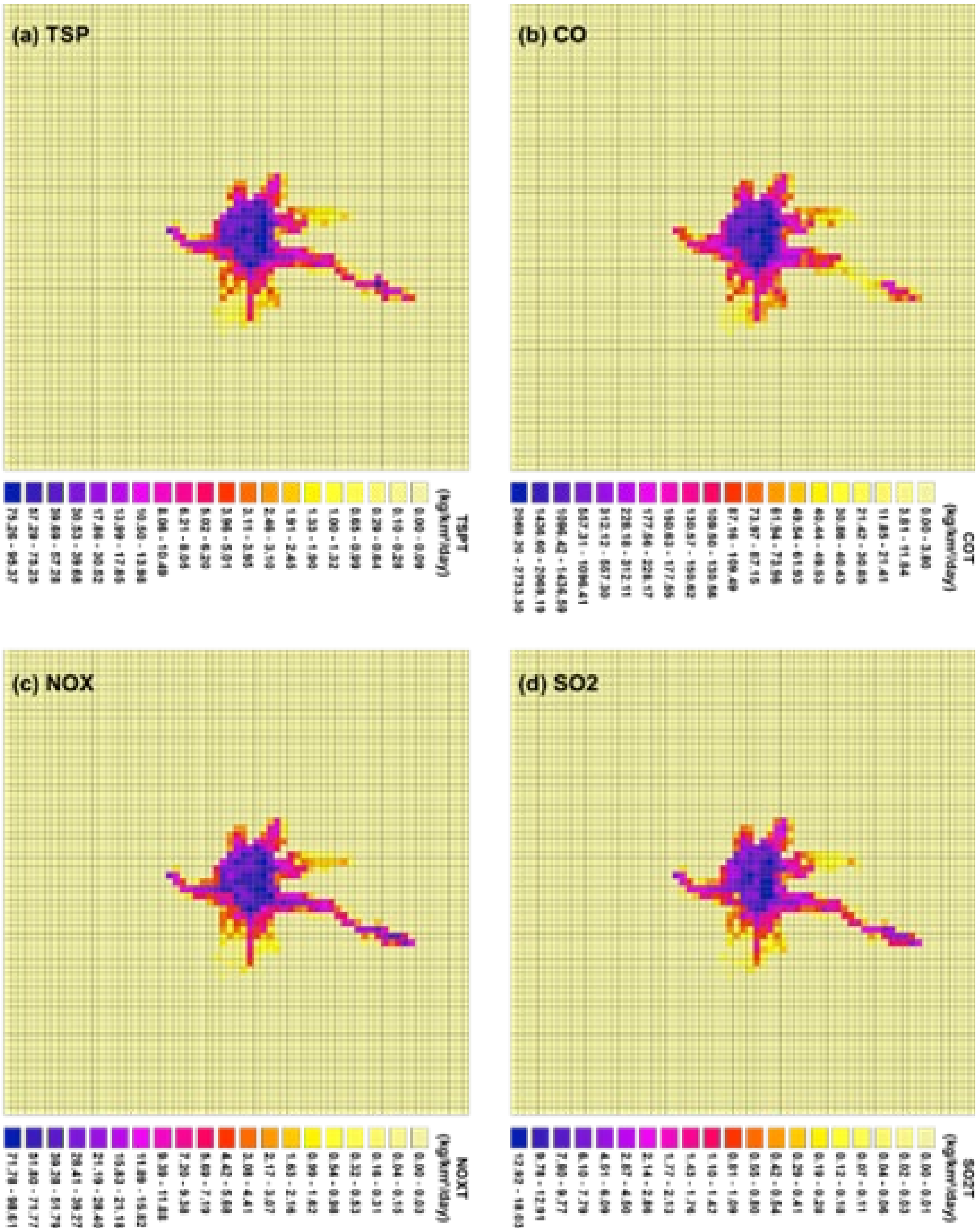


*Figure 6: Same as Figure 4 but for emission reduced on employing the modal shift assumption (see Section 2) for Metro Rail.*

## 4. Conclusion

Air pollution in the Kathmandu Valley has become a serious problem challenging the health of people, heritage, aesthetic beauty, and economy of the valley. The problem, however, has proved to be difficult to deal with no effective solution to date. Current emission in the valley is far greater than the carrying capacity of the valley's atmosphere. Reduction of emission is only the key to maintaining the air quality of the valley considering the adverse meteorological condition that inhibits air pollution dispersion. The major contributor to the valley's emission, which is concentrated in the major city centers and highways, is the transportation sector with a larger share contribution from privately owned vehicles. Environment-friendly mass transit like Metro Rail is a viable alternative. Assuming the 50% public vehicle rider, 40% bike rider, 30% car rider, and 50% taxi rider modal shift with the introduction of the metro service, the total daily emission of the pollutants (TSP, CO, NOx, and SO2) in the study area get reduced by 4857, 118857, 4858, and 850 kg, respectively. However, the remaining emission after the assumed reduction is still large enough to bring severe air pollution. A larger percentage of the bike and private vehicle owners needs to be shifted to alternative modes of transportation. For that, larger mobility, comfort, and safety of the riders in the new means ought to be ensured for the significant modal shift.

## 5. Acknowledgment

A part of this study was done under the Project "Air Pollution Dispersion Modeling and Control System Development for Emissions over Kathmandu Valley and Lumbini Area" for the Department of Environment, Ministry of Forests and Environment, Government of Nepal. The authors would like to acknowledge the department and other fellow project members for the same.

# 6. References

*Amatya, B.L. (2017). A conceptual study of the development of an underground metro rail system in the Kathmandu Valley, Nepal, Proceedings of the World Tunnel Congress 2017.*

*Amatya, B.L. (2020). How to Build the Underground Metro Rail in Kathmandu. Promoting cultural change in engineering practices for the Development of Nepal: Learning from the UK, Proceedings of 5th SONEUK Conference, p.41.*

*Chen, Y. and Whalley, A. (2012). Green infrastructure: The effects of urban rail transit on air quality. American Economic Journal: Economic Policy, 4(1), pp.58-97.*

*DOTM (2020). [online], https://old.dotm.gov.np/uploads/files/Vehicle%20data%20till%202076.pdf (Accessed: 17 March 2022)*

*Goel, D. and Gupta, S. (2017). The effect of metro expansions on air pollution in Delhi. The World Bank Economic Review, 31(1), pp.271-294.*

*Investment Board Nepal and Department of Railways (2020). Kathmandu Valley Metro Project. [online] https://ibn.gov.np/wp-content/uploads/2020/04/Kathmandu-Valley-Metro-Project.pdf] (Accessed: 17 March 2022)*

*Kitada, T. and Regmi, R.P., 2003. Dynamics of air pollution transport in late wintertime over Kathmandu Valley, Nepal: As revealed with numerical simulation. Journal of Applied Meteorology and Climatology, 42(12), pp.1770-1798.*

*KSUTP (2018) Nepal: Kathmandu Sustainable Urban Transport Project (KSUTP), Social Monitoring Report, Project Number: 44058-013, Loan / Grant2656/0212-NEP (SF).*

*myRepublica (2017). Traffic management in Kathmandu valley becoming tougher. [online] http://myrepublica.nagariknetwork.com/news/traffic-management-in-kathmandu-valley-becoming-tougher/ (Accessed: 17 March 2022).*

*Regmi, R.P., Kitada, T. and Kurata, G. (2003). Numerical simulation of late wintertime local flows in Kathmandu valley, Nepal: Implication for air pollution transport. Journal of Applied Meteorology, 42(3), pp.389-403.*

*Regmi, R.P., Kitada, T., Guenter, G., Kafle, G.C., Maharjan, S., Shrestha, S., Khadka, A.K., Adhakari, S. (2018). Air Pollution Dispersion Modeling and Control System Development for Emission over Kathmandu Valley and Lumbini Area, Department of Environment, Ministry of Forests and Environment, Government of Nepal, Kathmandu.*

*Shrestha, R.M. and Malla, S. (1996). Air pollution from energy use in a developing country city: The case of Kathmandu Valley, Nepal. Energy, 21(9), pp.785-794.*

*Shrestha, R.M., Kim Oanh, N.T., Shrestha, R., Rupakheti, M., Permadi, D.A., Kanabkaew, T. and Salony, R., 2013. Atmospheric Brown Cloud (ABC) Emission Inventory Manual (EIM). United Nation Environmental Programme (UNEP), Nairobi, Kenya.*

*Thakur, A. (2022). Bengaluru Metro significantly contributed to reduction of carbon emission, finds study. [online] https://indianexpress.com/article/cities/bangalore/bengaluru-metro-carbon-emission-reduction-study-7789656/ (Accessed: 01 March 2022 ).*

# Status of application of BIM in Architecture, Engineering and Construction projects in Nepal

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## Abstract

Building Information Modelling (BIM) has been gaining global popularity in the Architecture, Engineering, and Construction (AEC) industry. It has been considered as a solution for the shortcomings of traditional methods of carrying out projects and utilise in managing the assets throughout their life cycle. But Nepal still uses the conventional method for designing and construction process. The purpose of this research was to study and establish status of BIM application in Nepal. Extensive literature review was conducted by reviewing the publications in international journals. A questionnaire survey of engineers and architects working in Nepal was conducted. The responses of 113 participants were analysed by using quantitative data analysis techniques. The top barriers for adoption of BIM in Nepal were identified. The findings showed that the level of awareness of BIM in Nepal as low and the use of BIM was concluded as in Level 1 of Bew and Richards' maturity model i.e. it is in early stages. A thematic analysis carried out on the qualitative responses in the survey were in line with pattern of variables from literature. It is envisaged that the findings of the study could be used as a guidance for the future development and understanding to increase awareness and adoption of BIM in Nepal.

*Keywords:* Building Information Modelling (BIM), Adoption, Awareness, Barriers, AEC Industry

## 1. Introduction

BIM can be defined as the process of using information technology for sharing, modelling, evaluation, collaboration, and management of a virtually building model within a building life cycle (Ahmad et al., 2012). BIM supports collaboration and communication between a multitude of professionals, suppliers and constructors. According to Eastman et al 2008, the use of BIM can increase the value of building, shorten the project duration, provide reliable cost estimates, produce market-ready services, optimize facility management and maintenance. Thus, BIM can be the information backbone of the whole AEC industry, and this increase the value of workflow.

The AEC industry is one of the growing industries in Nepal, which lacks knowledge sharing and communication between different parties involved in a project. The industry is still lagging in the adoption of innovative methods and processes for example the industry is using a set of 2D drawings in the design and construction of a building or infrastructure facility. Construction is a labour-intensive industry that has been using traditionally method of drawings and specifications delivered by architects and engineers to the owners/clients. Any changes or discrepancies are corrected typically by a long trail of paperwork causing multiple delays along with cost and time over-run. The Architecture, Engineering and Construction (AEC) industry has long sought techniques to increase productivity and quality, cut project cost, and lessen project delivery time. Building information modelling (BIM) offers the potential to accomplish these objectives (Azhar et al, 2008). There is a lack of research regarding BIM in Nepal whether architects and engineers are using BIM effectively or not. Very few architecture and engineering firms are using BIM which is in initial stage. To date, there is no project that can be cited as being completed in Nepal using BIM tools and processes. At present, the work is done through a set of drawing drafted using AutoCAD. 3D modelling is gaining popularity for architectural exterior and interior views but only few 3d modelling are done using BIM.

The aim of the study is to examine the factors that are essential for the adoption of BIM, assess the level of awareness of BIM amongst Engineers and Architects in Nepal and recommend ways forward to improve the efficiencies and effectives in the delivery of construction projects in Nepal.

## 2. BIM Maturity, benefits and perceived barriers

Various stages of BIM modelling have been developed in terms of the information integrated in the model as dimensions(D). 3D-Modelling (an intelligent 3D CAD model; 4D- Scheduling; 5D-Cost Estimating; 6D-Sustainable Design (Green Design); 7D-Facility Management and 8D- Health and Safety and so on. Several software that support BIM have been developed over the years, the most commonly used software include: Tekla BIMsight, Revit, Navisworks, BIMx, ArchiCAD. The adoption of BIM and its maturity in the AEC industry shall be observed from its applications.

The Bew-Richards BIM Maturity Model shown in Figure 1 is the most widely used maturity model to discuss the BIM maturity in an industry or an organisation.

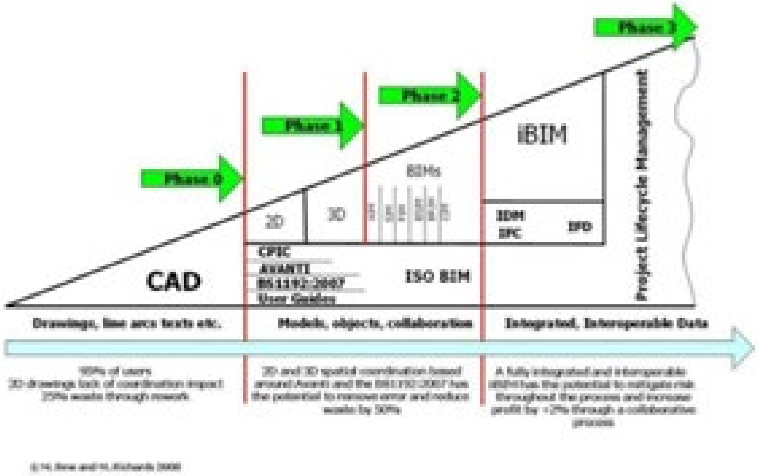


*Figure 1: Bew-Richards BIM Maturity Model (Bew & Richards, 2008)*

Level 0 is the first stage where BIM is just a CAD tool. Level 1 involves partly modelling in 3D which can run in coordination with other protocols that help in information management. In level 2, 2D and 3D models of earlier levels are developed further to create a digital model of the proposed facility. Parametric modelling is done in which objects can be cognitive and can be programmed to work relative to one another. At this level of BIM development, waste and error can be cut by up to 50% (Gould, 2010). In level 3, BIM becomes fully interoperable and can be shared by all project participants in real time. The process of information sharing is done through information management protocols. At this stage of BIM development, BIM utilisation can increase profit and mitigate risk significantly (Bew & Richard, 2008; Gould, 2010).

By integrating BIM with construction project management and infrastructure lifecycle management (ILM) solutions, project stakeholders can gain new efficiencies across the entire project lifecycle. BIM model also helps owners to achieve more control and more savings using BIM in project design and construction (Eastman et al 2008).

There are several problems when implementing BIM in fragmented AEC industry and this relates to many different barriers hindering effective adoption of BIM (Lindblad, 2013). Table 1 presents the reasons for not applying BIM as identified in various research studies conducted by Yan & Damian, 2019; Howard & Björk, 2008; Arayici et al 2009; and Kjartansdóttir, 2011.

*Table 1: Reasons for not using BIM in projects*

| | |
|---|---|
| • People refuse to learn and think current design technology is enough for them to design the projects | • Reluctance to initiate new workflows or train staff |
| • people think that BIM is unsuitable for the projects | • Firms do not have enough opportunity for BIM implementation |
| • Conception that BIM wastes time and human resources | • BIM does not offer enough of a financial gain to warrant its use |
| • High cost of education, copyright and training | • BIM lacks features or flexibility to create building model/drawing |
| • Need of sharing information | • Clients are not requiring BIM |
| • Absence of legal issues to implement BIM | • The existing CAD system fulfils the need to design and draft |
| • Firms are not familiar enough with BIM use | • BIM does not reduce time used on drafting compared with current drawing approach. |

## 3. Research Methodology

A quantitative research strategy facilitated by a questionnaire survey with few additional qualitative questions was used for this study. The questionnaire consisted of structured and closed-ended (as well as multiple choice) questions. Demographic information was collected to understand the research setting. Respondents were asked to rate the question using a Five-point Likert scale for example 1 for strongly agree and 5 for strongly degree.

The professionals involved in architecture and engineering firm of Kathmandu valley were selected for the study. The study population was limited to Kathmandu valley. Due to lack of official data for engineers and architects in Kathmandu valley, a population of 9296 was considered as per the data used by Nepal Engineers Association for election in Kathmandu in 2018. The total number of Engineers and Architect is expected to be higher considering recent graduates and unregistered professionals, however, this was the only authentic information available for this study. Using the formula used by Cochran (1963), the sample size for the study was estimated as 370.

A pre-testing was carried out using 5% of the sample size of 18 using convenience sampling method. A few modifications to the questions were made as a result of pre-testing. Kobocollect tool was used for carrying out the survey. The quantitative data collected from the questionnaire were analysed through MS Excel and SPSS software. Descriptive Statistics (Frequencies and Percentile, the Mean, Standard Deviation and Relative Important Index- RII) and inferential statistics using t-test (two-tailed) and p-value, for significant test were used. Two optional questions at the end of the survey questions were designed to gain additional opinion regarding the topic. A thematic analysis was used for the qualitative questions.

# 4. Results and Discussion

A total of 113 completed responses were received which is less than 50% of the estimated sample size (370). The achieved margin of error is calculated as 9%. For a questionnaire survey and level of accuracy required for this study, less than 10% margin of error has been achieved, which is considered acceptable.

## 4.1 Respondents' Profiles

The target respondents of the questionnaire survey were the professionals (Architects, Civil Engineers, Mechanical Engineers, Electrical Engineers, and other Engineers who work in design and construction) in the AEC industry in Kathmandu valley. This section analyses the demographic data of the 113 respondents. Table 2 presents the characteristics of the respondents as follows:

*Table 2: Respondents' Demographic Data*

| General information about respondents | Categories | Frequency | Percentage |
|---|---|---|---|
| Gender | Male | 65 | 57.5% |
| | Female | 48 | 42.5% |
| Educational Qualification | Bachelor's Degree | 91 | 80.5% |
| | Master's Degree | 22 | 19.5% |
| | PhD | 0 | 0.0% |
| Study place of Professional Degree | Nepal | 89 | 78.8% |
| | Abroad | 18 | 15.9% |
| | Both | 6 | 5.3% |
| Field of study | Architecture | 41 | 36.3% |
| | Civil Engineering | 37 | 32.7% |
| | Electrical Engineering | 6 | 5.3% |
| | Mechanical Engineering | 29 | 25.7% |
| | Other | 0 | 0.0% |
| Nature of the workplace | Consultant | 50 | 44.2% |
| | NGOs | 5 | 4.4% |
| | Contractor | 22 | 19.5% |
| | Governmental | 28 | 24.8% |
| | Academics/Research | 1 | 0.9% |
| | Other | 7 | 6.2% |
| Current field -present job | Designer | 55 | 48.7% |
| | Supervisor | 4 | 3.5% |
| | Site Engineer | 22 | 19.5% |
| | Project Manager | 5 | 4.4% |
| | Other | 19 | 16.8% |
| | Academics/Researcher | 8 | 7.1% |
| Years of experience | Less than 5 years | 89 | 78.8% |
| | From 5 to less than 10 years | 16 | 14.2% |
| | 10 years and more | 8 | 7.0% |
| Percentage of implementation the work by using 3D programs | Less than 25% | 42 | 37.2% |
| | From 25% to less than 50% | 25 | 22.1% |
| | From 50% to less than 70% | 24 | 21.2% |
| | 70% and more | 22 | 19.5% |
| Which software tool do you use to carry out projects? (Respondent were asked to choose multiple options, percentages calculated based on total of 251 responses) | AutoCAD (2D) | 93 | 37.05% |
| | AutoCAD (3D) | 23 | 9.16% |
| | Sketchup | 58 | 23.11% |
| | Revit | 27 | 10.75% |
| | 3ds Max | 5 | 2.00% |
| | ArchiCAD | 5 | 2.00% |
| | Tekla Structure | 3 | 1.20% |
| | Navisworks | 1 | 0.39% |
| | Other | 36 | 14.34% |

The survey results presented in Table 2 show that the use of 3D software in the design and construction of built assets in Nepal is very low. 3D software are used only by Architects for both the exterior and the interior design of the building and by civil engineers for structural analysis. Where BIM software used, "Revit" was found to be most used with 10.75% of respondents using it. Other BIM software like ArchiCAD, Tekla Structures and Navisworks were used less than 5% in total.

## 4.2 Level of Awareness of BIM

The first set of questions consisted of nine statements to assess the level of the awareness of BIM amongst Engineers and Architects in Nepal. The statements were named from B.1 to B.9. The descriptive statistics, i.e. Means, Standard Deviations (SD), t-value (two-tailed), probabilities (P-value), Relative Importance Indices (RII), and finally ranks were established according to RII and presented in Table 4 as follows based on their rank. The critical value of t: at degree of freedom (df) is [113-1] = 112 and significance probability level of 0.05 equals to 1.98. The same values were used in table 4 and 5 too.

*Table 3: Level of Awareness of BIM amongst Engineer and Architects in Nepal*

| No. | Level of awareness of BIM amongst Engineers and Architects in Nepal | Mean | SD | RII (%) | t-value (two-tailed) | P value (Sig) | Rank |
|---|---|---|---|---|---|---|---|
| B.8 | *I think that BIM technology is important for the AEC industry in Nepal.* | 3.84 | 0.786 | 76.81 | 11.360 | 0.000 | 1 |
| B.9 | *I think that BIM technology has a positive impact on the sustainable environment.* | 3.82 | 0.735 | 76.46 | 11.859 | 0.000 | 2 |
| B.7 | *I know that Revit and ArchiCAD programs are BIM technology techniques.* | 3.31 | 1.078 | 66.19 | 3.057 | 0.003 | 3 |
| B.4 | *I have a good idea about the concept of BIM technology.* | 2.68 | 1.046 | 53.63 | -3.252 | 0.002 | 4 |
| B.6 | *I have an idea about how to use BIM technology programs.* | 2.66 | 1.099 | 53.27 | -3.289 | 0.002 | 5 |
| B.5 | *I have a high rate of information regarding the use of BIM technology in Engineering project management.* | 2.53 | 0.983 | 50.62 | -5.083 | 0.000 | 6 |
| B.1 | *I have read some research and studies about BIM.* | 2.33 | 0.977 | 46.55 | -7.290 | 0.000 | 7 |
| B.2 | *Some of my college courses at University talked about BIM.* | 2.14 | 0.972 | 42.83 | -9.405 | 0.000 | 8 |
| B.3 | *I use BIM technology in my job.* | 2.04 | 1.206 | 40.88 | -8.462 | 0.000 | 9 |
| | All Statements | 2.82 | 0.140 | 56.36 | -13.916 | 0.000 | |

The numerical scores obtained from the questionnaire responses (Table 3) provided an indication of the awareness level of BIM amongst Engineers and Architects in Nepal. The findings indicated that "I think that BIM technology is important for the AEC industry in Nepal." (B.8) got the highest rank according to the overall respondents. "I think that BIM technology has a positive impact on the sustainable environment." (B.9) got the second rank. This showed that the respondents were aware of the importance of BIM. "Some of my college courses at University talked about BIM." (B.2) was ranked as the 8th position.

About 67% total respondents who studied in Nepal had never taken or rarely known about courses about BIM in their universities. Remaining 33% of the total respondents have sometimes or often known about BIM courses. Similarly, Architects (36% of respondents) were the highest group who have learned about BIM in university with 41.4%. 62% of respondents have never or rarely learned about BIM courses. This highlights the architecture and engineering courses in Nepal do not include BIM in their curriculum. "I use BIM technology in my job." (B.3) was ranked in the 9th position. It is a meaningful and realistic result about the current situation with AutoCAD (2D) and SketchUp dominating for 2D drafting and 3D modelling respectively.

The mean for all statements in "the level of awareness level amongst Engineers and Architects in Nepal" equals to 2.83. The total RII equals to 56.36% which is less than the neutral value of RII is 60% (3/5* 100). The total P-value of all items is 0.00, which is less than the significance level 0.05. Based on these results, it can be concluded that the awareness level of BIM amongst Engineers and Architects in Nepal is low.

## 4.3 Strength of barriers in the adoption of BIM system in design and construction

To investigate the strength of barriers in adoption of BIM system in design and construction in Nepal, 14 statements (C.1 to C.14) were used. The descriptive statistics were used to analyse the data as shown in table 4.

*Table 3: Level of Awareness of BIM amongst Engineer and Architects in Nepal*

| No. | Strength of barriers in adoption of BIM system in design and construction in Nepal | Mean | SD | RII (%) | t-value (two-tailed) | P value (Sig) | Rank |
|---|---|---|---|---|---|---|---|
| C.13 | *Architects/ Engineers are willing to learn new applications because of their educational culture & their understanding of limitations of existing programs they are dealing with.* | 4.05 | 0.8 | 81.06 | 13.952 | 0.000 | 1 |
| C.14 | *There is a need for real case studies of BIM implementations in AEC projects in Nepal to demonstrate the positive return of investment.* | 4.05 | 0.73 | 81.06 | 15.290 | 0.000 | 2 |
| C.8 | *Small firms lack investment to start a new workflow that is necessary for the adoption of BIM effectively.* | 3.65 | 0.801 | 72.92 | 8.626 | 0.000 | 3 |
| C.9 | *Governmental framework and regulations do not exist to support the implementation of BIM.* | 3.58 | 0.754 | 71.50 | 8.177 | 0.000 | 4 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| C.6 | *Effective collaboration among project stakeholders to exchange necessary information for BIM application is difficult due to the fragmented nature of the AEC industry.* | 3.54 | 0.641 | 70.80 | 8.955 | 0.000 | 5 |
| C.4 | *Professionals think that the current CAD system and other conventional programs satisfy the need of designing and performing the work and complete the project efficiently.* | 3.52 | 0.757 | 70.44 | 7.302 | 0.000 | 6 |
| C.12 | *There are opportunities for education or training on the use of BIM, whether in the university or any governmental or private training organizations.* | 3.45 | 0.906 | 69.03 | 5.280 | 0.000 | 7 |
| C.1 | *The cost of BIM software and necessary hardware updates is high.* | 3.44 | 0.694 | 68.85 | 6.740 | 0.000 | 8 |
| C.7 | *The AEC companies and institutions resist for any change can occur in the workflow system whilst using the BIM.* | 3.41 | 0.715 | 68.14 | 6.096 | 0.000 | 9 |
| C.11 | *Architects/ Engineers have necessary skills in the use of BIM.* | 3.16 | 0.941 | 63.19 | 1.807 | 0.075 | 10 |
| C.5 | *Stakeholders are aware of the benefits that BIM can bring to projects and companies.* | 3.11 | 0.9 | 62.12 | 1.299 | 0.212 | 11 |
| C.2 | *Project stakeholders are aware of the benefits of using BIM.* | 2.98 | 0.866 | 59.65 | -0.245 | 0.828 | 12 |
| C.3 | *The AEC practitioner have knowledge of how to use BIM in AEC projects.* | 2.96 | 0.706 | 59.29 | -0.602 | 0.595 | 13 |
| C.10 | *The clients are actively demanding the use of BIM in design and construction of the projects.* | 2.95 | 1.007 | 58.94 | -0.528 | 0.576 | 14 |
| | All Statements | 3.42 | 0.103 | 68.36 | 42.949 | 0.000 | |

Table 4 provides RIIs and ranks from the highest degree (The strongest BIM barrier) to the least degree (The most vulnerable BIM barrier) of BIM barriers, respectively. The findings indicated that "Architects/ Engineers are willing to learn new applications because of their educational culture & their understanding of limitations of existing programs they are dealing with." (C.13) with (RII =81.06%; P-value = 0.00) got the highest rank according to the overall respondents. This indicates the limitation of the current work programs used and the need for such solutions.

"There is a need for real case studies of BIM implementations in AEC projects in Nepal to demonstrate the positive return of investment." (C.14) with (RII = 81.06%; P-value = 0.00) got the second rank. This finding is result of the lack of real cases of BIM implementation in Nepal. The findings for the statement "Professionals think that the current CAD system and other conventional programs satisfy the need of designing and performing the work and complete the project efficiently." (C.4) ranks 5th position with (RII= 70.8% and P-value = 0.00). The use of AutoCAD by most of the respondents (37.05%) is consistent with this finding, where current work system is found to be conventional.

The overall results for the field of "Strength of barriers in adoption of BIM system in design and construction in Nepal" show that the Mean for all statements equals 3.42. The total RII equals 68.36%, which is higher than 60% (neutral value of RII as discussed earlier). As shown, the value of t-test (42.949) is greater than the critical value of t (1.98). The total P-value of all items also equals 0.00, which is less than the significance level 0.05. So, the result is statistically significant.

The top five barriers to BIM adoption, which were rated by the respondents, are logical and acceptable to be the strongest barriers in adoption of BIM system in design and construction in Nepal. Based on all the previous results, BIM barriers are substantially affecting the adoption of BIM in the AEC industry in Nepal.

## 4.4 Current status of BIM adoption in AEC firms

The final set of questions asked to establish status of BIM adoption in AEC firms consisted of nine statements to assess the use of BIM during different stages of design and construction. The statements were named from D.1 to D.9 (Table 5).

*Table 5: Use of BIM in different stages of construction*

| No. | Use of BIM in different stages of construction | Mean | SD | RII (%) | t-value (two-tailed) | P value (Sig) | Rank |
|---|---|---|---|---|---|---|---|
| D.3 | *Use of BIM during design and detailing stages* | 2.58 | 1.419 | 51.50 | -3.181 | 0.002 | 1 |
| D.1 | *Use of BIM software and tools* | 2.44 | 1.288 | 48.85 | -4.600 | 0.000 | 2 |
| D.4 | *Use of BIM during analysis* | 2.35 | 1.342 | 47.08 | -5.116 | 0.002 | 3 |
| D.2 | *Use of BIM in conceptual design* | 2.35 | 1.266 | 46.90 | -5.498 | 0.000 | 4 |
| D.5 | *Use of BIM during construction and fabrication* | 2.29 | 1.367 | 45.84 | -5.504 | 0.000 | 5 |
| D.6 | *Use of BIM during scheduling and estimating* | 2.19 | 1.315 | 43.89 | -6.509 | 0.000 | 6 |
| D.7 | *Use of BIM for interdisciplinary engineering professions (electrical, mechanical, plumbing, sustainability, etc.)* | 2.18 | 1.304 | 43.54 | -6.709 | 0.000 | 7 |
| D.9 | *Use of BIM during operation and maintenance* | 2.00 | 1.217 | 40.00 | -8.732 | 0.000 | 8 |
| D.8 | *BIM uses during renovation* | 1.93 | 1.178 | 38.58 | -9.662 | 0.000 | 9 |
| | All Statements | 2.26 | 0.070 | 45.1311 | -113.363 | 0.000 | |

The findings indicated that "Use of BIM during design and detailing stages" (D.3) got the highest rank. A cross-tabulations were done between this statement and 'Present nature of job' for further analysis which revealed that out of 48.6% of respondents working as designers, 43.6% are regularly using BIM software for design and detailing. Similarly, the finding for "Use of BIM software and tools" (D.1) with (RII=48.85%, P-value = 0.000) got the second rank according to the overall respondents". "BIM uses during renovation" (D.8) was ranked 9th position or last with (RII = 38.58%, P=0.000). The mean data shows the inclination of respondent towards "never or rarely" maximum with 73.5% of all respondents. The overall results for the field of "Use of BIM in different stages of construction" show that the Mean for all statements equals 2.26. The total RII equals 45.13%, which is less than 60% (neutral value of RII as discussed earlier). As shown, the value of t-test (113.363) is greater than the critical value of t (1.98). The total P-value of all items also equals 0.00, which is less than the significance level 0.05. So, the result is statistically significant.

Analysing the mean score for BIM uses in different stages which is all less than 3 (standard mean) & percentage of software use indicate maximum use of AutoCAD (2D) and SketchUp for drafting and 3D modelling, it can be concluded that use of BIM is in early stages (Level 0 of Bew-Richards' BIM Maturity Model). Detail of the projects that participants were involved was not collected, further analysis in the use of BIM based on the scale of projects could not be analysed.

## 4.5 Thematic Analysis

To analyse the views of the respondents for the two text-based questions (Table 6: E.1 and E.2), a thematic analysis was used to analyse the 33 responses received, relevant themes and codes were identified and evaluated.

*Table 6: Thematic analysis details*

| Question | Themes | Codes (words used by the respondents in their response) |
|---|---|---|
| *E.1: How do you describe the status of BIM use in Nepal?* | Evolving | Developing, slowly growing, beginner level<br>Improving, no systematic use, limited use |
| | Awareness | low awareness, less aware |
| | Requirement & cost | lower client requirement, less affordability, expensive |
| *E.2: How can we promote the use of BIM in Nepal?* | Education | university courses, awareness training & workshops |
| | Cost | Marketing, funding to users |
| | Requirement & regulations | Introduction to workplace, compulsory regulation, client requirement |

The thematic analysis supported the findings from the literature review and quantitative data analysis highlighting that cost for BIM was established as one of the barriers in adoption of BIM system. Lack of education or training has been acknowledged as one of factors of low awareness and barriers of BIM adoption in Nepal Governmental framework and client requirement have been identified as barriers of BIM. A suitable governmental framework and mandating BIM would be required for the promotion of BIM adoption.

## 5. Conclusions and Recommendations

This paper identifies the status of BIM use in Nepal as low and the adoption of BIM is in early stages. The level of awareness amongst Engineers and Architects in Nepal is also low. Currently AutoCAD and SketchUp are mostly used for 2D drafting and 3D modelling respectively in the construction projects. The BIM methodology is not followed in projects. BIM, in some form, was used maximum during design and detailing stages by the designers. There is a need for real case studies and best practices to promote the use of BIM in Nepal. Education and training to increase BIM awareness and appropriate governmental policy and framework is essential. The AEC companies need to invest in trainings and workshops in BIM for the Architects and Engineers. Further studies should focus on BIM application from specific perspective either from consultant or contractor and can cover using BIM in design, construction and operations phases using case study projects. The topic for further studies can include BIM implementation benefits and challenges in Nepal by demonstrating a real-life BIM model of building and infrastructure projects.

# 6. References

*Ahmad, A. M., Demian, P., & Price, A. (2012). Building information modelling implementation plans a comparative analysis. School of Civil and Building Engineering, Loughborough University, UK.*

*Amade, B., Onwuka, U. S., Oguzie, J. O., Umoh, E. D., & Uduma, P. N. (2018). Building Information Modelling and its application in building construction projects. PM World Journal, VII(XII).*

*Arayici, Y., Khosrowshahi, F., Ponting, A., & Mihindu, S. (2009). Towards implementation of building information modelling in the construction industry. Proceedings of the Fifth International Conference on Construction in the 21st Century. Istanbul, Turkey 1342-1351.*

*Azhar, S. (2011). Building information modelling (BIM): Trends, benefits, risks, and challenges for the AEC industry. Leadership and Management in Engineering, 241-252.*

*Azhar, S., Nadeem, A., Leung, B. H., & Mok, J. Y. (2008). Building Information Modelling (BIM): A new paradigm for visual interactive modelling and simulation for construction projects. First International Conference on Construction in Developing Countries, 1, 435-46.*

*Bew, M., & Richard, M. (2008). BIM Maturity Ramp. Building Smart, CPIC.*

*Cochran, W. G. (1963). Sampling Techniques (2nd ed.). New York: John Wiley and Sons, Inc.*

*Crowley, C. (2013). Identifying opportunities for quantity surveyors to enhance and expand the traditional quantity surveying role by adopting building information modelling. CITA BIM Gathering, 71-77.*

*Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2008). BIM handbook: A guide to building information modelling for owners, managers, designers, engineers and contractors. John Wiley & Sons.*
*Gould, L. (2010). What is BIM and should we care? Construction Research & Innovation, 26-31.*

*Howard, R., & Björk, B. C. (2008). Building Information Modelling – Experts' views on standardisation and industry deployment. Advanced Engineering Informatics,22(2), 271-280.*

*Kjartansdóttir, I. B. (2011). BIM adoption in Iceland and its relation to lean construction. MSc Thesis, Construction Management, the School of Science and Engineering, Reykjavík University, Iceland.*

*Lindblad, H. (2013). Study of the implementation process of BIM in construction projects. Retrieved from https://www.diva-portal.org/smash/record.jsf?pid=diva2%3A633132&dswid=-5134*

*Yan, H., & Damian, P. (2019). Benefits and Barriers of Building Information Modelling. Department of Civil and Building Engineering, Loughborough University, UK.*

# *Feasibility of Underground Kathmandu Metro Rail-Patan Line*

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## Abstract

Traffic congestion in the capital city, Kathmandu, has become a serious problem for the commuters and the government itself. The valley is in a need of a robust public transport system. The introduction of the Kathmandu Metro Rail will be an evolutionary change replacing the old transport system in response to the perceived socio-economic needs of the people. Especially, due to the limited right of the way of the existing road, the elevated or at-grade metro is not feasible in the core area of the valley. Similarly, considering the historical temples, monuments, and Rato-Machindra heritage route located along the Patan line, the underground metro route is found to be the best and most sustainable solution. Moreover, the underground metro through tunnels in the seismically active Kathmandu valley is found to be more beneficial and effective. The underground Kathmandu Metro-Patan line initiating from the central station at Bhrikutimandap ends at the launching portal at Khumaltar, Satdobato. A 6.2 km long-proposed line passes through the intermediate stations located at Tripureshowr, Pulchowk, and Lagankhel. The proposed metro route is in general 15-25m below ground level. However, while crossing the Bagmati river near Thapathali/Tripureshor, the tunnel axis depth is at a very shallow depth of 8m below the ground. Ground characterization along the line shows that the route is predominantly passing through the Kalimati formation. Prominent heritage and buildings of high importance located along the route are highlighted for an impact assessment.

*Keywords:* Kathmandu Metro Rail Patan Line, feasibility study, underground structures, heritages, tunnel

# 1. Background

An uncountable number of temples, historic monuments, and cultural heritage have made the Kathmandu Valley the best religious hub of Nepal. Similarly, the capital city, Kathmandu is the perfect destination for political and economic purposes. Even so, the growing demand for public transport, unplanned urbanization, and insufficient transport infrastructure are concluding that there is no reliable public transport in the Valley. Introducing Kathmandu Metro will be beneficial and a sustainable solution to coping with this problem.

# 2. Route Selection

A tentative network of four underground metro lines for the central part of the Valley, namely the Kathmandu Line (green), Patan Line (blue), Bishnumati Line (black), and Chakrapath Line (red) is proposed by (Amatya, 2017) (B.L. Amatya, 2020) as illustrated in Figure 1. The research section of the proposed Patan-Line is from the Bhrikutimandap to Satdobato as indicated within the blue rectangular box below.

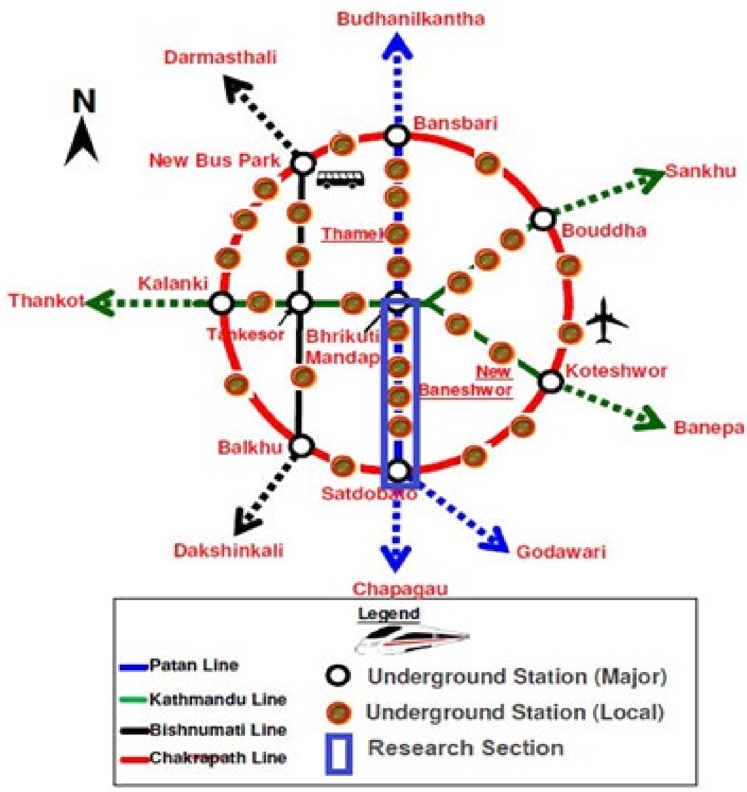


*Figure 1: Idealized Map of Kathmandu Metro Map. (B.L. Amatya, 2020)*

# 3. Ways of Metro Rail development

Metro route selection is a complex task. It is affected by various factors such as traffic density, city structure/urban pattern, surface and subsurface features, archaeological features/ heritage, and political influences. However, in the simplest approach, the routes in the valley in the city core area could be delineated by adopting either the existing major road alignments or the alignment of the major rivers of the valley such as the Bagmati and the Bishnumati.
In general, the metro rail route in the valley can be developed in three ways:

## 3.1 Surface track (at-grade)

Surface track or at-grade metro trains are those trains that are constructed on the natural surface with some levelling. It is suitable for the plain terrain without steep gradients.

## 3.2 Elevated track

An elevated railway or elevated train is a rapid transit railway with tracks above street level on a viaduct or other elevated structure (usually constructed from steel, cast iron, concrete, or bricks).

## 3.3 Underground tunnel

Metro Rails which are constructed beneath the ground level by boring the tunnels are commonly known as the Underground Metro Rail. These types of metro rail construction are suitable under dense settlements and stable ground conditions.

# 4. Features of Kathmandu Metro-Rail Patan Line

## 4.1 Natural Surface condition

As mentioned in Section 3, the simplest approach for selecting the metro-rail alignment in the dense settlement is to follow the existing roads or the rivers. Following the existing road gives enough space for the construction of the piers in the case of at-grade while reducing the induced settlement in the case of the underground tunnel. The proposed alignment with the intermediate stations is shown in Figure 2.

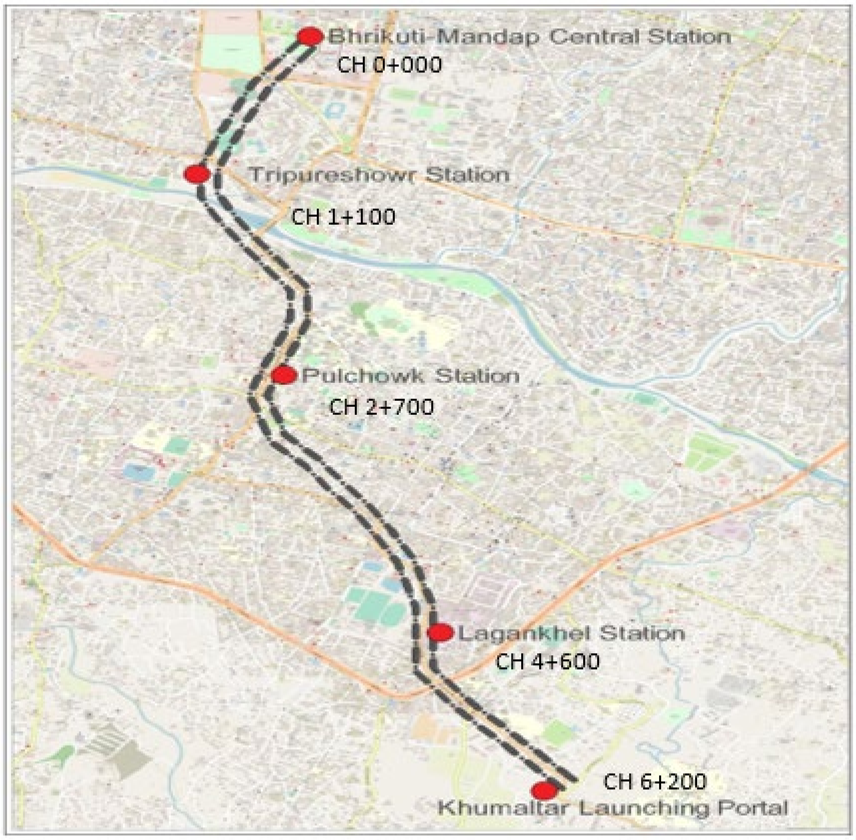


*Figure 2: Proposed stations of the Patan Line*

Similarly, the natural ground condition of the proposed route alignment is undulating in nature. As Kathmandu Valley is the ancient lake formed it possesses a higher altitude at the extremities and lower at the middle. Initiating from the Bhrikutimandap Central Station and terminating at the Khumaltar launching portal, the maximum altitude difference is around 68m. Bhrikutimandap central station is at 1292m from the mean sea level which continuously decreases up to the Bagmati river crossing and finally becomes at the altitude of 1272m. Similarly, on moving ahead from the Lagankhel station the natural ground surface attains a maximum altitude of 1340m which terminates at an altitude of 1332m at the Khumaltar Launching Portal as shown in figure 3. This ground condition of the proposed alignment does not favour the surface or at-grade metro rail construction.

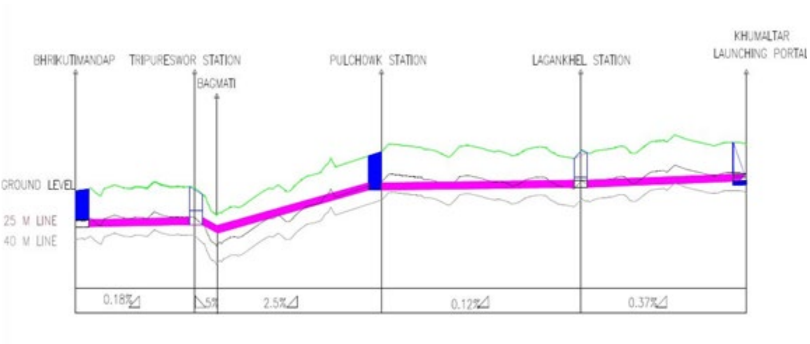


*Figure 3: Longitudinal Profile-Patan Line*

## 4.2 Limited right of way

Existing roads along the proposed Kathmandu Metro Patan-Line are barely four-lane. Similarly, where the construction is to be carried out in the middle of the road, central two lanes including the median will be required for construction activities. During piling and open foundation work, a width of about 9 m (minimum) will be required for construction and the same will be barricaded (Anon., 2018). As the result due to the limited right of the way and sharp turning of the existing road, it is impossible to construct the elevated structures in the proposed Patan Line.

## 4.3 Heritage Consideration

Kathmandu is well known as the city of temples and old monasteries. Historical temples and religious places like Pashupatinath, Boudha, Krishna Mandir, Durbar Squares, and many others are in the Valley. Thus, any new infrastructure should be planned without any negative effects on them. Similarly, UNESCO listed heritage, palaces, and ancient sites that should remain unaffected by the proposed metro-rail project. The prominent sites along the proposed Kathmandu Metro- Patan line are illustrated in Figure 4.

Moreover, the Patan area has a heritage route for the annual Machindra Nath Chariot festival as indicated by the red line in Figure 5. The metro route passing through the area must be underground to prevent any physical obstruction to the annual chariot festival route to preserve the culture of the town taking place for the last several hundred years.

In case of the elevated metro-rail alignment may pass through or over the prominent heritage sites. Even the heritages have to be dismantled during the implementation of the metro-rail project. Therefore, the construction of the elevated metro structures will be a huge mistake from the heritage conservation point of the view. On the other hand, the concrete structures and piers of the elevated metro rail project also destroy the aesthetic beauty of the city.


*Figure 4: Prominent sites along Kathmandu Metro-Patan Line*

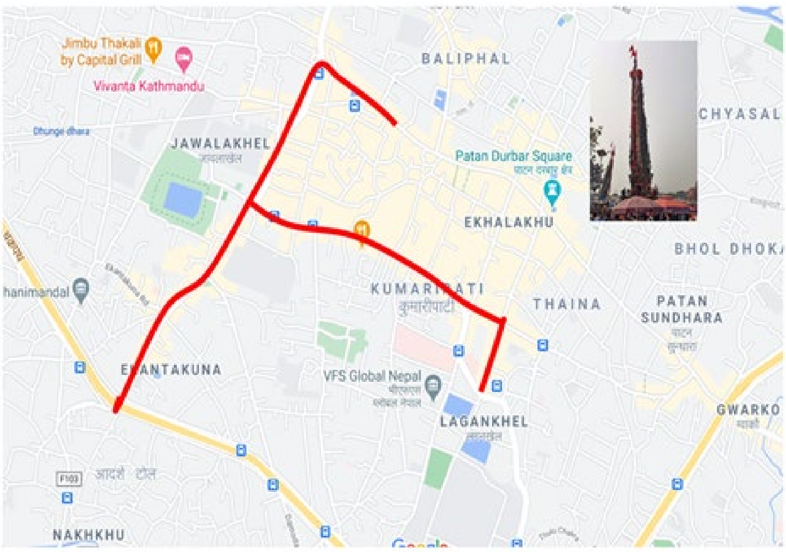


*Figure 5 Machindra Nath chariot festival heritage route (red line)*

## 4.4 Seismic Consideration

Nepal is located in the seismic-prone zone and is frequently affected by major earthquakes like the 1998 Nepal- Bihar earthquake and the 2015 Gorkha earthquake. Seismic study shows that Kathmandu is located in an earthquake-prone zone and the elevated metro is susceptible to more damage than underground metro structures. Thus, the more the depth of the underground structures more will be the safety and the taller the structures above the ground more will be the seismic risk as mentioned in the table below. As the result, as per the seismic perspective, elevated metro rail structures are more vulnerable than underground tunnel structures.

*Table 1. Ratios of ground motion at depth to the motion at the ground surface (Power, et al., 1996)*

| Tunnel Depth (m) | The ratio of ground motion at tunnel depth to motion at the ground surface |
|---|---|
| ≤ 6 | 1.0 |
| 6-15 | 0.9 |
| 15-30 | 0.8 |
| ≥ 30 | 0.7 |

## 4.5 Soil Consideration

The proposed Patan Line route crosses the Bagmati river at nearly 200m downstream of the Kupondole Bridge. Elevation at the Bhrikutimandap is 1292m and the lowest elevation is at the centre of the Bagmati river i.e., 1272m from sea level. From the investigation, it is concluded that the proposed alignment mostly passes through the Kalimati Formation (clayey silt /silty clay) and lies below the groundwater table. Starting from Bhrikutimandap Central Station up to Pulchowk Metro Station (2+700m Chainage) the alignment is within Kalimati Formation. On forwarding from Pulchowk Metro Station up to Satdobato chowk (5+300m Chainage) the alignment seems to be on Chapagaun Formation.

Geotechnical Investigation Reports (GIRs) from the Department of Railways and Multi-Lab Disciplinary Pvt. Ltd was studied and various correlations were referred and the following conclusions were made: wet density at various sections in the alignment is found to be in the range of 15-20 KN/m3, the drained angle of shearing resistance is found to be 20°, drained and undrained cohesion are found to be in the range of 15-19 KPa and 30-60 KPa respectively, drained and undrained Young's Modulus of Elasticity is found to be 23 MPa and 36 MPa respectively, and drained and undrained Poisson's ratios were found to be 0.3 and 0.5 respectively.

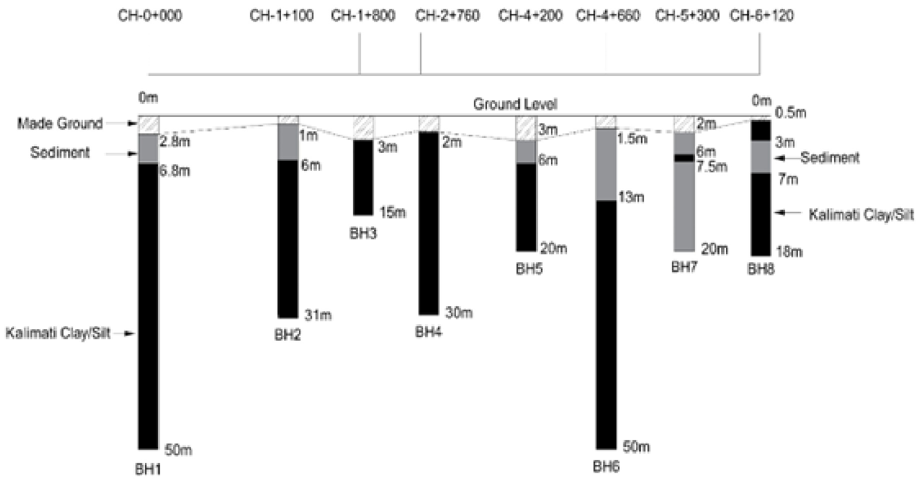


*Figure 6. Historical boreholes along the Patan Line*

Amid worse soil conditions as compared to the soil parameters of the proposed Kathmandu Metro Patan Line, existing metro rails of India such as Delhi Metro Rail and Kolkata Metro Rail are functioning well. As the result, a detailed geotechnical study shows that the soil of the proposed alignment is competent enough for the underground tunnel construction.

## 5. Conclusion

This paper presents a case study of the analysis of the Kathmandu Metro-Patan Line and demonstrates that an underground tunnel is the best way of the metro construction in the valley. Considering natural surface conditions, limited right of way, heritage consideration, seismic consideration, and soil consideration, the underground tunnel is the solution for the Kathmandu Metro-Rail construction. On the other hand, the elevated metro system will also damage the beauty and aesthetics of this historic city. Inferring all these facts and most importantly preserving the pristine environment of the Valley, a robust and reliable underground metro system accessing larger numbers of commuters is the robust need of Kathmandu Valley.

## 6. Acknowledgement

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## 7. References

*Amatya, B. (2017). A conceptual study on the development of an underground metro rail system in the Kathmandu Valley, Nepal. Proceedings of the World Tunnel Congress.*

*B.L. Amatya, A. B. (2020). Tunneling and underground stations in the ground condition of Kathmandu Valley, Nepal. ITA-AITES World Tunnel Congress, WTC2020, and 46th General Assembly Kaula Lumpur Convention.*

*India, G. O. (2018). STANDARDIZATION OF CIVIL ENGINEERING STRUCTURES OF METRO SYSTEM October 2018, Delhi: s.n.*

*Power, M., Rosidi, D. & Kaneshiro, J. (1996). Strawman: screening, evaluation, and retrofit design of tunnels, New York: National Center for Earthquake Engineering Research. .*

# *Assessment of Safety Practices in Earthquake Reconstruction and Retrofitting Projects*

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## Abstract

Construction industry has been growing in Nepal at a fast pace. This has a major contribution to the economy of Nepal providing a large number of employments in the country. Frequent occurrence of natural disasters such as earthquake, flood and landslides have increased construction works in the country significantly. The Gorkha Earthquake in 2015 in Nepal had caused tremendous damage to infrastructure and loss of lives. It caused damage to both building structures including heritage structures and lifelines like road networks, hydropower projects and water supply systems. This has added a need for large number of reconstruction and retrofitting projects in Nepal. With the increase in construction projects, the number of accidents has also increased. This indicates that the Health and Safety has become an important issue in the construction projects hence required attention. In this context, this study focuses on investigating of safety issues practices in reconstruction and retrofitting projects in the Kathmandu Valley. This study was conducted covering seven reconstructions and retrofitting projects where primary data from the field visits was collected combining data obtained from the secondary sources. Demographic survey was carried out with the help of a questionnaire and filled the questionnaire to get the demographic details of the workers by asking them individually at the live sites. The findings of this study indicate that training, education and experience of workers had a significant role in decreasing the likelihood of occurrence of accidents at site. This is the important outcome from this study that project management can adopt to follow the safety legislation and implementation at the site of the reconstruction and retrofitting projects for improving overall safety.

*Keywords:* Construction projects, Earthquake reconstruction and retrofitting, Safety practices

## 1. Introduction

The construction industry has a large contribution to the economy of a country but, it is affected by several issues like cost overrun, time overrun, price fluctuation triggered by inflation and most importantly due to poor safety performance (Abu Aisheh et al., 2021). According to the report published by International Labour Organization (ILO), 2.3 million workers die each year worldwide due to occupational accident (International Labour Organization, 2017). It is reported that construction is always risky because of outdoor operations, work-at heights, complicated on-site plants and equipment operation coupled with workers attitudes and behaviours towards safety (Choudhry and Fang, 2008). Various tasks are carried out simultaneously in the construction site. All these works are to be implemented with proper coordination with each other. The communication between the workers should be very efficient to ensure proper coordination between them. Even small negligence can have a catastrophic outcome, causing a major accident, putting the project objective in jeopardy. The consequence of an accident may range from a minor short-term delay in work up to the loss of human life. Construction accidents are of various categories. OSHA (2011) has defined falls, electrocution, struck-by and caught-in or caught-between as fatal four hazards. Every year, these fatal four have claimed injuries and deaths of many construction workers as well as third parties. Each year, construction industry is responsible for a disproportionate number of fatalities, lost work hours, and high injury rates. The majority of accidents in this sector are caused by workers' human errors (Hasanzadeh et al., 2019). In developed countries, considerable attention is provided to safety. Whereas, in developing or underdeveloped countries, the condition varies as the consideration of safety is far behind in its implementation (Kheni et al., 2010).

In addition to the increasing number of construction projects in Nepal, the devastating earthquake of April 25th, 2015, named Gorkha Earthquake, has added a large number of demolition projects, reconstruction and retrofitting projects to the list. At present, Nepal is in the post-disaster reconstruction phase. Many structures which were damaged by Gorkha Earthquake are being either completely demolished and reconstructed or retrofitted. The addition of these projects has contributed to the escalation of construction-related accidents in the recent years.

Post-disaster reconstruction is a field on which a lot of thorough research is yet to be done (Alexander, 2010). Although it is a fact that Post-Disaster Reconstruction (PDR) has a lot more ambiguity and complexities than a regular construction project, they are both treated in a similar manner and no special consideration is given to the PDR projects. Construction workers involved in PDR are prone to all the construction hazards of regular construction but with a higher level of exposure (Uddin and Pradhananga, 2019). Despite the added exposure to hazard in a reconstruction/retrofitting project, they are still governed by the same set of laws, rules and regulations of a regular construction project. In addition to that, even the available laws, rules and regulations are found to be neglected in practice. This has affected the safety aspects of the construction industry to a large scale. Workers' safety has not been a prominent research topic among academics when it comes to PDR projects.

# 2. Literature Review

## 2.1 Post-Disaster Reconstruction (PDR) Phase

Total reconstruction of a structure after a disaster refers to the action of bringing the structure back to its original state or even better than its pre-disaster state. There are broadly four stages in a disaster recovery process, they are namely, disaster assessment, preliminary rehabilitation, intricate reconstruction and recovery management. PDR phase involves the activities like demolition of damaged structure, debris management, reconstruction, restoration, retrofitting and seismic strengthening.

### 2.1.1 Retrofitting

Retrofitting is a fairly new concept in the construction industry of Nepal, which deals with restoring a damaged structure to its original form and function. There are three categories of retrofitting: repair, restore and seismic strengthening.

## 2.2 Reconstruction

During reconstruction, a damaged structure is completely dismantled. The site is then cleared and the debris is properly managed. The debris may be further classified into two categories: reusable and scrap. New architectural plans are prepared, either by preserving the originality or by updating the plans according to the new requirements. In most cases even though the interior plans are modified the exterior aesthetics is preserved as per the original design (Gujarat State Disaster Management Authority, 2002).

## 2.3 Construction Accident

Regardless of the size, scale or type of a construction project, construction workers are regularly exposed to the hazardous working environments of a construction site. Accidents can happen at any time to any person and its probability of occurrence can only be minimized but never be completely removed. The possibility of accident originates from the system itself, the work environment and the workers themselves. Staying prepared for the worst case scenario while working at a construction site is the best preventive measure that a worker can adopt in order to stay safe from a construction accident (Vikas and Ilango, 2015).
Occupational Safety and Health Administration (OSHA) has categorized the causes of construction accident into the following fatal fours (OSHA, 2011):

- Falls: Falls from height are one of the major causes of construction deaths; 381 out of 971 total construction fatalities in 2017 were found to be caused due to fall. Situations or events that could cause a construction worker to lose his/her balance and fall are known as fall risks.
- Struck by an object: When a worker makes a sudden and violent contact with a moving object or a part of equipment this could cause a serious injury to the worker. Such hazard is called struck by an object hazard.
- Electrocution: Electrical hazards can cause various types of construction accidents like burns, shocks, fires, and even explosions. Electrocution is the condition or an incident in which a worker comes in to contact with a dangerous amount of electricity.

ß Caught in between: Caught in or between injuries occur when a construction worker is crushed between two objects.

## 2.4 Health Hazards in Construction Sites

Construction workers are more prone to getting occupational diseases because of their employment on the construction site, especially if they are exposed to toxic substances and hardworking circumstances. The following are major causes of health hazards in construction sites (Health and Safety Executive, 2006).

- Asbestos: Asbestos exposure can lead to serious respiratory disorders like asbestosis and cancer.
- Manual handling: Back and other injuries may cause by lifting large and uncomfortable loads.
- Noise and vibration: Hearing loss can be caused by loud noise, and hand-arm vibration syndrome can be caused by using vibrating instruments repeatedly.
- Chemicals: Skin disorders such as dermatitis can be caused by exposure to materials such as cement and solvents.

### 2.5 Training

Training is an essential component of safety management. This is because the workers who perform tasks without adequate training have comparatively higher probability to experience serious injuries and/or even death. Hence, the management should always make sure that all workers are pre-informed about the rules and regulations of site regarding safety at work before they start working. For this purpose, regular training programmes shall be conducted with the involvement of all the workers. The management shall not charge any extra cost to the workers for the training provided and also shall schedule the trainings during work hours as far as possible (DoLIDAR, 2017).

### 2.6 Labor Act, 2074

Labor Acts are passed in order to safeguard rights of the workers in Nepal. Various amendments are made to these acts time and again according to the requirement. Labor Act, 2074 was passed on August 11, 2017 under the orders of the Parliament and it was acknowledged and brought into practice under the order of the President on September 04, 2017. The New Labor Act is a major update to the older Labor Act 1992 (2048). The New Labor Act has brought complete change in employment regime in Nepal. The current Labor Act is far from perfect and many major amendments are yet to come in the future but for now, the rights of the construction workers are promised to be protected by the Act.

## 3. Methodology

Systematic literature review methodology was adopted for the study. To increase the possibility of covering all the materials regarding the topic of this study, technical reports, governmental and non-governmental reports, thesis works and newspaper articles were also taken into consideration as existing literature. Questionnaire survey was carried out to collect primary data for the study from seven different retrofitting projects based in Kathmandu, Nepal.

### 3.1 Study Area

A total of seven monument reconstruction/retrofitting projects were chosen for study which is illustrated in the Table 1. Some of the photographs of the sites are shown Picture 1 to Picture 3.

*Table 1: List of Reconstruction and Retrofitting Projects considered in the study*

| S.N. | Project Name |
|---|---|
| 1. | Dharahara |
| 2. | Adjoining building at North and South sides of Singhadurbar West Gate |
| 3. | Department of Road, Babarmahal |
| 4. | Kaiser Mahal |
| 5. | Budhanilkantha Dharmashala |
| 6. | Bal Mandir |
| 7. | Nepal Administrative Staff College |

Picture 1: Dharahara

Picture 2: Nepal Administrative Staff College

Picture 3: Adjoining building at North and South sides of Singhadurbar West Gate

## 3.2 Data Collection

Data collection techniques included demographic survey and questionnaire survey.

## 3.3 Data Analysis

All the collected data were classified into appropriate categories and finally compiled. MS Excel was used to determine statistical parameters.

### 3.3.1 Chi Square Test

Chi square test is a nonparametric test used to check independence between two variables. It is used to analyse categorical data (Singhal and Rana, 2015). In this study, Chi-square test was adopted because accident, training, age-group, education and experience are all categorical data. Equation (1) was used to calculate chi-square statistic.

$$\chi^2 = \sum_{i=1}^{n} \frac{(O_i - E_i)^2}{E_i} \quad (1)$$

where,
O = observed value
E = expected value

## 4. Results and Discussion

Demographic survey was carried out with the help of a questionnaire prepared based on existing literatures. The questionnaires were printed and distributed to surveyors who then filled the demographic details of the workers by asking them individually.

### 4.1 Age Group

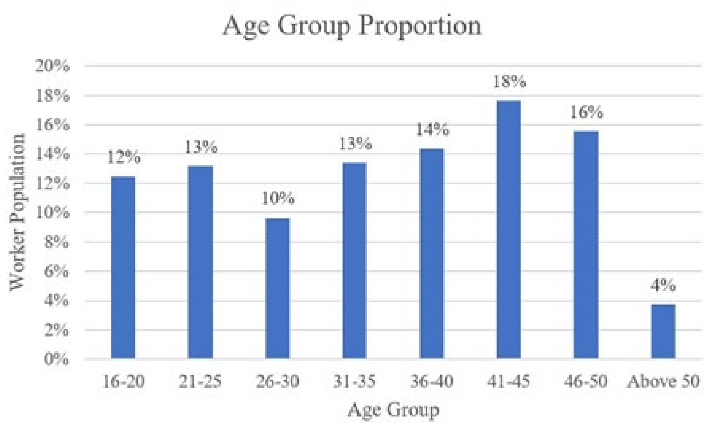


*Figure 1: Worker population distribution with respect to age group*

Figure 1 shows that majority of the workers were middle aged with only 4% of workers being of age above 50. The highest number of workers belonged to the age group of 41-45 years old with a proportion of 18% of the total worker population. As much as 16% of the workers belonged to the age group of 46-50 years old. Similarly, 14% of the total worker population belonged to the age group of 36-40 years old. Both the age groups of 21-25 and 31-35 years old comprised of similar population sizes with a proportion of 13% of the total worker population each. The observation showed that around 12% of the worker population belonged to the age group of 16-20 years old whereas only 10% of the worker population belonged to the age group of 26-30 years old. The graph illustrates that no distinct pattern is established between population distribution of workers and their age.

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## 4.2 Gender

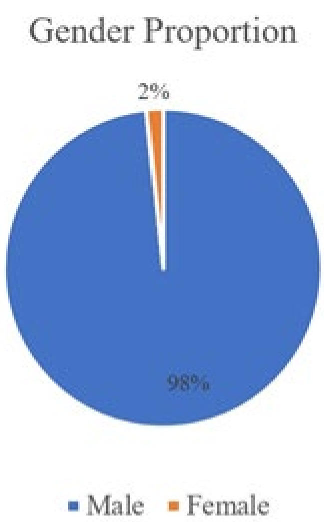


*Figure 2: Worker population distribution with respect to gender*

Figure 2 depicts the survey showed that only 2% of the total worker population were women whereas 98% of the population were men. The women were observed to be designated to cooking and housekeeping activities whereas men were enrolled to various other posts such as labor, mason, carpenter, bar-bender, welder, metal worker, plumber, electrician, painter, machine operator, store keeper, surveyor, etc.

## 4.3 Education

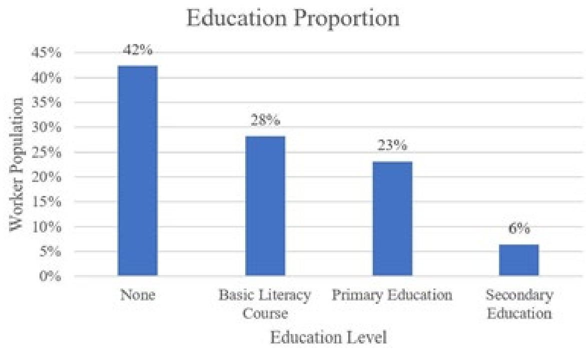


*Figure 3: Worker population distribution with respect to education level*

Figure 3 illustrates the demographic survey illustrated that 42% of the total worker population were illiterate. Around 28% of the worker population had basic literacy courses whereas 23% of the total worker population had received primary education. Similarly, only 6% of the worker population had received secondary education. No worker was found to have higher education than secondary level.

## 4.4 Experience

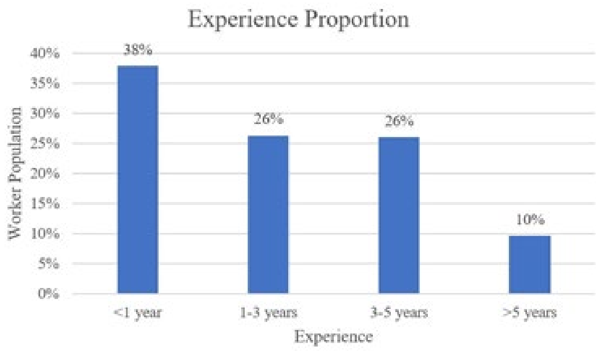


*Figure 4: Worker population distribution with respect to years of experience*

It was seen that around 38% of the worker population had less than a year of experience as shown in Figure 4. Around 26% of the worker population had 1-3 years of experience. Similarly, another 26% of the population had 3-5 years of experience whereas only 10% of the population had work experience of more than 5 years.

## 4.5 Accident

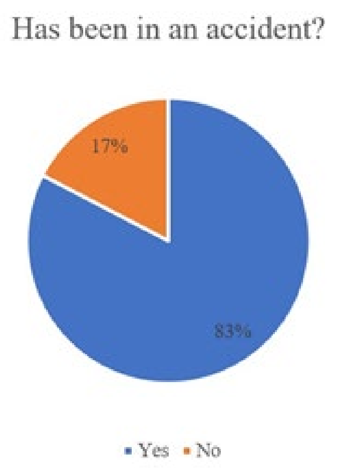


*Figure 5: Worker population distribution with respect to occurrence of accident*

The survey presented that about 83% of the total worker population have had experienced accident during their work ranging from a minor accident to a major one. Around 17% of the population stated that they hadn't experienced any kind of work-related accident till date as depicted in Figure 5.

## 4.6 Training

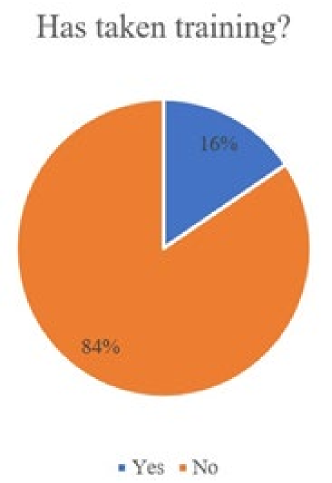


*Figure 6: Worker population distribution with respect to training received*

Figure 6 shows that as much as 84% of the total worker population haven't taken any kind of training related to their work in the construction site. Only 16% of the population have received work related training beforehand. Thus, huge proportion of untrained workers could be one of the reasons for majority of accidents at construction sites.

## 4.7 Relation between demographic variables

### 4.7.1 Training and Accident

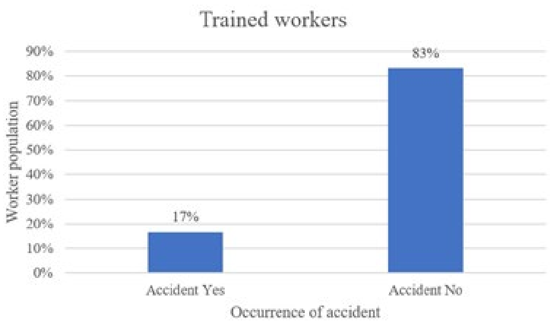



*Figure 7: Trained worker population vs. occurrence of accident*
*Figure 8: Untrained worker population vs. occurrence of accident*

It was seen that only 17% of the worker population who have received training had experienced accident whereas the remaining 83% haven't experienced any kind of accident while working as illustrated in Figure 7. As shown in Figure 8, it was also seen that as much as 95% of the worker population who are untrained had experienced accident whereas only 5% of the untrained worker population haven't experienced any kind of accident while working.

### 4.7.2 Education and Accident

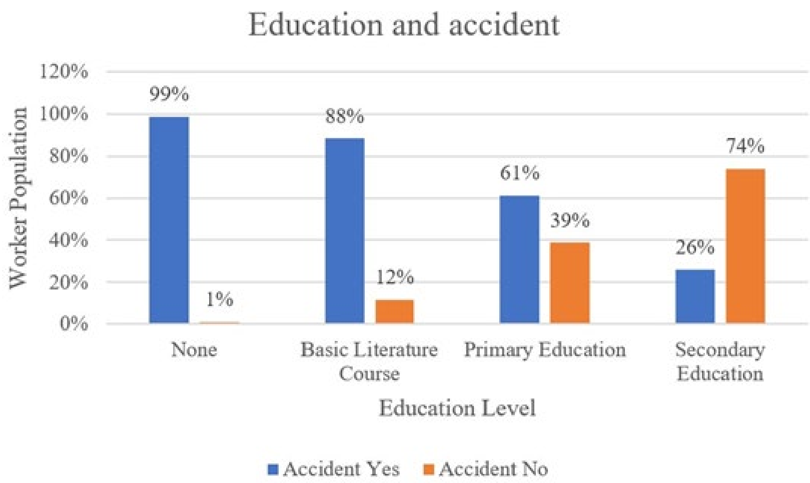


*Figure 9: Worker population vs. education and accident*

It was seen that the worker proportion experiencing accident declines as the level of education increases. Similarly, the worker proportion not experiencing accident is increasing as the level of education increases as shown in Figure 9.

### 4.7.3 Experience and Accident

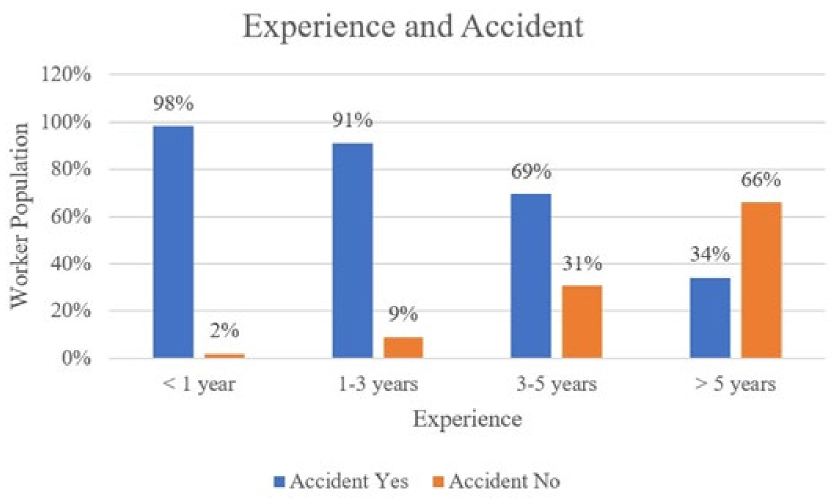


*Figure 10: Worker population vs. experience and accident*

The relationship between worker population against accident is depicted in Figure 10. It can be seen that the worker proportion experiencing accident declines as the years of experience increases. Similarly, the worker proportion not experiencing accident is increasing as the years of experience increases. Certain clauses to be followed during the time of recruitment could possibly decrease the number of inexperienced workers which in turn could reduce the rate of occurrence of accidents at site.

## 5. Conclusions and recommendations for future works

The conclusions that were drawn from this study are presented as follows:

- Safety clauses were included in contract of all the visited sites, yet not all the clauses were seemed to be implemented in practice.
- Although contract clause clearly stated that accident record had to be maintained at any time in site, it was not found to be maintained at any of the seven sites.
- The workers who had received training were less likely to have an accident at site as compared to the workers who had not received any training.
- As the level of education of workers increased, the occurrence of accident decreased.
- Experienced workers were less likely to have an accident at site as compared to inexperienced workers.
- The findings of this study can be employed as guidance for reconstruction or retrofit works in the context of construction sector in Nepal.

The following are few recommendations that could make a visible improvement in the safety sector of the reconstruction and retrofitting projects that are to be carried out in the future:

- Concerned authority shall regularly inspect whether the accident records are properly maintained at every site or not, as well as any preventive measures are adopted to avoid future occurrence of accidents.
- A culture of rewarding and punishing workers shall be introduced; workers following safety rules shall be rewarded whereas workers breaking safety rules shall be punished.
- It is recommended that the management shall organize regular safety awareness programme for the construction workers.
- It is recommended to assign basic literature course as minimum academic qualification during the hiring process of construction workers.
- Minimum experience level shall be associated in the hiring process of construction workers as per nature of the job.

## 6. Acknowledgements

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## 7. References

*Abu Aisheh, Y. I., Tayeh, B. A., Alaloul, W. S. & Jouda, A. F. 2021. Barriers of Occupational Safety Implementation in Infrastructure Projects: Gaza Strip Case. Int J Environ Res Public Health, 18(7), pp.*

*Alexander, D. E. 2010. Rebuilding after Disasters: From Emergency to Sustainability. Construction Management and Economics, 28(10), pp 1117-1119.*

*Choudhry, R. M. & Fang, D. 2008. Why operatives engage in unsafe work behavior: Investigating factors on construction sites. Safety Science, 46(4), pp 566-584.*

*DoLIDAR 2017. Occupational safety and health guidelines. Ministry of Federal Affairs and Local Development.*

*Gujarat State Disaster Management Authority 2002. Repair, Restoration and Retrofitting of Masonry Buildings in Kachchh earthquake Affected Areas of Gujarat. Government of Gujarat.*

*Hasanzadeh, S., Dao, B., Esmaeili, B. & Dodd, M. D. 2019. Role of Personality in Construction Safety: Investigating the Relationships between Personality, Attentional Failure, and Hazard Identification under Fall-Hazard Conditions. Journal of Construction Engineering and Management, 145(9), pp.*

*Health and Safety Executive 2006. Health and safety in construction.*

*International Labour Organization 2017. The ILO's Social Finance Programme. Publications of the International Labour Office.*

*Kheni, N. A., Gibb, A. G. F. & Dainty, A. R. J. 2010. Health and Safety Management within Small- and Medium-Sized Enterprises (SMEs) in Developing Countries. Journal of Construction Engineering and Management.*

*OSHA 2011. Occupational Safety and Health Administration. United States Department of Labor.*

*Singhal, R. & Rana, R. 2015. Chi-square test and its application in hypothesis testing. Journal of the Practice of Cardiovascular Sciences, 1*
*Uddin, S. M. J. & Pradhananga, N. 2019. Construction Workers' Health and Safety at Post-Disaster Reconstruction (PDR) Phase: A Knowledge Gap Analysis.*

*Vikas, V. & Ilango, S. P. 2015. Study on construction accidents, their causes and mitigation. National Conference on Civil Structure and Environment Engineering.*

# *Collaborative framework with shared responsibility for relief management in disaster scenarios*

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## Abstract

Disaster instances have been increasing both in frequency and intensity causing the tragic loss of life and making life harder for survivors. Disaster relief management plays a crucial role in enhancing the lifestyle of disaster victims by managing the impacts of disasters. Disaster relief management is a process with many collaborative sectors where different stakeholders should operate in all major phases of the disaster management progression. In the different phases of the disaster management process, many collaborative government organisations, along with non-government organisations, leadership, community, and media at different levels need to share the responsibility with disaster victims to achieve effective disaster relief management. Shared responsibility enhances disaster relief management effectiveness and reduces the disaster impact on the victims. Considering the diverse roles of different stakeholders, there has been a need for a framework that can bind different stakeholders together during disaster management. This paper explores a framework with major stakeholders of disaster relief management and how different stakeholders can take part in an effective disaster relief management process. The framework also highlights how each stakeholder can contribute to the relief management at different phases post-disaster. The paper also explores some of the shared responsibility collaborative practices that have been implemented around the world in response to disasters as disaster relief management processes. In addition, this paper highlights the knowledge obtained from those disaster instances and how it can be applied to disaster mitigation, and how it can be helpful in preparing for future disaster scenarios.

*Keywords:* Disaster; Relief Management; Collaborative Framework; Shared Responsibility

## 1. Introduction

A disaster is defined as "a serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses which exceed the ability of the affected community or society to cope using its resources" (UNISDR: United Nations International Strategy for Disaster Reduction). Every year, natural disasters, such as earthquakes, hurricanes, landslides, volcanic eruptions, tsunamis, avalanches, extreme cold, heatwaves, and cyclones kill thousands of people around the world. The nature and level of disasters vary from small to large scales and affect people's lives. Therefore, a quick response with relief items is crucial. In the aftermath of a disaster, sufficient relief items must be distributed over some time to minimise human losses and to improve the quality of life of the survivors. To achieve this, an effective disaster relief management framework is essential to distribute relief items such as food, water, medical supplies, and clothing to the disaster affected areas to enhance the quality life of the disaster victims.

Disasters often occur without cautioning and unexpectedly leading to a series of adverse consequences. Therefore, disaster relief management must be prepared to address these consequences effectively. The United Nations define disaster management as "The systematic process of using administrative decisions, organization, operational skills and capacities to implement policies, strategies and coping capacities of the society and communities to lessen the impacts of natural hazards and related environmental and technological disasters. This comprises activities, including structural and non-structural measures to avoid or to limit adverse effects of hazards" (Reduction, 2004). According to the Federal Emergency Management Agency (FEMA), the disaster management lifecycle has been divided into four main phases: mitigation, preparedness, response, and recovery (Hoyos et al., 2015). Each phase is crucial in making disaster relief management highly effective. Mitigation, rarely seen as urgent, is the effort to curtail the loss of life and property by minimising the impact of disasters (Bosher et al., 2007). The mitigation is achieved through risk analysis with the available information. The risk analysis provides a foundation for mitigation activities for risk reduction. Preparedness within the field of disaster relief management is defined as a way of being ready to respond to a disaster, crisis or any other type of emergency (Guerdan, 2009). This phase includes developing plans for the actions that will improve the chances of successfully dealing with a disaster. The response phase deals with how to respond to the disaster. By being able to act responsibly and safely, the chance of survival increases in a disaster (Rawls and Turnquist, 2010). The recovery phase deals with after a disaster where any actions must take care of the victims (Coles and Buckle, 2004). It requires the delivery of food, medicine, tents, sanitation equipment, tools, and other necessities to the people in distress, often for extended periods of time.

Several disaster relief management models have been used over the years for the relief items distribution in disaster environment. However, there have been many disaster instances where the management had gone through challenges in terms of sharing responsibility effectively during the relief items distribution as the disaster relief management has appeared a complex task often associated with uncertainty and dynamics (Crosweller and Tschakert, 2021). Global disaster relief management initiatives have changed over the year, and has been continuously expanding and growing in terms of engagement of different stakeholders with a collective approach whereby every stakeholder has a role in disaster response (Lassa, 2018). In recent years, shared responsibility among the stakeholders such as government organisations, non-government organisations, leadership, citizens and media appeared to be effective way of disaster relief management (Medel et al., 2020). In different disaster scenarios, the shared responsibilities have already proven very effective to save lives and property and are expected to remain so for years to come. Study on disasters in Australia, China, Philippines, Korea, Japan and Indonesia has shown that the accomplishment of effective disaster management depends on the collaborative effort from multi-stakeholders along with the governmental policies, plans, and tools (Lin et al., 2017).

Studies have suggested that any disaster requires different stakeholders' involvement in disaster relief management with better integrated and cohesive interactions (Atkinson and Curnin, 2020). In this regard, collaborative approaches and initiatives are required to be explored for disaster relief management that can assure cooperation among different major stakeholders. Studies have also presented that government collaboration with other stakeholders improves the efficiency of disaster relief management along with collaborative performance (Medel et al., 2020). All these studies have highlighted that there has been diverse organisational engagement. Without collaboration, the effectiveness of the relief management has always been compromised. The research has also highlighted that in many of the scenarios there has not been a guided framework to establish collaborative working. Sharing the responsibilities with well-established and controlled communication has been the need to achieve a higher level of effectiveness in disaster relief management. In this paper, we present a collaborative framework with shared responsibility in disaster relief management. The framework has five key stakeholders, Government Organisations, Non-Government Organisations (NGOs), Leadership, Community and Media, with shared responsibility for disaster relief management. Collaborative shared responsibility entails the engagement of key stakeholders of the governmental system and their obligations in disaster relief management. The framework will help guide the roles and responsibilities of all the major stakeholders. One of the biggest advantages of collaborative shared responsibility is the use of knowledge resources from multiple sources as disasters always stretch the bounds of emergency resources and governmental preparedness. The collaborative shared responsibility approach gives the flexibility to bring all the stakeholders together to contribute their potential in the best way for disaster resilience.

The remainder of this paper is organised into the following sections. In section 2, a collaborative framework with shared responsibility for disaster relief management is presented which describes the framework architecture and components. In the section, major roles of five key stakeholders in disaster scenarios have been presented. This section also highlights how each stakeholder can contribute to the common goal of enhancing the disaster victim's life. Finally, in the section, a discussion of the framework along with the conclusion of the paper is presented.

## 2. Collaborative Framework with Shared Responsibility

With the augmented scope and severity of disasters in recent years, it has become imperative to review the traditional disaster relief management approach characterized by a centralised government organisation. Though centralised government policies favour more controlled management for better and more timely disaster relief management, a collaborative shared responsibility framework enhances the effectiveness of disaster resilience.


*Figure 1: Collaborative framework with five core elements having shared responsibility in disaster relief management*

In general, collaboration is defined as any joint activity between two or more organisations that work together to achieve a common goal. Collaboration occurs when individuals/ stakeholders from different organisations act together through their combined strength, resources, knowledge and skills and share ownership of the collaborations. Different types of collaboration can be formed across stakeholders with different levels of commitment for a specified period. When managing disaster relief distribution, the involvement of different organisations from different sectors needs to be coordinated effectively. This, however, requires comprehensive intra-organizational communications to maximise the capacity of organisations to handle a disaster impact.

A collaborative framework with five major stakeholders with shared responsibility for disaster relief management has been presented as shown in Figure 1. The collaborative framework incorporates five major stakeholders: Government Organisations, NGOs, Leadership, Community and Media. In the framework, the government organisations have been at the top of the hierarchy whereas the other four stakeholders are considered at the second level of the hierarchy. Disaster relief management tasks have been connected (green solid lines) with all the five stakeholders, which also indicates the communication, information and activity sharing with the relief distribution process. The framework also includes a connection (dotted purple lines) from government organisations to all other stakeholders. These lines show the control mechanism from the government organisations to all the stakeholders regarding disaster relief management. The control line reflects the obligation set by the government organisations to the corresponding stakeholders. The collaborative framework supports all basic disaster relief management factors under disaster situations. These factors are largely the system under which government organisations and other stakeholders operate and accomplish their tasks. These factors, namely the way organisations notice the disaster scenarios, the severity and its necessities, and the way they control and perform relief distribution tasks, are expected to affect the effectiveness of disaster resilience. These factors combined create a collaborative and shared responsible environment that determines the success or the failure of relief operations in terms of decision-making for disaster relief management

## 3. Stakeholders of Collaborative Shared Responsibility for Disaster Relief Management

In the presented framework, following five major stakeholders, their responsibility in disaster relief management is discussed. The framework is developed after reviewing several disaster relief management strategies implemented in different countries. Major stakeholders are identified based on the case-based scenarios presented in different disaster relief management case studies.

### 3.1 Government Organisations:

Government organisations act as a system during disaster relief management with wealth, knowledge, resources, control and the power of decision making (Crosweller and Tschakert, 2021). The government organisation has an abundance of valuable resources in terms of skilled professionals, relief items, money and other assets that can be managed to minimise the disaster impact on the victims. A set of principles, processes and control mechanisms are pre-defined by the government organisation for disaster resilience. Government organisations can potentially accomplish their goal by sharing responsibility with other stakeholders and can play the controlling body to achieve their objectives (Busch and Givens, 2013). This controlled shared responsibility has been observed in the case of Hurricane Katrina in 2005, where Walmart played a crucial role in distributing relief items. A similar set of acts has been observed in the case of the Hebei Spirit oil spill in Korea, where the government organisation has the advantages of disaster management in terms of centralised precise management (Cheong, 2011). This study has also shown how the government organisations play the controlling body of the management for different geographical and cultural diversity.

### 3.2 Non-Government Organisation:

Non-government Organisations (NGOs) such as Red Cross, United Nations, and the private sectors appeared more as service providers to individuals or communities in need during disaster relief management. Their role can be observed as a substitute for government organisations' objectives and functions. There have been examples of NGOs' involvement with success stories around the world in many disaster scenarios such as Indian Ocean Tsunamis, and Japanese Tsunamis (Lassa, 2018). In these disaster cases and others, the major roles of NGOs have been providing relief items, establishing health camps, engaging in rescue tasks, setting temporary shades and so on. As a success story, a study from the Bam earthquake, Iran, showed that the government organisations and NGOs spontaneously engaged in disaster relief management in terms of rescue tasks, food distribution, and physical and mental treatment (Fallah and Hosseini Nejad, 2020). The study has revealed that the disaster victims were satisfied with NGOs' actions, but the governmental organisations were not able to coordinate well with them. This study has also highlighted that good and controlled communication is highly important to make any task effective.

### 3.3 Community/Citizens:

Community/citizens appears as one major stakeholder in disaster relief management (Drennan and Morrissey, 2019). Citizens' engagement has proven to be crucial for faster recovery after any disaster. A study conducted in Australia and the United Kingdom (UK) highlighted that community resilience during disaster management is a multi-dimensional aspect (Coles and Buckle, 2004, Drennan and Morrissey, 2019). The community appears in different but equally important ways in response to disaster relief management. For example, any family or group of people appearing as a leading role in communicating with other schools/park areas to establish temporary shelter after a disaster. Another study on community responses to Hurricane Katrina demonstrated the importance of local knowledge, resources, and cooperative strategies in determining their survival and recovery (Patterson et al., 2010). In this study, it has been noted that the Jewish Family Service (JFS) compiled an Emergency Care Contact List, for which senior citizens could voluntarily pre-enrol. After the hurricane, JFS delivered services and assistance to seniors who are known to be potentially vulnerable. Similarly, the leadership of the Vietnamese community facilitated evacuation. Everyone who left then also alerted Vietnamese communities in the surrounding areas. Another study conducted by Athe Australian emergency management doctrine recognised and emphasised the importance of community-led recovery in terms of enabling communities to take ownership of their recovery process and leverage the skills, capabilities and resources within an affected area, building their resilience through the recovery process a different study conducted by the International Federation of the Red Cross emphasises that local knowledge enables decision-makers to more effectively engage with affected populations and act as a mediator to both identify community needs, organise recovery efforts and build resilience. This research has suggested that local community leaders are more engaged in the community over the extended timeframe of disaster recovery (Drennan and Morrissey, 2019). In general, the community is often associated with social factors that are associated with self-motivated cooperation. The self-motivated community plays a positive role in disaster resilience.

### 3.4 Leadership:

In disaster relief management, the role of the leader is extremely vital in bringing order and a state of calmness for disaster victims. Logically, leaders in disaster scenarios may appear with different hierarchies and ranks, such as the head of the disaster central management team, and the local community leader where the disaster had occurred. In normal conditions, leadership decisions are made after a process of discussion and coordination with experts' advice. But leadership in a disaster scenario appeared as applying the strategic tasks that incorporate all activities associated with disaster relief management. These roles of leaders in disaster scenarios are different from normal scenarios as under the disaster safety, support, evacuation, positivity and hope are among top priorities (Mahmud et al., 2020). For example, after the Indian Ocean tsunami in 2004, the Indonesian President stated the tsunami was a national disaster and executed the deployment of available resources for disaster relief. In the same disaster, the Indonesian Vice-President sent a high-ranking official from Jakarta to disaster relief tasks, while the President asked the international community for open emergency relief support. The president issued orders that allowed ease of access to international flights, visa requirements and exclusion from customs taxes for relief supplies (Mahmud et al., 2020). A report by the Stockholm International Peace Research Institute described that on the following day of the declaration, there was overwhelming international support for disaster resilience. A study from Japan Tsunami 2011 showed that community leaders had demonstrated 'active leadership' in the identification objectives and identification of stakeholders and understanding of the socio-cultural perspective for disaster relief management (Lin et al., 2017). In both studies, it has been observed that the active and timely role of leadership gives the effective direction for disaster resilience.

### 3.5 Media:

Communication is also one of the major stakeholders in disaster relief management. Communication in a disaster scenario can be established using various ways such as television, newspaper, leaflet, SMS, audio/visible signals, and the internet. Nowadays, different forms of social media such as Facebook, Twitter, Whatsapp Messenger, and Instagram, ranging from prompt messaging to social networking sites appeared as an effective tool for communication with citizens (Ahmed, 2011). Communication through mass media in a disaster scenario has the advantage of communicating with larger groups even in cases of a partial failure of the existing communication infrastructure (Nair, 2010). In many countries, overall disaster relief management has been released often without highlighting the importance of media and the right communication channel for disaster warnings or alerts (Nayak, 2012). But the fact is media plays a key role in motivating and allowing disaster victims to prepare for the disaster resilience and reasonably apply themselves during and after the disaster. If the disaster warning or alert is made timely and accurately then it helps all responsible stakeholders to act towards effective disaster relief management. Media has its role in three stages including before, during, and after the occurrence of disasters. On the other hand, it has also been observed that media can also contribute to worsening the situation with cross-purpose disaster management when the message is not been communicated on time or the massage is inaccurate (Soltani, 2015). To avoid such a situation, the governmental control mechanism is crucial. The control mechanism directs the media to reach the disaster victims with the right and timely messages.

## 4. Discussion and Conclusion

Natural disasters are inevitable, and it is almost impossible to fully repair the damage caused by them. But it is possible to minimize the potential risk by developing effective disaster relief management such as preparing early disaster warning strategies, implementing relief items distribution to the disaster victims, and helping with rehabilitation and post-disaster reduction. The role of government organisations is crucial as they establish the first stage of disaster relief management. However, it is important to note that the lack of knowledge on the disaster-affected region, affected individuals and groups, and geographical and cultural diversity at the governmental management level may have a negative impact on the distribution relief management. To overcome the negative impact, during disaster scenarios, collaborative shared responsibility can be defined. The collaboration can be on the existing network or with any stakeholders that can contribute even if there has not been any no previous history of collaboration. Government organisations play a crucial role in developing a more stable and controlled collaborative shared responsibility by providing the needed resources and expertise. Despite an evolving consent for collaborative shared responsibility in disaster management, there is still no clear arrangement on what and how the responsibility can be shared (Busch and Givens, 2013). But the effective engagement and management of multiple stakeholders in coordination with government organisations is a key element of the disaster recovery process. Another challenge for shared responsibility is to maintain a sense of accountability. Frequent communication, knowledge sharing, information exchange and clearly stating the expectations from each stakeholder can undoubtedly improve the shared responsibility as these lead to converging the disaster relief management objectives.

The roles of NGOs in disaster relief management have been increasing due to the rising challenges of disaster occurrence and its uncertainty. In a disaster scenario, the major role of the NGO is to establish a strong relationship among the government organisations, leadership, and community for the effective mitigation of disaster resilience. Collaboration between NGOs with government organisations and other sectors complements the relief tasks with their expertise and resources. More often, it has been observed that there are many NGOs that have a direct link to disaster regions and disaster victims as they have worked more closely with them in normal scenarios. In addition, the NGOs act promptly in disaster scenarios in a flexible way to support the other stakeholders for disaster resilience. Leaders in disaster relief management are another key stakeholder as they have the ability to make decisions and manage good relationships with disaster victims. To bring higher effectiveness in disaster relief management, leaders need to familiarise themselves with the disaster region, and cultural and geographical diversity and accommodate that knowledge in their decision-making processes. In disaster relief management, leaders often carry out leadership roles of coordination that reduce susceptibility and minimise the loss of life and property. Additionally, effective leadership in a disaster situation is when the leader can comprehensibly coordinate different agencies to minimise the disaster impact.

Engagement of the community is one of the most important aspects of disaster that needs to be considered in every disaster relief management process. Active participation of citizens for minimising the disaster impact and recovery help in successfully implementing disaster resilience plans. Therefore, in the disaster relief management plans, involving the disaster affected citizens needs to be considered as part of the sustainable action plan. It has been observed that not every community is equal and beneficial, therefore the strengths and weaknesses of the community must be considered in disaster relief management. The engagement of the community has a positive impact as more often the well-functioning community organisations have the faith of their members and hold the moral authority to adopt cooperative behaviour and teamwork at the local level which is harder for governmental organisations to achieve. The local communities also have strong abilities to assess the individual requirements and distribute relief items efficiently and equitably. Because of this local level knowledge, it is important to include local communities in disaster relief management and establish collaborated shared responsibility between communities and government organisations.
The media is treated as another key stakeholder for disaster relief management as the media can help the timely broadcast of information to the wider community in a short amount of time. Media can increase the speed of response in disasters by facilitating the proper spreading of information, which eventually helps in speeding up the process of disaster resilience. The media also can communicate in both directions by articulating the disaster victim's emotions to the government organisations. However, there are a few issues such as having incomplete and untimely messages, conflicting information from different media, and setting accountability in social media is a major challenge. The control mechanism of government organisations can minimise these negative impacts on media communication.

In this paper, we presented a framework with collaborative shared responsibility for disaster relief management. The framework presents the five key stakeholders and their responsibility in disaster resilience. The framework will have a positive impact on the operational efficiency of disaster relief management and can respond faster to different stakeholders after any disaster.

However, the scope and nature of collaboration and responsibility may vary by disaster types, impacts, and cultural and geographical diversity. In many countries, such as with Nepal, there is a great diversity in culture and geography. These diversities bring a high risk of uncontrolled relief management. The presented framework guides the establishment of proper communication and hence a precise control mechanism to make the relief management task more effective. In summary, the shared responsibility makes disaster relief management more flexible in terms of effective relief item distribution. Operationally, shared responsibility enables government organisations to manage the resources rapidly, making the relief distribution system more responsive even in scenarios with great cultural and geographical diversity.

# 5. References


*AHMED, A. 2011. Use of social media in disaster management.*

*ATKINSON, C. & CURNIN, S. 2020. Sharing responsibility in disaster management policy. Progress in disaster science, 7, 100122.*

*BOSHER, L., DAINTY, A., CARRILLO, P., GLASS AND, J. & PRICE, A. 2007. Integrating disaster risk management into construction: a UK perspective. Building research and information, 35, 163-177.*

*BUSCH, N. E. & GIVENS, A. D. 2013. Achieving resilience in disaster management: The role of public-private partnerships. Journal of strategic security, 6, 1-19.*

*CHEONG, S.-M. 2011. The role of government in disaster management: the case of the Hebei Spirit oil spill compensation. Environment and Planning C: Government and Policy, 29, 1073-1086.*

*COLES, E. & BUCKLE, P. 2004. Developing community resilience as a foundation for effective disaster recovery. Australian Journal of Emergency Management, The, 19, 6-15.*

*CROSWELLER, M. & TSCHAKERT, P. 2021. Disaster management and the need for a reinstated social contract of shared responsibility. International Journal of Disaster Risk Reduction, 63, 102440.*

*DRENNAN, L. & MORRISSEY, L. 2019. Resilience policy in practice—Surveying the role of community based organisations in local disaster management. Local Government Studies, 45, 328-349.*

*FALLAH, S. & HOSSEINI NEJAD, J. 2020. The Role of Non-Governmental Organizations in Disaster Management: A Case study of Bam Earthquake, Iran. Journal of Disaster and Emergency Research, 1, 43-50.*

*GUERDAN, B. R. 2009. Disaster preparedness and disaster management. Am J Clin Med, 6, 32-40.*

*HOYOS, M. C., MORALES, R. S. & AKHAVAN-TABATABAEI, R. 2015. OR models with stochastic components in disaster operations management: A literature survey. Computers & Industrial Engineering, 82, 183-197.*

*LASSA, J. A. 2018. Roles of non-government organizations in disaster risk reduction. Oxford Research Encyclopedia of Natural Hazard Science.*

*LIN, Y., KELEMEN, M. & KIYOMIYA, T. 2017. The role of community leadership in disaster recovery projects: Tsunami lessons from Japan. International Journal of Project Management, 35, 913-924.*

*MAHMUD, A., MOHAMMAD, Z. & ABDULLAH, K. A. 2020. Leadership in disaster management: Theory versus reality. Journal of Clinical and Health Science, 5, 4-11.*

*MEDEL, K., KOUSAR, R. & MASOOD, T. 2020. A collaboration–resilience framework for disaster management supply networks: a case study of the Philippines. Journal of Humanitarian Logistics and Supply Chain Management.*

*NAIR, P. 2010. Role of media in disaster management. Mass Communicator, 4, 36-40.*

*NAYAK, K. 2012. Role of media in disaster reduction. Odisha Review, 2, 135-147.*

*PATTERSON, O., WEIL, F. & PATEL, K. 2010. The role of community in disaster response: conceptual models. Population Research and Policy Review, 29, 127-141.*

*RAWLS, C. G. & TURNQUIST, M. A. 2010. Pre-positioning of emergency supplies for disaster response. Transportation research part B: Methodological, 44, 521-534.*

*REDUCTION, I. S. F. D. 2004. Living with risk: A global review of disaster reduction initiatives.*

*SOLTANI, F. 2015. Mass media and its role in increasing society's involvement in disaster management. International Journal of Health System and Disaster Management, 3, 12.*

# *Quantitative Measurement of Safety Culture of the Nepalese Construction Industry*

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## Abstract

Safety culture in construction industries of developing countries has not been able to draw much attention. With the increase of construction works specially in developing countries, health and safety has become a major issue. Lack of safety culture in construction environment can pose a hazard which can lead to a main cause of accidents and injuries. Therefore, a study on safety culture in construction industries of developing countries is crucial. This study quantifies the safety culture status in the construction industries in Nepal. A questionnaire has been designed to conduct a survey to collect data from all sectors of construction. The survey respondents (Management level staff who implement the H&S) have scored the safety performance of their organisations based on the 32 safety culture elements. The study then assessed the safety culture level of the construction companies class "A" and class "B" (constructing Buildings, Roads, Hydropower, etc.) in the context of the Nepalese construction industry as these companies have constructed large projects. Statistical analysis has been used to analyze the data collected from the industries. A t-test is used to find the significant relationship between the safety culture elements. In the study, the safety culture level of the construction company class "A" and class "B", are found to be 68.86 and 61.21 compared to very good worldwide safety performance firms with a safety culture level of 91.4 points, while the low safety performance companies with a safety culture level of 58 points respectively. This will help to understand the safety culture level of construction industry in maintaining a safety performance of the industry and to take a further action to reduce accident rates in the construction industries.

*Keywords:* Safety Culture, Construction Industry, Quantitative Measurement, Safety Culture Elements

## 1. Introduction

The construction sector is thriving in Nepal with many small and large-scale constructions, from houses to megaprojects, moving forward at full pace and providing jobs to thousands. But, negligence and lack of safety standards also make construction a risky industry for many workers to join (Centre for the study Labour and Mobility, 2021). According to the International Labour Organization (2021), over 2.78 million work-related deaths and 374 million non-fatal injuries are recorded annually around the world. The extent of construction accidents is severe in Nepal compared to other countries. No such concrete data could be found looking at work-related deaths and injuries in Nepal (Shrestha et al., 2011).

Construction industries have a tag name of being highly hazardous because of the unique nature of the unequally high incidence of accidents and fatalities that widely happen in the construction sector world (Nabi et al., 2020). Various prominent scholars support the use of proactive indicators like safety culture investigation rather than focusing on reactive measures, like several accidents or injuries that occurred (Choudhry et al., 2007 & Cooper PhD, M., 2000) The lack of safety culture is the main cause of injuries and accidents in workplaces, especially in high-risk industries like construction sites. In recent years, scholars express increasing attention to the concept of safety culture due to its crucial role associated with the reduction of accidents and deaths on construction sites (Choudhry et al., 2007 & Cooper PhD, M., 2000). Safety culture is inversely correlated with accidents and injury occurrences in extraordinarily hazardous fields, including construction sites (Choudhry et al., 2007 & Cooper PhD).

The total score of quantitative measurement of the safety culture of 82 Chinese enterprises has got 77.4 points (Jiang et al., 2020). Safety culture, as a term, is left flexible for openness and discussion to encompass the culture's dynamic and changing nature. However, in the literature, there is a lack of guidance on how safety culture can be evaluated and measured effectively (Choudhry et al., 2007). Safety culture is considered to be associated with generating a safe work environment (Ismail et al., 2012).

This paper presents a study which finds the safety culture gap between the Nepalese companies' Class "A" and "B" and the international safety performance companies. The remainder of the paper discusses the safety performance of the companies in relation to the safety culture.

# 2. Literature Review

## 2.1 History of safety culture

The development of the safety culture concept is an effect of the evolution of safety management systems and understanding accident causation. The theories of accident causation have progressed through several stages in an effort to identify the root causes of system failures. The first stage, which spanned the period 1940-1960, was focused on machines and hardware improvements because, due to the rapid development of new machinery, most accidents were attributed to mechanical malfunctions (Cooter et al., 1997). The second stage, which took place between 1960 and 1980, focused researchers' attention on human factors because employees were seen as the weakest link in the system (Flin et al., 1996). The third stage considered the interaction of human and technical factors (Cooter et al., 1997).

Safety culture has become the focus of all industries and has received much attention in recent years. Choudhry et al. (2007) stressed that safety culture is considered to be the main factor that influences employees' attitudes and behaviours in respect to the organization's ongoing safety performance. It is intrinsically linked to organizational culture and has attracted a wide range of industries (Choudhry et al., 2007). Safety culture can be encapsulated in the characteristics of the organizational culture that have impacts on attitudes and behaviours related to hazard control and elimination (Cooter et al., 1997). Although the term "safety culture" has been extensively used for many years, the concept is still not fully clear (Guldenmund, F., 2000). The U.K. Health and Safety Commission (HSC,1993) developed one of the most commonly used definitions of safety culture: "The product of individual and group values, attitudes, perceptions, competencies, and patterns of behaviour that determine the commitment to, and the style and proficiency of, an organization's health and safety management". It gives the fundamental concept of safety culture.

## 2.2 Occupational health and safety in Nepal

The concept of occupational safety and health is still an emerging concept in Nepal. Health and safety is still not the prime focus of the involved sectors. There is no proper safety and preventive measures at site and the workers are not aware of their environment in most of the labour-based construction sites of Nepal (Koirala, 2018).

## 2.3 Framework for safety management

The model of safety management (Fig. 1) was used as a framework for discussion of the results of the research. The key elements of the model are:

1. The commitment of management to excellence in safety
2. Line management ownership of the safety agenda
3. Involvement in safety activities, complemented by training
4. Comprehensive safety practices
5. The safety organization and safety specialists

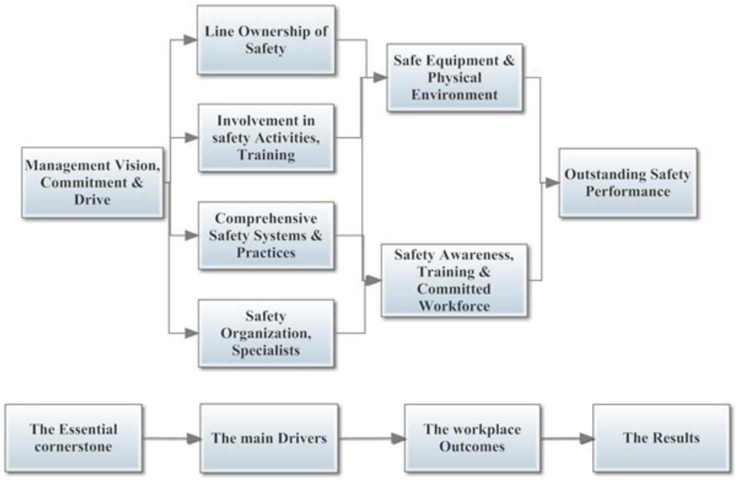


*Figure 1: In the Model Framework, the key factors are the" behavioural" elements (Stewart, J., 2002)*

## 2.4 Elements of safety culture and its scale

The elements of safety culture (Hea et al., 2012), shown in Table 1, is used to analyse the safety culture in the construction sector in Nepal. These elements are used to quantify the culture such as in Jiang et al., 2020.

*Table 1: The elements of safety culture (Hea et al., 2012)*

| S.N. | Key element | S.N. | Key element |
|---|---|---|---|
| 1 | Relative importance of safety | 17 | Safety council demands |
| 2 | Preventable extent of deaths and injuries | 18 | Formation way of safety system |
| 3 | Safety creates economic benefits | 19 | Consistent implementation of safety systems |
| 4 | Degree of safety into enterprise management | 20 | Types of investigated accidents |
| 5 | Safety depends mainly on safety awareness | 21 | Types of safety check |
| 6 | responsibility of work safety | 22 | Caring for injured workers |
| 7 | Awareness of safety input | 23 | Amateur safety management |
| 8 | Role of safety regulations | 24 | Treatment of safety performance |
| 9 | Safety values formation level | 25 | Facilities satisfaction |
| 10 | Degree of leaders' responsibility | 26 | Mastering of Safety performance |
| 11 | Understanding of the role of the safety sector | 27 | Safety performance and human resources |
| 12 | Degree of employee's participation in safety | 28 | Safety management of subsidiary and co-firms |
| 13 | Level of safety training needs | 29 | Function of safety organization |
| 14 | Degree of the department's safety responsibility | 30 | Work of safety department |
| 15 | Effects of community safety | 31 | Overall safety expectations |
| 16 | Function of safety management system | 32 | Emergency response capabilities |

# 3. Methodology

## 3.1 Introduction

Tools for assessing safety culture can be classified as either qualitative or quantitative methods. Quantitative approaches attempt to numerically measure or score safety culture using procedures that are often highly standardized and calibrated such as highly structured interviews, surveys and questionnaires, and Q-sorts (Wreathall, J., 1995).

For objective two, questionnaire preparation was developed using 10 questions to get general idea about demographic information and 32 elements of safety culture contains separate questions.

Stewart conducted follow-up research on 5 companies with good safety performance and 5 companies with poor safety performance, including Dupont Canada Company, Shell Oil Company, etc., and proposed 25 safety culture indicators based on his years of safety work experience. On this basis, Stewart, J., (2002) developed a questionnaire to conduct surveys and statistical analysis on five enterprises with advanced safety performance (less than two accidents occurred during 200,000 man-hours) and five enterprises with poor safety performance. Through analysis, it can be concluded that enterprises with advanced safety performance have these safety concept items in common, and employees of enterprises with advanced safety performance have a better understanding of safety concepts, while employees of enterprises with poor safety performance have a poor understanding of safety concepts, so as to prove the rationality of the excellent safety management model and 25 safety concept items (Stewart, J., 2002). The research group to which the authors belong to had slightly modified Stewart's safety culture element table (including 25 elements) (Stewart, J., 2002).

These elements are taken from multiple and the contents in the safety culture questionnaire corresponding to each element are greatly modified in accordance with the oriental cultural background. The revised questionnaire can be directly applied to the Nepalese Construction company for quantitative measurement of safety culture by collecting various research papers and selecting questions through consultation with professionals related to health and safety.

## 3.2 Study Area and Population

As of FY 2020, there are more than 15000 registered contractors in FCAN (2020), which are classified into different classes as shown in Table 2 Class "A" and Class "B" with populations of 266 and 267 contractors respectively, were used as strata for this study. The benefit of stratified sampling is that even samples from the smallest strata are not missing during the sampling process.

Proportionate stratification was used to distribute the total sample size over different strata proportionately. Strata sample sizes were calculated using the following equation.

$n_i = (N_i/N)*n$

Where $n_i$ is the sample size for strata "i", N is the total population size, and n is the total sample size.

Total sample size n is calculated from the finite population as shown below using Cochran (Stat Trek, 2021) equation.

$$n = \frac{Z^2 pq}{e^2} \quad (1)$$

Where Z: Z- score for level of significant (α) =1.96

p=q=0.5 (for maximum sample size

e= margin of error=10%=0.1

$$n = \frac{1.96^2 * 0.5 * 0.5}{0.1^2}$$

n =96.04≈96 samples

For finite population:

$$n = \frac{n}{1 + \frac{n-1}{population\ size}} \quad (2)$$

$$n = \frac{96}{1 + \frac{96-1}{533}}$$

n=81.47≈82 samples

For class "A": 266 registered contractors

$$N_A = \frac{266}{533} * 82 = 40.92 \approx 41 \text{ samples}$$

For class "B": 267 registered contractors

$$N_A = \frac{266}{533} * 82 = 41.07 \approx 41 \text{ samples}$$

*Table 2: Statistic of number of Company in Nepal*

| SN | Types | Population |
|---|---|---|
| 1 | Class A | 266 |
| 2 | Class B | 267 |
| 3 | Class C | 1902 |
| 4 | Class D | 13365 |
| | Total | 15800 |

*Table 3: Statistic of Selected population of Company in Nepal*

| SN | Types | No of Company |
|---|---|---|
| 1 | Class A | 41 |
| 2 | Class B | 41 |
| | Total | 82 |

A total of 82 companies were targeted for the study including Class A and Class B companies as shown in Table 3.

## 3.3 Statistical Analysis

### 3.3.1 Descriptive Statistics

Demographic information includes education, safety training, age, work position and work experiences. Data check is a part of descriptive statistics and it is performed by checking outliers' data, missing data, doing normality check, linearity check and homoscedasticity test to check for any potential analysis weaknesses that can be improved upon, which may have negative effects on the study reliability and validity.

### 3.3.2 Raw data conversion and score calculation method

The total score of safety culture quantitative measurement data is 100 points. Employees' scores for each element of safety culture can be calculated using the following methods. Firstly, the options of the questionnaire represented by the 32 safety culture elements were directly derived from the Safety Culture Analysis Program (SCAP). Then through a certain rule, the original data, that is, the questionnaire options A, B, C, D, E were converted into scores (denoted as $S_A$, $S_B$, $S_C$, $S_D$, $S_E$).

### 3.3.3 The scores of the construction company under different elements

From questionnaire survey, the responders give the rating in the form of the five Likert scale, and each scale having score 1, 0.8, 0.6, 0.4, and 0.2. Each element total score calculated using equation (3). $N_{1.0}$ is the frequency of occurrence of very high score. $N_{0.2}$ is the frequency of occurrence of very low score.

$$Si = 100(1N1 + 0.8N0.8 + 0.6N0.6 + 0.4N0.4 + 0.2N0.2)/N. \ldots\ldots\ldots\ldots (3)$$

In this research, total score of qualitative measurement of the safety culture is hundred, and the quantitative measurement method is used (Guo, 2010). This method is used to study the Safety Culture.

## 4. Results and Discussion

### 4.1 Survey Statistics

The research population consists of the construction companies class "A" and "B" whose responses are obtained from personnel who work in these construction companies in Nepal. This study targeted the middle management level in these construction sites due to the nature of questions assessing the safety management system and management commitment to safety. The minimum sample size is 82, but 92 responders responded, so the data was collected with less than 10% marginal errors.

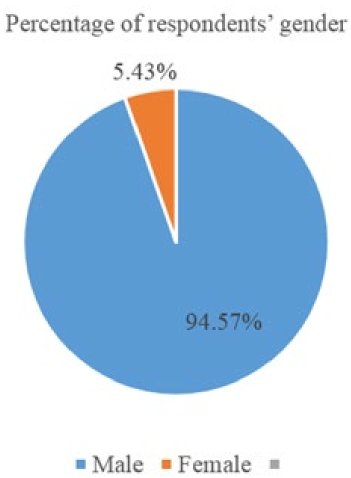


*Figure 2: Percentage of respondents' gender*

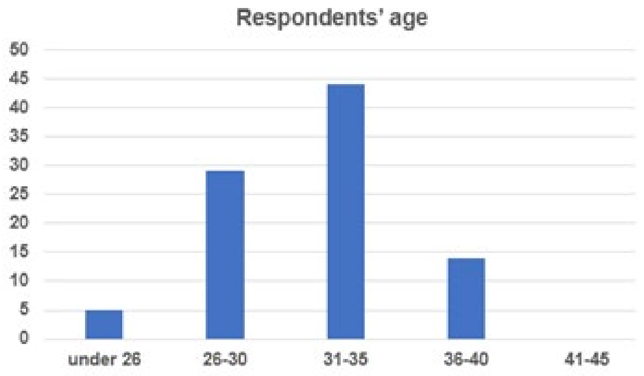


*Figure 3: Statistics of respondents' age*


*Figure 4: Percentage of respondents' Training taken*

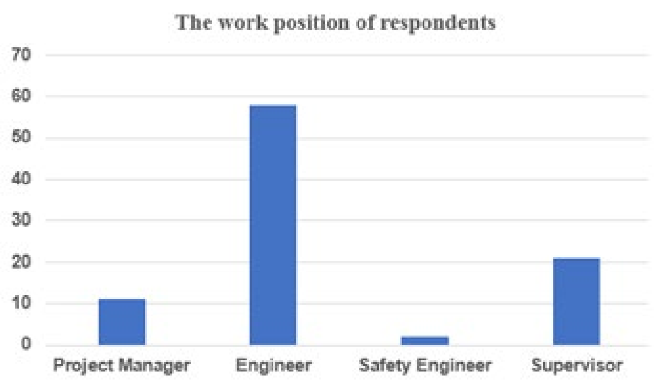


*Figure 5: Statistics of the experience of respondents.*

*Table 4: Statistics of respondents' education level*

| Education | Frequency | Percentage |
|---|---|---|
| Diploma | 7 | 7.61% |
| Bachelor | 69 | 75.00% |
| Master | 16 | 17.39% |
| PHD | 0 | 0.00% |
| Total | 92 | 100.00% |

*Table 5: Statistics of Construction Class*

| Class | Sample Size | Response Count |
|---|---|---|
| Class A | 41 | 49 |
| Class B | 41 | 43 |
| Total | 82 | 92 |

## 4.2 The elements of safety culture

The questionnaire included more than a hundred measure quantitative of safety culture grouped in 32 elements, listed as an output of literature review. Each element includes separate questions measuring the quantitative of the safety culture of contractors.
Using this formula, the score of each element is determined and plot the line chart to compare between the two types of Construction Companies (Class: "A" and Class "B").
The line chart shown in Figure 6 demonstrated the companies did not focus to keep the safety culture in construction company.

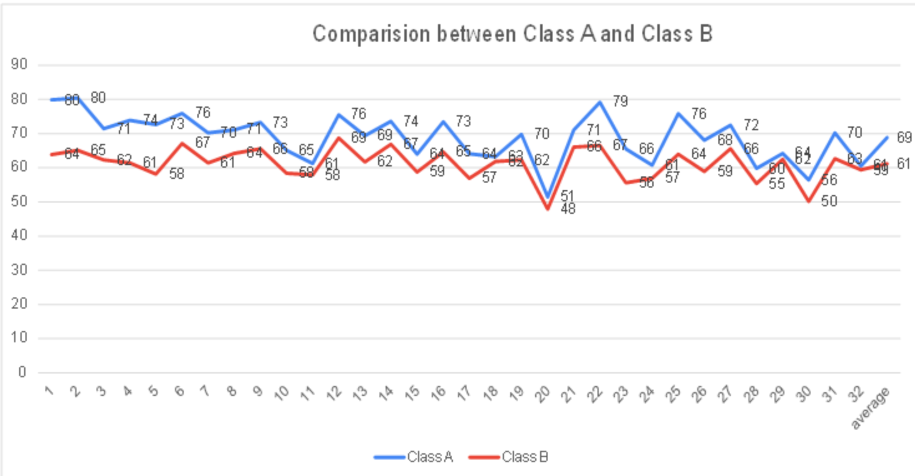


*Figure 6: Statistics of Construction Class*

Based on the quantitative measurement data of safety culture obtained, this survey analysed the situation of the contractor's safety culture, including 92 sample sizes. The surveyed company were mainly concentrated in building construction, road, hydropower etc. The staff structure, gender, education level and working years of each company represent in 92 sample sizes were obtained. Total score of quantitative measurement of safety culture in targeted. The overall average level of safety culture of the construction company Class "A" and Class "B" were 68.86 and 61.21 points.

The Safety culture's Scores of excellent international safety performance enterprise and the poor international safety performance enterprise were taken from Jiang et al., (2020).

*Table 6: Safety culture*

| Safety culture element | The excellent international safety performance enterprise | The poor safety culture performance enterprise | Nepalese company Class "A" | Nepalese Company Class "B" |
|---|---|---|---|---|
| 1 | 94 | 56 | 79.9 | 63.9 |
| 2 | 95 | 74.8 | 80.4 | 65.1 |
| 3 | 94.2 | 72.2 | 71.4 | 62.3 |
| 4 | 90.8 | 60.4 | 73.9 | 61.4 |
| 5 | 92.1 | 52.9 | 72.7 | 58.1 |
| 6 | 92.1 | 52.9 | 75.9 | 67.1 |
| 7 | 92.1 | 52.9 | 70.2 | 61.4 |
| 8 | 92.1 | 52.9 | 71.1 | 64.2 |
| 9 | 92.1 | 52.9 | 73.3 | 65.6 |
| 10 | 92.1 | 52.9 | 65.1 | 58.4 |
| 11 | 97.0 | 50.8 | 61.2 | 57.9 |
| 12 | 81.8 | 39 | 75.5 | 68.7 |
| 13 | 89.8 | 37.2 | 69.4 | 61.7 |
| 14 | 92.1 | 52.9 | 73.6 | 66.9 |
| 15 | 92.1 | 52.9 | 63.9 | 58.8 |
| 16 | 92.1 | 52.9 | 73.5 | 64.7 |
| 17 | 98.8 | 45.8 | 64.1 | 56.9 |
| 18 | 92.6 | 61.6 | 63.3 | 61.9 |
| 19 | 90.6 | 51.0 | 69.8 | 62.3 |
| 20 | 96 | 60.4 | 51.4 | 47.9 |
| 21 | 86.8 | 50.8 | 71.0 | 66.0 |
| 22 | 93.6 | 59.0 | 79.2 | 66.5 |
| 23 | 99.2 | 28.4 | 65.5 | 55.6 |
| 24 | 92.1 | 52.9 | 60.7 | 56.9 |
| 25 | 92.1 | 52.9 | 75.8 | 64.0 |
| 26 | 96.8 | 46.0 | 68.1 | 59.0 |
| 27 | 92.1 | 52.9 | 72.4 | 65.6 |
| 28 | 92.1 | 52.9 | 59.8 | 55.3 |
| 29 | 90.4 | 57.8 | 64.2 | 62.5 |
| 30 | 88.4 | 48.4 | 56.4 | 50.1 |
| 31 | 92.1 | 52.9 | 70.2 | 62.7 |
| 32 | 92.1 | 52.9 | 60.5 | 59.4 |

## 4.3 Testing Research Hypotheses

Testing determines the present scenario of score of safety culture. A quantitative measure of each element in the construction company is the final objective. The hypothesis is tested from the independent t-test using IBM SPSS software (Table 7).

**Hypothesis**
The respondents reflect the company's view on quantitative measurement result of safety culture at significant level α = 0.05.
**Null hypothesis ($H_o$):** There is no significant relationship between the elements of safety culture and company classes.
**Alternate hypothesis ($H_1$):** There is significant different between quantitative measure of the elements of safety culture and company classes.

*Table 7: Independent Samples Test of 32 Elements*

| Element | T | P-Value | Remarks |
|---|---|---|---|
| average of 1 | 9.369 | 0.00 | $H_0$ Rejected(P<.05) |
| average of 2 | 6.491 | 0.00 | $H_0$ Rejected(P<.05) |
| average of 3 | 4.069 | 0.00 | $H_0$ Rejected(P<.05) |
| average of 4 | 4.828 | 0.00 | $H_0$ Rejected(P<.05) |
| average of 5 | 7.181 | 0.00 | $H_0$ Rejected(P<.05) |
| average of 6 | 4.243 | 0.00 | $H_0$ rejected(P<.05) |
| average of 7 | 5.157 | 0.00 | $H_0$ rejected(P<.05) |
| average of 8 | 3.094 | 0.00 | $H_0$ rejected(P<.05) |
| average of 9 | 1.489 | 0.14 | $H_0$ accepted(P>.05) |
| average of 10 | 3.798 | 0.00 | $H_0$ rejected(P<.05) |

| Element | T | P-Value | Remarks |
|---|---|---|---|
| average of 11 | 2.108 | 0.04 | $H_0$ rejected(P<.05) |
| average of 12 | 2.392 | 0.02 | $H_0$ rejected(P<.05) |
| average of 13 | 2.559 | 0.01 | $H_0$ rejected(P<.05) |
| average of 14 | 2.305 | 0.02 | $H_0$ rejected(P<.05) |
| average of 15 | 2.535 | 0.01 | $H_0$ rejected(P<.05) |
| average of 16 | 3.526 | 0.00 | $H_0$ rejected(P<.05) |
| average of 17 | 2.570 | 0.01 | $H_0$ rejected(P<.05) |
| average of 18 | 0.571 | 0.57 | $H_0$ accepted(P>.05) |
| average of 19 | 2.280 | 0.02 | $H_0$ rejected(P<.05) |
| average of 20 | 1.156 | 0.25 | $H_0$ accepted(P>.05) |

| Element | T | P-Value | Remarks |
|---|---|---|---|
| average of 21 | 2.052 | 0.04 | $H_0$ rejected(P<.05) |
| average of 22 | 4.830 | 0.00 | $H_0$ rejected(P<.05) |
| average of 23 | 3.538 | 0.00 | $H_0$ rejected(P<.05) |
| average of 24 | 2.014 | 0.05 | $H_0$ accepted(P>.05) |
| average of 25 | 4.324 | 0.00 | $H_0$ rejected(P<.05) |
| average of 26 | 3.897 | 0.00 | $H_0$ rejected(P<.05) |
| average of 27 | 2.432 | 0.02 | $H_0$ rejected(P<.05) |

| Element | T | P-Value | Remarks |
|---|---|---|---|
| average of 28 | 2.262 | 0.03 | $H_0$ rejected(P<.05) |
| average of 29 | 0.959 | 0.34 | $H_0$ accepted(P>.05) |
| average of 30 | 3.161 | 0.00 | $H_0$ rejected(P<.05) |
| average of 31 | 2.633 | 0.01 | $H_0$ rejected(P<.05) |
| average of 32 | 0.564 | 0.57 | $H_0$ accepted(P>.05) |
| All Average | 5.278 | 0.00 | $H_0$ rejected(P<.05) |

Remarks: From independent t test, since $p < .05$ is less than our chosen significance level $\alpha = 0.05$, the null hypothesis is rejected, and conclude that the quantitative measurement result of safety culture element is different.

Based on the results, we can state the following:
The element 1, 2, 3, 4, 5, 6, 7, 8, 19, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31. Overall average. From the independent t-test, since $p < .05$, is less than our chosen significance level $\alpha = 0.05$, the null hypothesis is rejected, and conclude that the quantitative measurement result of the safety culture element is a significant difference between Construction companies' class "A" and "B".
The independent t-test, since $p < .05$ is less than our chosen significance level $\alpha = 0.05$ of the elements 9, 18, 20, 29 and 32, the null hypothesis is accepted, and conclude that the quantitative measurement result of safety culture element is not significantly different between Construction companies' class "A" and "B".

## 5. Conclusions and Recommendation

In the context of the Nepalese construction industry, the safety culture level of the construction company class "A" and Class "B", are 68.86 and 61.21 respectively which is between the level of safety culture of the enterprises with the best international safety performance and the poor enterprises. But from result, the safety culture from the excellent international safety performance enterprise was still a wide gap. The Nepalese construction companies have to improve the safety culture to improve safety performance, increase profit and reduce accidents and incidents.

There is a significant relationship between the score of qualitative measures of the elements of safety culture and Construction Company Classes (Class "A" and Class "B"). Only elements Safety values formation level, Formation way of safety system, Types of investigated accidents, Function of safety organization, and Emergency response capabilities have no significant difference between the categorized company classes (Class "A" and Class "B"). For registering, the Company class "A" need more capable, turnover, experience than the Company Class "B" (FCAN, 2020).

This research includes only Class "A" and Class "B" construction companies, so further research should focus on Class "C" and Class D study, qualitative survey, and document analysis for more reliable output. Further research on Cross-comparison with other countries could be made in order to detect any similarities and differences in the issues concerning the safety culture. Further research on similar research could be carried out in other regions which may help in cross-comparisons.

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## 7. References

*Choudhry, R. M. (2007). Developing a model of construction safety culture. Journal of Management in Engineering, 23(4), 207-212.*

*Cooper PhD, M. (2000). Towards a model of safety culture. Safety Science, 36(2), 111-136. doi:https://doi.org/10.1016/S0925-7535(00)00035-7*

*Jiang, W., Fu, G., Liang, C., Han, W.(2020). Study on quantitative measurement result of safety culture. Safety Science, 128. https://doi.org/10.1016/j.ssci.2020.104751*

*Cooter, R., & Luckin, B. (1997). Accident in Accidents in History: Injuries, Fatalities and Social Relations. Journal of Social History.*

*FCAN. (2020). Construction Industry in Nepal. Federation of Contractors association in Nepal.*

*Flin, R., Mearns, K., Gordon, R., & Fleming, M. (1996). Risk perception by offshore workers on UK oil and gas platforms. Journal of Management in Engineering, 12 pp131-145. https://doi.org/10.1016/0925-7535(96)00011-2*

*Guldenmund, F. (2000). The nature of safety culture: A review of theory and research. Safety Science, 34(1), 215-257. doi:https://doi.org/10.1016/S0925-7535(00)00014-X*

*Guo, J. (2010). Development and application of enterprise safety culture online analysis. China University Mining and Technology Beijing: (Beijing).*

*Hea, A., Xub, S., & Fua, G. (2012). Study on the Basic Problems of Safety Culture. China Academy of Safety Science and Technology, 245 – 249.*

*HSC (Health And Safety Commission)(1993). Third report: organising for safety. ACSNI Study Group on Human Factors. London: HMSO*

*ILO. (2021). Retrieved from Safety and health at work: https://www.ilo.org/global/topics/safety-and-health-at-work/lang--en/index.htm*

*Ismail, F., Ahmad, N., & Isnaini, N. A. (2012). Assessing the Behavioural Factors' of Safety*

*Culture for the Malaysian Construction Companies. Social and Behavioral Sciences, 35 583-582. https://doi.org/10.1016/j.sbspro.2012.03.063*

*Joshi, S., Shrestha, S., & Vaidya, S. (2011). Occupational Safety and Health Studies in Nepal. International Journal of Occupational Safety and Health, 1(1), 19–26. doi:https://doi.org/10.3126/ijosh.v1i1.4725*

*Nabi, M. A., & . (2020). A System Dynamics Model for Construction Safety Behavior. Procedia Computer Science, 168, 249-256. doi:https://doi.org/10.1016/j.procs.2020.02.254.*

*Stat Trek (2021). Smart Survey https://stattrek.com/sample-size/stratified-sample.aspx*

*Statistics How To(2021). Statistics How To https://www.statisticshowto.com/probability-and-statistics/find-sample-size/*

*Stewart, J. (2002). Managing for World Class safety. New York: John wiley & Sons Inc.*

*The Construction Business Rules-2056. (2000). Retrieved from http://cdms.cbps.gov.np/Acts/construction-businessrules-2056.pdf*

*Wreathall, J. (1995). Organizational culture, behaviour norms, and safety. In A. Carnino & G.Weiman (Eds.). Austria: American Nuclear Society, (pp. (pp. 24–28).*

*Yong-ping, Z. (2010). Collection and Research of Safety Climate Sample Data in Coal Industry. Beijing: China University of Mining and Technology.*

*Yu Guang-tao, W. E.-p. (2007). Study on Safety Culture in a Petrochemical Plant Based on Participant Observation. China Safety Science Journal, 17, pp.93-101.*

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