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Research Article

Study on Tinau Flood at Butwal: An Evacuation Perspective

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Abstract

The Tinau Flood, caused by Tinau River during monsoon, is one of the most devastating hazards at Butwal. Butwal is densely populated business hub located in Butwal Sub-Metropolitan City, Lumbini Province, Nepal. The flood threatens lives and properties along the riverbank. An efficient evacuation plan for potential flood victims is crucial to save their lives. Mathematical optimization model, in particular, network flow model could be a tool for designing the plan. Literature flourishes mathematical models including network flow models for evacuation planning. In this paper, we study lexicographically maximum contraflow (Lex-Max Contraflow) problem and implement it to real data set for Tinau flood evacuation to propose optimum evacuation route plan along with optimum distribution of evacuees among shelters based on their suitable prioritization.

Keywords: Network flow problem, Network contraflow, Lexicographically maximum flow problem, Multi-networks, Tinau flood.

AMS(MOS) Subject Classification: 90B10, 90B20, 90B50.

1 Introduction

Disasters caused by natural hazards such as floods, earthquakes, and landslides have become the most urgent global challenges. Due to its geographical structure (hills, mountains, and numerous rivers of various sizes) and climate (monsoon), Nepal experiences such hazards time and again. The frequent hazards in Nepal during the monsoon are floods and landslides, which have caused severe catastrophes. Nepal ranks second in South Asia for flood risk,

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[33]. The 2008 Koshi flood, the 2017 Terai flood, the 2021 Melamchi flood, and the most recent flood in Kathmandu in September 2024 are a few floods in Nepal that caused notable disasters. Between 2017 and 2022, floods in various parts of Nepal caused 538 fatalities and a huge economic loss, [1]. This isn't just the case in Nepal. According to a study [38], floods and landslides accounted for 44% of all disasters and impacted 2.6 billion people globally between 2000 and 2019. Furthermore, floods constitute the biggest natural hazard to urban areas, endangering over 379 million people worldwide, [34].

Most of the cities in Nepal are situated at the basin of rivers and in the lap of hills. The city Butwal, situated at Butwal Sub-Metropolitan City (BSMC), is one among them. The areas in the bank of Tinau River in the city regularly experience flooding during the monsoon, endangering lives. In particular, impact of flood is experienced in Devinagar situated in Ward No. 11 of BSMC among its 19 wards. Besides flood, the north-east part of the city is threatened by massive landslide locally known as Jyotinagar Landslide.

Himalayan range is source of three major rivers in Nepal: Koshi, Gandaki and Karnali. They have historically been associated with major floods causing a huge loss of lives and properties, [14]. Similarly, Mahabharat Hills are source of many other medium sized rivers that also cause significant floods and devastations, including fatalities, see [2] and [14]. Likewise, Tinau is medium sized river that is flowing from Mahabharat Hills at Palpa district. This river supports the region for irrigation. Besides, Tinau flood has become one of the most dangerous hazards at Butwal during monsoon. During late winter and spring, the river experiences minimal flow whereas in the monsoon there is a substantial increase in water volume, [14]. In 2011, the residents of the squatter settlements witnessed 17 houses across Tinau River being swept away in just one hour, [14]. According to the local people, residents of Butwal's squatter communities alternately patrol Tinau River at night during monsoon in order to keep an eye out for rising flood levels that could threaten their properties and lives.

Nepal has developed a framework for disaster management through several key policies and institutions. These include the Constitution of Nepal (2015), the Disaster Risk Reduction and Management Act (2017), the National Policy for Disaster Risk Reduction (2018), and the National Disaster Risk Reduction Strategic Action Plan (2018–2030). The Nepal Police, Armed Police Force, and Nepal Army play vital roles in disaster responses – early warning system, rescue operations, and preparedness [35]. However, effective implementation is challenged due to political, legal, economic, and managerial limitations.

There is a critical condition because squatter communities are concentrated in high-risk marginal lands. These locations often have poor-quality housing and working environments, contributing to an unhealthy living situation, [28]. According to the data provided by the Ward Office (Ward No. 11), about 14,000 people live in Tinau flood prone region. There are 649 houses situated in high-risk zones, 897 houses in risk zones, [39]. This Ward has the highest population density in BSMC. According to the data in 2019, there are 43,698 people in Ward No. 11, whereas total population of BSMC is 1,56,576, [41]. These scenario show that emergency evacuation for potential Tinau flood victims is essential.

an efficient evacuation plan helps to quickly and effectively move evacuees from disastrous zones to safe destinations. There are different evacuation strategies in practices around the world based on the nature of disaster and situation. Addressing the issue in Tinau flood is also crucial due to the dense population, deteriorating living conditions, and the rise of unplanned and uncontrolled squatter settlements, [28]. Based on our knowledge there is no study on Tinau flood with respect to evacuation. However, an evacuation plan has been proposed for the possible victims of Jyotinagar landslide at Butwal in [11].

The rest of the paper is structured as follows: Section 2 discusses the some worth-mentioning evacuation strategies. In Section 3, an overview on network flow problems is presented followed by mathematical formulation of Lex-Max Contraflow problem. Section 4 presents a case illustration using an actual data-set with useful findings emerged out from investigation. Section 5 concludes the paper with some recommendation.

2 Evacuation Strategies

Government of Nepal has been actively working to develop and implement flood management plans to mitigate the impacts of frequent floods. These plans emphasize early warning systems, infrastructure developments, community-based flood risk reduction strategies, and river management. Under the Sendai Framework for Disaster Risk Reduction (2015-2030), Nepal has aligned its flood management strategies with global best practices, focusing on minimizing loss of life and property damage. The National Disaster Risk Reduction and Management Authority (NDRRMA) plays a pivotal role in coordinating these efforts across various regions, ensuring a more cohesive and effective response to flood-related disasters, [40]. Although various organizations, both governmental and non-governmental, are engaged in disaster response efforts, there remains a lack of clarity regarding roles, responsibilities, and accountability, particularly among government agencies. It also still lacks a proper mathematical evacuation plans.

There is a significant gap between South Asian and developed countries in urban flood hazard and management practices. South Asian cities still lack high-resolution Digital Elevation/Terrain Model (DEM) data and accurate short-duration rainfall measurements, [27]. For different models that are used for flood management, including highlighting urban flood hazard methods using hydraulic and hydrological models, as well as urban flood management practices in South Asia, [27].

The two main modeling approaches for evacuation are macroscopic and microscopic. Individual agents (people or vehicles) and their intricate interactions with surroundings and systems during evacuation are modeled by microscopic approach. It analyzes system-dynamics and optimizes processes by concentrating on fine-grained behaviors. Authors in [12], for example, use such agent based traffic flow model for evacuation planning. In contrast, macroscopic models capture overall crowd patterns but overlook individual diversity. For large-scale evacuations where aggregate trends matter more than individual behavior, macroscopic model may be more appropriate. This model analyzes mass flows, focusing on flow rates and densities rather than individual behaviors. It applies principles from fluid dynamics, traffic flow theory, and mathematical optimization, making it ideal for large-scale evacuation analysis and system performance optimization. Fluid dynamics in evacuation models is a powerful tool for simulating and optimizing large-scale movements, identifying bottlenecks, and improving evacuation efficiency by treating evacuees or vehicles as flowing entities. Traffic flow theory in evacuation models is critical for optimizing the movement of vehicles, minimizing congestion, and ensuring efficient evacuations. The choice of model depends on the level of details required, the type of evacuation (e.g., vehicle vs. pedestrian), and the optimization objectives (e.g., minimizing evacuation time or avoiding congestion), etc. These models are integral in disaster management and urban planning to ensure that evacuation strategies are efficient. Moreover, a hybrid evacuation model combines both macroscopic and microscopic approaches to optimize evacuation performance. This model aims to balance the granularity of individual interactions with large-scale efficiency, [37]. Hybrid evacuation model has been thoroughly studied in [17] including dynamics and agent-based model.

Mathematical optimization technique (a macroscopic model); in particular, network flow model; provides efficient tools for modeling, preparing and managing evacuation planning. The goal is to maximize the movement of people from dangerous zones to safe zones efficiently. For modeling, the available road network topology can be converted as an evacuation network, which consists of arcs and vertices. The road segments are represented as arcs, and the junctions/shelters are represented as vertices, whereas dangerous places and safe places are sources and sinks, respectively. Our concern, in this paper, is a network flow model based optimization technique, namely, Lex-Max Contraflow model [9].

3 Lex-Max Contraflow Model for Evacuation Planning

3.1 Overview on Network Flow Problems

The maximum flow problem, a central problem in a network flow theory, aims to send a maximum amount of flow units from the source to the sink through available network. The first solution technique for static version –the maximum static flow (MSF) problem, is based on the path flow augmentation, [18]. Since then the solution technique has continuously been improved with respect to time complexity, [15], [16], [21], [26], [4], etc. For the maximum dynamic flow (MDF) problem, there are two different solution techniques– based on time expanded network [19] leading a pseudo-polynomial time algorithm and based on temporally repeated flows [20]) leading to a polynomial time algorithm. This problem has been extended to quickest flow problem and earliest flow problem by many authors, [30] [22], [23], [5], etc. These problems capture the essence of an evacuation scenarios and thus are applicable on them. An integrated solution technique for minimizing evacuation time can be found in [3] in which the evacuation network is composed of two constituent sub-networks.

Network contraflow is an approach that allows the reversibility of arc direction wherever required. The approach is useful for improving an actual road network's outbound capacity by switching the direction of inbound roads during evacuations. The contraflow approach was applied in emergency evacuations, see [25], [36], etc. The analytical solution of the contraflow network problem was proposed in [32]. Since then the evacuation network flow problem have been studied by authors, e.g., [24], [13], [9], [31], etc.

The model with non-conservation flow constraints allows for keeping flow units at intermediate vertices, [6] and [7]. Talking about the evacuation planning problems, such intermediate vertices are temporary shelters which are capacitated and prioritized, and capable of holding evacuees which cannot be sent to the destination due to road network structure and/or time limitation. The maximum flow problem with these attributes is known as lexicographically maximum flow (Lex-Max Flow) problem. The problem for single source and multiple sink without fixed vertex capacities was investigated in [29, 30] as a variant of the classical maximum flow problem. Considering the fixed vertex capacities at the prioritized vertices, a polynomial time algorithm for the static version of the problem and a pseudo-polynomial time algorithm for the dynamic case, are developed in [8].

A model for a maximum contraflow problem over multi-network is proposed and its solution procedure is discussed in [10] for discrete as well as continuous time setting. Moreover, the authors also proposed a solution technique for an earliest arrival contraflow problem on two terminal series parallel multi-network. As an extension of the work in [10], a lexicographically maximum contraflow (Lex-Max Contraflow) problem with vertex capacities has been studied in [9] and a polynomial and pseudo-polynomial time solution algorithms for static case and dynamic multi-network case, respectively, have been proposed. This paper implements the proposed algorithm for the real data set of Tinau flood at Butwal.

3.2 Mathematical Formulation

Road network with parallel and anti-parallel lanes with junctions can be treated as multi-network. A Dynamic multi-network $\mathscr{N} = (V, A, u(a), l(a), \tau(a), k(v), s, d, T)$ represent the road network of a city consisting of set of vertices V, i.e., junctions, with vertex capacities

$k(v)$ for all $v \in V$ and set of directed arcs $A = V \times V$, i.e., road segments or lanes, with arc capacities $u(a)$ and arc transit times $\tau(a)$ for all $a \in A$. Moreover, s and d are the specified vertices, namely, source (flood area) and sink (safety), respectively, and T is the time horizon for overall evacuation process which we consider in discrete manner. For the case study purpose we assume the number of vertices and arcs on $\mathscr{N}$ to be finite. Intermediate vertices, i.e., $v \in V\backslash\{s, d\}$, with holding capacities are called temporarily shelters. We prioritize them (temporarily shelters) on the basis of facilities, distance from source or risk factor, etc. Let $\mathcal{S} = \{v_1, v_2, ..., v_r\}$ be terminal set with $d = v_1 > v_2 > ... > v_r$ prioritized from higher to lower priority where $S \subset V$. Let us take vertex capacity $k(v)$ to be finite for all $v \in V\backslash\{s, d\}$ but vertex capacity in the sink has infinite, i.e., $k(d) = \infty$. However, we suppose that the sink has also finite capacity during implementation.

The number of flow units $f(a, t)$ entering arc $a \in A$ for all $a \in A$ for all time units $t \in \{0, 1, 2, ..., T\}$, is required to be bounded by its capacity $u(a, t)$. That is,

$$0 \le f(a, t) \le u(a, t) \quad \forall\, a \in A \text{ and } \quad \forall\, t \in \{0, 1, 2, ..., T\} \tag{3.1}$$

Flow value $f(a, t)$ has to be equal to zero for $t > T - \tau(a)$. The excess flow $ex_f(v, t)$ at vertex $v \in V$ at time $t \in T$, is defined as follows and satisfies

$$\sum_{a\in\delta^-(v)} \sum_{\xi=0}^{t-\tau(a)} f(a, \xi) - \sum_{a\in\delta^+(v)} \sum_{\xi=0}^{t} f(a, \xi) = ex_f(v, t) \ge 0 \quad \forall v \in V\backslash\{s, d\} \tag{3.2}$$

where $\delta^-(v)$ and $\delta^+(v)$ denote for the set of arcs entering into the vertex v and leaving from it, respectively. If capacity constraint 3.1 satisfies then flow value f, from the source s to sink d, is said to be a feasible flow. Also, the excess flow units $f(a, t)$ at each vertex $v \in S$ at time $t \in \{0, 1, 2, ..., T\}$, is required to be bounded by its capacity $k(v)$. That is,

$$ex_f(v, T) \le k(v), \forall v \in S \tag{3.3}$$

As a result, for time horizon T, flow units held at vertices $v \in S$ equals the total flow of evacuees leaving from source s. That is,

$$\sum_{a\in\delta^+(v)} \sum_{\xi=0}^{T} f(a, \xi) - \sum_{a\in\delta^-(v)} \sum_{\xi=0}^{T} f(a, \xi) = \sum_{v\in S} ex_f(v, T) \tag{3.4}$$

To sum up, the objective of Lex-Max Contraflow problem over multi-network $\mathscr{N}$ satisfying the conditions from 3.1 to 3.4 is to maximize the flow from source to each vertices in terminal set $\mathcal{S}$ in lexicographical order, that is, in given order, if arc reversal is allowed.

3.3 Solution Approach

Here, we discuss the flow computation technique for Lex-Max Contraflow problem. We are given an evacuation network $\mathscr{N} = (V, A, u(a), l(a), \tau(a), k(v), s, d, T)$ which at first is to be transformed to an undirected network $\widetilde{\mathscr{N}} = (V, \widetilde{A}, u(\widetilde{a}), l(\widetilde{a}), \tau(\widetilde{a}), k(v), s, d, T)$ with $l(a) = 0 \;\forall\; a \in A$ using algorithm in [9]. Next, we introduce artificial vertices ${v_i}'$ and connect with v_{i_T} to get artificial arcs; (v_i, v_i'), (v_i', v_i). Artificial arcs (v_i, v_i') have $k(v_i)$ capacities and zero transit time; and artificial arcs (v_i', v_i) have infinite capacities and zero transit time. But real arcs have original capacities and transit times. Parallel arcs $(v, w) \in \widetilde{\mathscr{N}}$ have been labeled as $(v, w)_i$ such that $\tau(v, w)_i < \tau(v, w)_{i+1}$ on the multi-network which help to avoid the obstruction of applying algorithm. After that, the network should be transformed into time-expanded network $\mathscr{N}^{\mathscr{T}}$ [8] and we compute the maximum static flow $s_0 - d'$ in the time expanded network. Repeat this process, we get maximum dynamic flow. If and only if there is non-negative flow along arc $a \notin A$ or if the flow along arc $(v, w) \in A$ is greater than $u(v, w)$, then arc $(w, v) \in A$ is reversed. Finally, we obtain solution of Lex-Max Contraflow for multi-network $\mathscr{N}$. This process has been summarized in the Algorithm 1. The algorithm runs in pseudo-polynomial time as it uses time expanded network.

Algorithm 1 : LexMDCF Algorithm for Multi-network [9]

1. Given a dynamic multi-network $\mathcal{N} = (V, A, l(a), u(a), \tau(a), k(a), s, d, T)$, $\mathcal{S} = \{v_1, \ldots, v_r\}$ with $d = v_1 \succ \cdots \succ v_r$, $l(a) = 0$ for all $a \in A$ and integer inputs.
2. Transform $\mathcal{N}$ into undirected multi-network $\tilde{\mathcal{N}} = (V, \tilde{A}, l(\tilde{a}), u(\tilde{a}), \tau(\tilde{a}), k(v), s, d, T)$ as in Algorithm in [10] and set $l(\tilde{a}) = 0 \;\forall\; \tilde{a} \in \tilde{A}$.
3. Label each parallel arcs $(v, w) \in \tilde{\mathcal{N}}$ as $(v, w)_i$ such that $\tau(v, w)_i < \tau(v, w)_{i+1}$ for $i = 1, 2, \ldots, q$; $q < m = |A|$.
4. Compute LexMDF on network $\tilde{\mathcal{N}}$ using algorithm in [8].
5. Perform flow decomposition into path and cycle flows of maximum flows obtained from step-4 and remove all cycle flows.
6. Arc $(w, v) \in A$ is reversed if and only if the flow along arc $(v, w) \in A$ is greater than $u(v, w)$ or if there is non-negative flow along arc $a \notin A$.
7. Obtain Lex-Max Contraflow solution for multi-network $\mathcal{N}$.

4 Tinau Flood Evacuation: a Case Study

This section presents a case study on evacuation of potential Tinau Flood victims at Butwal. This section demonstrates detailed about potential victim households, evacuees, evacuation spaces and road network with capacities and transit times indicating flood catchment area.

4.1 Study Area

Butwal, a sub-metropolitan city in Rupandehi district of Lumbini Province, Western Nepal, spans an area of 101.69 sq. km. Geographically, it lies between latitudes $27^0 36' 55$”N and $27^0 44' 55$”N, and longitudes $83^0 21' 40$”E and $83^0 30' 20$”E. The city is located at an altitude of 177 meters above sea level, 256 km west of Kathmandu. This residental area, situated approximately 27 km away from the well-known religious site of Lumbini, is also about 3 km away from Siddha Baba Temple. The city is densely populated being a business hub of the region. The Tinau river crosses from the middle of city threatening the people in every monsoon. The Tinau River starts from Palpa district and flows along Terai before reaching India. In the case study, we consider the area of BSMC, concentrating on Ward No. 11, and some region of Tilottama Municipality. The study area has been shown in Figure 1.

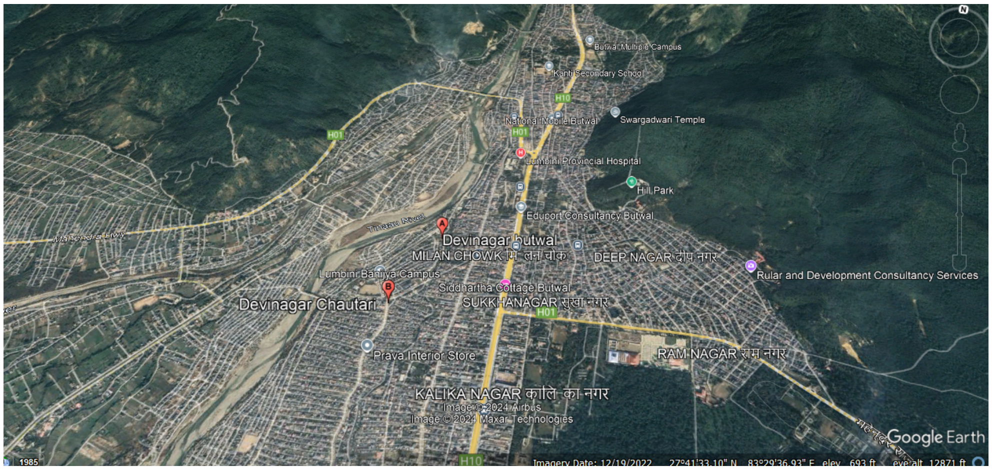

Figure 1: Flood Victim Area: Source-Google Earth Pro

Road Network Topology: Two major Highways– Mahendra Highway and Siddhartha Highway, pass through Butwal. Several road segments connect these highways within the study area, and both major and minor roads have been considered, as shown in the Figure 1. In this study, we have considered 102 major and some appropriate minor road segments within BSMC and Tilottama Municipality. The capacity of the road segments are the number of lanes available whereas the transit times are calculated on the basis of length of the road segment and normal speed of the vehicle comparing with travel time shown in google map.

Evacuation Spaces: Evacuation shelters are open spaces and school scolleges around the flood affected area. We consider 39 places, including 13 intermediate shelters and a sink. We designated 11 schools colleges, 2 parks, and Butwal Dhago Karakhana as shelters. Classrooms and open spaces are utilized for evacuees to reside. Additionally, the halls within schools colleges are allocated for medical purposes, particularly for providing medical assistance to injured individuals. There are around 790 classrooms of various sizes (from 12 ft. × 20 ft. to 34 ft. × 40 ft.), along with open spaces totaling 210,522.29 square feet. We prioritize shelters based on factors facilities, distance from source, and their holding capacities.

4.2 Evacuees

Ward-wise population data is available as secondary data; however, it cannot be directly utilized in our study since the impact of flood is confined to specific portions of BSMC which is Ward No. 11. Additionally, to the best of our knowledge, no secondary data on evacuation spaces exists for the research site. Furthermore, finding accumulated data regarding road conditions in written or published form is challenging. As a result, we had to collect the required data ourselves. Firstly, we collected the data of flood victims with the coordination of Ward No. 11 of BSMC. We identified that approximately 14,000 individuals with 1546 houses will be affected from the Tinau flood. According to the report given by the Ward Office of Ward No. 11, there are two types of flood victims: high-risk zone people and risk-zone people.

4.3 Computational Result

In the following we present computational results for three different scenarios.

Scenario-I: In this scenario, the shelters are considered only the in-house spaces which are classrooms of school/college, halls in factories, and sheds at picnic spots/parks. We observed 14 such temporary shelters. Here, Kalika Manavgyan School is the sink. The capacities and priority order of shelters together with flow values for different time horizon have been presented in Table 1. The purpose of considering only the in-house shelters is to save evacuees from rains, thunderstorms and snakes (being a snake prone area).

Scenario-II: In this scenario, only the open spaces are considered as shelters which are play grounds of school/college and open spaces of picnic sports/ parks. Here, we observed 14 temporary shelters similar to scenario-I. Here, Banbatika is the sink. The capacities and priority order of shelters together with flow values for different time horizon have been presented in Table 2. The purpose of considering only the open spaces as a shelter is to kept large number of evacuees.

Scenario-III: In this scenario, both the in-house spaces and the open spaces are considered as shelters. The shelters and their priority order are as in the scenario-II. However, their capacities increase due to the consideration. The purpose of this consideration is to accommodate a larger number of evacuees. The capacities and priority order of shelters, along with flow values for different time horizons, are presented in Table 3.

Table 1: Maximum flow values with and without contraflow for Scenario-I.

S.N.	Evacuation Spaces (Vertices)	Vertex Capacity	Priority Order	Flow value ($T = 13$)	Contraflow value ($T = 12$)
1	Kalika Manavgyan School	420	1	420	420
2	New Horizon School	381	2	381	381
3	Banbatika	144	3	144	144
4	Kalika Campus	135	4	135	135
5	Manimukunda School	132	5	132	132
6	Tilotama Campus	114	6	114	114
7	Janajagriti School	66	7	66	66
8	Siddhartha School	240	8	240	240
9	Siddheswar School	72	9	72	72
10	Jana Joyti School	126	10	126	126
11	Butwal Dhago Karkhana	100	11	100	100
12	Kanti Sec. School	318	12	318	318
13	Madimukunda Sen Park	84	13	84	84
14	Butwal Multiple Campus	198	14	198	198

Table 2: Maximum flow values with and without contraflow for Scenario-II.

S.N.	Evacuation Spaces (Vertices)	Vertex Capacity	Priority Order	Flow ($T = 23$)	Contraflow ($T = 23$)	Flow ($T = 30$)	Contraflow ($T = 30$)
1	Banbatika	7404	1	2070	4140	3330	6660
2	Kalika Manavgyan School	423	2	423	423	423	423
3	Kalika Campus	948	3	948	948	948	948
4	New Horizon School	210	4	180	180	180	180
5	Manimukunda School	258	5	258	258	258	258
6	Siddheswar School	1356	6	1356	1356	1356	1356
7	Janajagriti School	423	7	423	423	423	423
8	Siddhartha School	372	8	372	372	372	372
9	Tilotama Campus	228	9	0	228	0	228
10	Jana Joyti School	135	10	135	135	135	135
11	Kanti Sec. School	372	11	360	360	360	360
12	Butwal Dhago Karkhana	135	12	135	135	135	135
13	Madimukunda Sen Park	1332	13	1332	1332	1332	1332
14	Butwal Multiple Campus	447	14	0	447	447	447

For each scenario, flood victims (evacuees) are gathered at Devinagar playground (the source), and are sent to safe zone and relatively safe prioritized zones. Prioritization of vertices is based on the factors such as capacity, distance from the source, available facilities (e.g., access of medical facilities, drinking water, etc.), risk factors (on the basis of ground level, as flood occurs during monsoon) and other relevant considerations.

Table 3: Maximum flow values with and without contraflow for Scenario-III.

S.N.	Evacuation Spaces (Vertices)	Vertex Capacity	Priority Order	Flow ($T = 23$)	Contraflow ($T = 23$)	Flow ($T = 30$)	Contraflow ($T = 30$)
1	Banbatika	7548	1	2070	4140	3330	6660
2	Kalika Manavgyan School	843	2	843	843	843	843
3	Kalika Campus	1083	3	1080	1080	1080	1080
4	New Horizon School	591	4	591	591	591	591
5	Manimukunda School	390	5	360	360	360	360
6	Siddheswar School	1428	6	1428	1428	1428	1428
7	Janajagriti School	489	7	450	489	450	489
8	Siddhartha School	612	8	612	612	612	612
9	Tilotama Campus	342	9	0	342	0	342
10	Jana Joyti Sec. School	261	10	261	261	261	261
11	Kanti Sec. School	693	11	630	693	693	693
12	Butwal Dhago Karkhana	235	12	0	180	180	180
13	Madimukunda Sen Park	1416	13	0	1350	1350	1350
14	Butwal Multiple Campus	645	14	0	270	630	630

Being a discrete-time auto-based evacuation model, we consider the "two-second rule", treating each minute as a time unit. The average speed of vehicles is estimated to 550 meters per minute, which aligns closely with travel time observed via direct measurements and Google Maps data under normal traffic conditions. We show the findings for Scenario-I (Table 1) before and after the implementation of contraflow approach, taking into account the time horizon of 13 minutes without contraflow and 12 minutes with contraflow, evacuating approximately 2,530 people. The findings for Scenario-II (Table 2) and Scenario-III (Table 3) before and after the implementation of contraflow approach are shown, taking into account the time horizon of 23 and 30 minutes. In Scenario II, around 7,992 people can be evacuated in 23 minutes and 9,699 in 30 minutes without using contraflow. However, if contraflow is implemented, the number of evacuees increases to approximately 10,737 in 23 minutes and 13,257 in 30 minutes. Similarly, in Scenario III, about 8,325 and 11,808 people can be evacuated within 23 and 30 minutes, respectively, without contraflow. With contraflow, these numbers rise to approximately 12,639 and 15,519.

The algorithm was coded in Python 3.1 and run on a Windows 10 system equipped with 8 GB of RAM and a 2.10 GHz AMD Ryzen 5 5500U processor with Radeon Graphics. For Scenario I, the computation of flow value took approximately 1.5 minutes. In Scenario II and Scenario III, the execution time was about 2.5 and 3 minutes, respectively, for a time horizon of $T = 23$. Similarly, for $T = 30$, the program took 2.5 minutes for Scenario II and 3 minutes for Scenario III.

5 Conclusion and Discussion

The Tinau Flood, a devastating disaster that caused significant loss of lives and properties in Butwal, highlights the critical need for efficient evacuation planning. This study analyzed flood data, conducted field surveys, and gathered key information to develop an evacuation plan using a network flow optimization model, particularly, the Lex-Max Contraflow model. This model helped to determine the flow value, that is, the number of people that can be safely evacuated to shelters within a specific time horizon. The results have been presented for various scenarios, comparing the contraflow and without contraflow approaches with different time duration. Our case study shows that the application of contraflow approach in network flow model is essential as total maximum flow could be raised by about 51% when the approach is used. However, the model has limitations due to its pseudo-polynomial time complexity. Frequent evacuation rehearsals are recommended to ensure preparedness.

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