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Research Article

Evacuation Plan for Potential Victims of Jyotinagar Landslide at Butwal

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Abstract

Butwal, a city in Rupandehi district of Nepal, is a rapidly expanding business hub. The city's geographical location, population density, and lack of proper planning make it extremely vulnerable to natural calamities. Emergency evacuation is a major issue during disasters in such cities. The landslide, known locally as the Jyotinagar Landslide, poses a deadly risk in Butwal and requires an effective evacuation plan. The literature contains a variety of evacuation strategies for evacuation scenarios around the world that are based on the available resources and the types of disasters. In this study, we propose a mathematical optimization evacuation plan, as no such plan exists so far, for possible victims of the Jyotinagar Landslide at Butwal, Nepal, using the Lexicographical Maximum Dynamic Contraflow Algorithm.

Keywords: Network contraflows, Lexicographically maximum flows, Evacuation planning, Jyotinagar landslide.

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

1 Introduction

Most of the cities in Nepal are settled in the basin of rivers and/or hills. There are possibilities of occurring natural hazards such as earthquakes, landslides, floods, etc. since Nepal itself is an earthquake-prone region and there is excessive rainfall during a short period of

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time (monsoon). It is nearly hard to completely prevent disasters in any kind of hazards. The scenario is identical in the northern part (Butwal Bazar) of Butwal Sub-Metropolitan City, which is intersected by the Tinahu River that causes frequent floods; and has periodic severe landslides. The landslide in the north-east part of Butwal, known locally as the Jyotinagar Landslide, is one of the devastating disasters and requires an effective evacuation plan. It is crucial to identify the potential evacuation spots in the possible nearest locations of the landslide area (Jyotinagar) and develop an efficient evacuation plan so that the possible victims in future could be evacuated to the safety. In general, the primary goal of an evacuation plan is to maximize the resources available in existing transportation system so that the safest and fastest tour; and most efficient evacuation time of all anticipated evacuees of a building, or region could be ensured.

In this section we make a tour to Jyotinagar Landslide, introduce network flow models, highlights the importance of contraflow approach and capability of intermediate storage for efficient evacuation planning. As far as we know, no studies have been conducted on the Jyotinagar Landslide from an evacuation perspective, therefore potential victims are uninformed of evacuation strategies.

1.1 Jyotinagar Landslide

Butwal with the latitudes from $27°39.5'$ to $27°43.2'$ and the longitudes from $83°23'$ to $83°29.5'$ is located between the Siwaliks, tertiary molasse type sediments in the north and the northern marginal part of the Indo-Gangetic plain in the south,[11]. It is one of the fastest growing city with a sub-metropolitan, Butwal and a municipality, Tilottama. Total population of the two cities is $344,711$, [16]. It is situated where the Mahendra Highway and the Siddhartha Highway intersect each other. The region is consistently at the threats of Jyotinagar landslides and flooding of Tinahu Khola. This paper examines the Jyotinagar Landslide, which is a frequent occurrence and the primary impact of it is in the southern region of ward 3, the northern region of ward 4, and their surroundings, see the pictures in Figure 1.

The Siwalik rock is made up of three layers- lower, middle and upper part. The lower part is formed with sandstone, shale and mudstone. The mudstnoe is dominant over sandstone. The approximate thickness of this part is 2100m. The middle part is formed with coarse sandstone and mudstone. It consists of two parts. The lower one is steep cliff approximately 1200m and is formed with dominance of sandstone over mudstone. While the upper one is gravelly coarse grained with high potential for badland with dominance of sandstone over mudstone. It is approximately 700m. The upper part is approximately 300m with sandstone and conglomerate having high potential for bad-land. It has a tendency of slope failure [11]. The lower and middle parts have several tension cracks and old landslides.

Figure 1: Jyotinagar Landslide (Left), Residential area below it (Middle), and Damages due to it (Right):Source-HimalKhabar

Jyotinagar landslide at the south facing hill is the main geo-hazard in Butwal, [8]. The dip angle ($40° - 60°$) of the slope is unstable and is the source of frequent landslides [11]. Soil erosion and rock falls are common. The main reason for such frequent landslides are soft and fast weathering nature and exploitation of the construction materials. Around 1700 households nearby Chidiya Khola and Dobhan area basically southern part of ward 3 and northern part of ward 4 are directly under threat. Siddhartha highway suffers from rock fall, reason is landslide.

Jyotinagar Landslide was first noticed on 1978 which killed 64 people, see [19]. Villages Bhutaha, Makar, Chisapani and Chidiya Khola were emptied and the people were transformed to Bardaghat at Nawalparasi by the government. The second impact occurred on 1998 September 4 and 5. The landslide devastated 120 households with an estimated loss of five crores eighty one lakhs thirty one thousands Nepali currency. However, there was no loss of lives at the incident [6].

The recent landslide in 2020 and the more devastating one in 2021 widened the landslide area with its length nearly 1.5 km and increased the threat. The Jyotinagar landslide has paid attention not only to journalist but also to the researchers, e.g., [7, 11], etc. In this research, we consider only the aspect which finds out efficient routes during evacuation on such threats.

1.2 Evacuation Scenario as a Network Flow Model

It is logical to think of an evacuation region as a network prototype since it converts specific locations into vertices (also called nodes) and accesses or connection between them (may be bridges or road segments) into arcs (also called edges). Evacuees move over roadways like a flow moving along arcs. A network flow problem is the transfer of flow quantity from one or more designated locations within the network to another. An evacuation network is one that has been designed with the essential characteristics. In particular, the safe location where people are to be evacuated is thought to be the sink, while the risk zone where a disaster has occurred or is expected to occur soon is thought to be the source. Evacuees are present at the source, and the sink awaits them with sufficient shelter space.

Network flow problems designed for evacuation planning purpose are in a variety of forms based on the type of evacuation: availability of resources, disaster sensitivity, evacuee requirements, etc. The solution techniques for these problems depend upon problem size, behavioral and organizational situations, modes of transportation and traffic capacity, time dependency, origin-destination assignment, evacuation objectives, contraflow, etc., [9], [17]. In the majority of cases, dynamic versions of network flow models more accurately depict actual evacuation situations. The objectives of the model varies problem to problem depending upon evacuation parameters. One may aim in shifting as many evacuees as possible in a fixed time horizon whereas another may aim in shifting all the evacuees in minimum time period or shifting them as earlier as possible. It's not always simple to accomplish these goals in an effective manner. The difficulty depends upon the network architecture, the road attributes (e.g., congestion) and types of parameters (e.g., capacities, transit times) considered in the model. The difficulty also depends upon the type of solution we desire. We consider mathematical optimization model to study the evacuation scenario of Jyotinagar Landslide at Butwal.

In the following, we introduce two notions—namely, contraflow and the capability of intermediate storage—that are useful in efficient evacuation and are the essence of the evacuation model considered in this paper.

1.2.1 Contraflow

Contraflow is the reversibility of the direction of traffic flow in one or more lanes of a road for a predetermined amount of time. The main goal of evacuation is to remove everyone from dangerous areas as quickly as possible before a calamity strikes. Using the concept of network contraflow in an evacuation plan is one possible strategy to accelerate the process of accomplishing this goal [14]. The fact that moving into a risk zone is undesirable and that these lanes are left empty during evacuation is undoubtedly one factor that motivates the adoption of this strategy. This concept in evacuation planning enables the reversal of empty lanes, greatly increasing the capacity of routes in the opposite direction.

Although the contraflow strategy is crucial for emergency evacuations, these are not the only uses for it. This is frequently used to handle the directionally imbalanced traffic that comes with daily commuting in large cities, as well as the effects of religious gatherings, concert or tournament arrangements, etc.

Despite the extensive research on the contraflow strategy, its application in actual emergency evacuations is limited. This is because it is challenging to replicate the real traffic conditions in adopting contraflow techniques during an emergency [24]. There have been implementing the techniques, nevertheless, to evacuate some large urban areas that are at danger of natural calamities. It was initially used during the 1999 evacuation of Hurricane Floyd in the United States, with varying but generally favorable outcomes [23]. Additionally, Contraflow was used during the 2005 United States storms Katrina and Rita. Nevertheless, it was criticized for failing to use contraflow lanes and for imposing impromptu contraflow orders [14]. Rebennack et al. [18] proposed the first mathematical optimization model for the contraflow problem with solution procedures for static as well as dynamic time settings. Since then there is extensive research on the evacuation models based on network contraflow approach, see [13], [10], [4] [5], [15], etc.

1.2.2 Capability of Intermediate Storage

The number of evacuees in danger zones and the number of persons who use road topology right after a disaster (such as an earthquake) to get to their destination within a given time frame are typically unknown beforehand, [1]. Therefore, even though the sink is a secure destination, it is necessary to plan an evacuation so that as many evacuees as possible can also be sent to relatively safe sites distant from the risk zone. Because of the flow conservation requirement at intermediate vertices, modeling the evacuation problem with this feature is not evident in the network flow models with flow conservation constraints. In order to keep flow units at intermediate vertices as well, this characteristic should be turned off and weak-conservation requirements should be imposed in the model.

Evacuation models based on the network with intermediate storage capability have been studied analytically in literature, [3], [4], etc. There is an experimental result of evacuation scenario with the real data set of Kathmandu (within ring-road) in [4] in which author adopt the multi-network with capability of contraflow as well as capability of intermediate holding of evacuees. A similar case study for the data set of Kathmandu can also be found in [15]. As far as we know there is no such case studies for real data set of other cities of Nepal.

Outline. Rest of the paper is structured as follows. Section 2 discusses the mathematical formulation of network flow model to replicate the evacuation scenario. Section 3 demonstrates the real data set of the study area including the data collection procedure. The main result as the output of algorithm implementation has been given in Section 4. Section 5 concludes the paper with some recommendations.

2 Mathematical Formulation of LexMax Contraflow Problem

To develop an evacuation plan for possible victims of Jyotinagar Landslide, a mathematical optimization model (proposed in [5]) that uses the notion of network contraflow problems with intermediate storage capability, is considered. A network $N = (V, A)$ replicates the road network of the city area of consideration. Here, V and A represent the junctions (vertices) and road segments (arcs), respectively. We specify the landslide area and safe destination as the source and the sink denoted by s and d, respectively.

Further, we assume a terminal set $S \subset V$ (including d) with $\mathcal{S} := \{v_1, \dots, v_r\}$ prioritized from higher to lower priority, i.e., $d = v_1 \succ \dots \succ v_r$, to be given for temporarily shelters. Then the corresponding two-terminal evacuation network for time horizon T is represented as $\mathcal{N} = (V, A, l(a), u(a), \tau(a), k(v), s, d, T)$. Here, $l : A \to \mathbb{N}_0 := \mathbb{N} \cup \{0\}$ and $u : A \to \mathbb{N}_0$ represent the lower and upper arc capacity function which bounds the number of flow units on each arc $a \in A$ at each time step from below and from above, respectively. Similarly, the vertex capacity function $k : \mathcal{S} \to \mathbb{N}_0$ delimits the total number of evacuees, which may be held in each of the vertices $v \in S$. Moreover, the transit time function $\tau : A \to \mathbb{N}$ specifies the time needed by a flow unit to traverse an arc. Treat the time parameter in a discrete manner, i.e., $\mathcal{T} := \{0, 1, \dots, T\}$. A dynamic network is depicted in Figure 2.

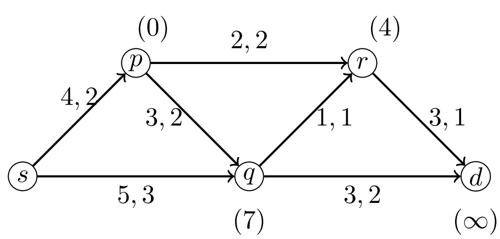

Figure 2: Evacuation network $\mathcal{N}$ with s and d as the source and sink, and $\{p, r, q\}$ the intermediate vertices. The numbers on the arcs refer to the arc capacities and the numbers in parenthesis above and below the vertices refer to the vertex capacities.

In this setup, let us consider the following three conditions:

1. Number of evacuees traveling on a road segment should not exceed its capacity for any time step. That is,

$$0 \leq f(a, t) \leq u(a) \ \forall \ a \in A \ \text{and} \ \ \forall \ t \in \mathcal{T}. \tag{2.1}$$

2. Number of evacuees entering to an intermediate vertex should be equal to the number of evacuees leaving it plus number of evacuees held on it (excess flow at v at time t,

$ex_f(v,t)$). That is,

$$0 \le ex_f(v,t) := \sum_{a\in\delta^-(v)} \sum_{\xi=0}^{t-\tau(a)} f(a,\xi) - \sum_{a\in\delta^+(v)} \sum_{\xi=0}^{t} f(a,\xi) \tag{2.2}$$

where $\delta^-(v) := \{a \in A : a = (w,v) \text{ for some vertex } w \in V\}$ and $\delta^+(v) := \{a \in A : a = (v,w) \text{ for some vertex } w \in V\}$ denote the set of arcs entering and leaving vertex $v \in V$, respectively.

3. Total number of evacuees held on any vertex should not be greater than its capacity. That is,

$$ex_f(v,T) \le k(v) \text{ for all } v \in \mathcal{S}. \tag{2.3}$$

With respect to above conditions, the objective of maximum contraflow evacuation planning problem is to lexicographically maximize the vector $(ex_f(v_1,T),\dots,ex_f(v_r,T))^\top$ such that $ex_f(v_i,T) \le k(v_i)$ for $i = 1,\dots,r$, if the direction of arcs on $\mathcal{N}$ are allowed to reverse. An arc $a = (v,w) \in A$ in which the flow could travel from vertex v to vertex w is replaced by the arc (w,v) for contraflow purpose.

3 Data Collection

Evacuation being a real-world challenge, one of the key jobs is to identify the necessary data – number of possible victim households, prospective evacuees, evacuation spaces; road network status with road capacity; and transit times; without flaws. Secondary data of ward-wise population can be accessible in online; however, these cannot be used directly in our study because the impact of landslides occurs in a partial portion of two separate wards (specifically, wards 3 and 4). As far as we know, there is no secondary data on evacuation spaces in the research site. Moreover, it is difficult to find written/published documentation of accumulated data about road's status. As a consequence, we were obliged to gather the necessary data ourselves– some from on site physically and some from an application called Google Earth Pro.

We have considered the region within the yellow boundary indicated in the figure 3 below which consists of city part of Butwal Sub-metropolitan City and Tilottama Municipality

3.1 Evacuees

The evacuees in our study are possible victims of the Jyotinagar Landslide, and they are residents of Butwal Sub-metropolitan City's southern Ward No. 3 and northern Ward No. 4. This area has about 700 dwellings and a population of about 10,000 people. Because

Figure 3: Region of study (inside the yellow boundary): Source-Google Earth Pro

the location includes Butwal Multiple Campus and its Hostel for faculty and students, the number of evacuees may be larger.

3.2 Evacuation Spaces

Based on our study and analysis, 18 suitable open spaces for evacuation shelters have been identified. The open spaces with corresponding size with respect to area and holding capacity of each designated space are listed in Table 1. Here, standard area (people per 45 square meter sphere) has been considered for the holding capacity of each intermediate evacuation spaces. These shelters can hold at least 3780 individual evacuees in total. However, with an area of 10 m^2 per person, the selected spaces (temporary shelters) can accommodate approximately 17000 individual evacuees.

3.3 Road Network Topology

Butwal is located at the intersection of two important routes in Nepal, the Mahendra Highway and the Siddhartha Highway. Along with the Siddhartha Highway, it connects western Nepal to Kathmandu through the Mahendra Highway and air (via the Gautam Buddha International Airport in Siddharthanagar along the Siddhratha Highway). The Siddhartha Highway also connects the Indian border at Sunauli with the hilly towns of Tansen and Pokhara.

Several road segments connect these two highways within the region of this study. Therefore, in addition to highways, the major road segments within the region were taken into account. Major and small road segments within the study region are depicted in the figures 4 and 5.

Figure 4: Road network in Butwal Sub-Metropolitan City within the study region: Source-Google Earth Pro

Figure 5: Road network in Tilottama Municipality within the study region: Source-Google Earth Pro

4 Flow Computation

In this section we present the results of flow computation together with the flow computation technique.

4.1 Flow Computation Technique

The number of evacuees to be shifted to the safe places are the flow units, i.e., number evacuees, in the network. We investigate the flow pattern, in the road network together with the evacuation spaces, that results a lexicographically maximum contraflow. For this we apply the lexicographically maximum dynamic contraflow (LexMDCF) solution technique for multi-network proposed in [5]. The technique is presented in Algorithm 1 below.

Algorithm 1 LexMDCF Algorithm for Multi-network [5]

1. Given a dynamic multi-network $\mathcal{N} = (V, A, l(a), u(a), \tau(a), k(a), s, d, T)$, $\mathcal{S} = \{v_1, \dots, v_r\}$ 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 [4] 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 $i = 1, 2, \dots, q$; $q < m = |A|$.
4. Compute LexMDF on network $\tilde{\mathcal{N}}$ using algorithm in [3].
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 LexMDCF solution for multi-network $\mathcal{N}$.

4.2 Network Flow Algorithm Implementation

We consider the Evacuation Scenario as presented in Section 3 in which we consider 54 vertices, 169 arcs and 18 temporary shelters. Butwal Multiple Campus (A) has open space in which potential evacuees can be gathered. This place is considered as the source. For computational comfort we consider Banbatika (u) as the sink and other 17 places as mentioned in the Table 1 are intermediate temporary shelters. Beside Banbatika (u), the sink, other 17 temporary shelters are prioritized as mentioned in the table. Table 1 also demonstrates the holding capacities in each individual temporary shelters. When taking into account the standard area (people per 45 square meter sphere) for the holding capacity, these shelters can accommodate a minimum of 3780 individual evacuees overall.

Shelters (apart from sink) are chosen at random for this case illustration; however, this can be done based on factors like their capacity, distance from the source, or amenities that are available, etc., [3]. The "two second rule" is adhered to since it is a discrete time auto-based evacuation planning model, treating each minute as a time unit. The average car speed is thought to be 550 m/h, which closely corresponds to the transit time for the segment shown by Google Maps data during regular traffic.

Table 1: Maximum flow values (evacuees) at temporary shelters (vertices) with and without contraflow.

S.N.	temporary Shelters (Vertices)	Vertex Capacity	Priority Order	Flow value ($T = 21$)	Contraflow value ($T = 17$)
1	Banbatika (u)	570	1	570	570
2	Girvan School (j)	30	2	30	30
3	Jitgadhi Playground (B1)	120	3	120	120
4	Manimukunda Sen Park (R)	270	4	270	270
5	Shanti Namuna School (k)	120	5	120	60
6	Ram Mani Campus (l)	210	6	60	0
7	BICC & Butwal Kalika Campus (r)	900	7	900	900
8	Sarada Chowk (v)	30	8	30	30
9	Yogikuti Chowk (V)	90	9	90	90
10	Shrawan Chowk (Bhatbhateni) (n)	120	10	120	120
11	Siddheshori Ma. Vi. (p)	330	11	330	300
12	JP Smarak Park (s)	300	12	30	0
13	Janjyoti Secondary School (f)	60	13	0	0
14	Kalika Ma. Vi. (A1)	120	14	120	120
15	Butwal Ma. Vi. (x)	30	15	30	30
16	Cable Car Station (D)	210	16	0	0
17	Devinagar Football Ground (a)	150	17	0	90
18	Kanti Ma. Vi. (F)	120	18	60	120
	Total	—	—	2880	2850

Implementing the Algorithm 1 for our road network data-set and consideration, the results are shown in Table 1 when the time horizon of 21 minutes and 17 minutes are taken into account. We see that 2880 autos (cars) can be shifted to the shelters with in 21 minutes. This number of autos is approximately equivalent to potential landslide victims at Devinagar, Butwal. We also notice from the table tha the same number of evacuees can be shifted to shelters in 17 minutes if we allow contraflow approach in the solution procedure. It is to be noted that one auto is equivalent to 4 people in our consideration. In conclusion, we observe that with in 17 minutes about 11000 evacuees can be evacuated to the designated shelters if contraflow approach is applied.

Python 3.9.1 was used to create the method, and it was executed on a Windows 10 PC with 64 GB of RAM and an Intel Core i9-9900k processor running at 3.60 GHz. The computation of lexicographically maximum flows for $T = 21$ took about 7 seconds. The inaccuracies related to the transit time of road segments would be reduced by using a finer discretization of time (the algorithm's regulating parameter) rather than a minute as the unit of time. But it makes the software more complex to operate in terms of time.

5 Concluding remark

The majority of Nepal's cities, including northern part (Butwal Bazar) of Butwal Sub-Metropolitan City, are located in river basins or on hills. These may be suffered from natural hazards such as earthquakes, landslides, floods, and so on because Nepal is an earthquake-prone region with heavy rainfall over a short period of time (monsoon). We considered the evacuation scenario of Jyotinagar Landslide on the forehead of Butwal Bazar.

We gathered necessary evacuation data and implement a mathematical optimization model, namely Lexicographically Maximum Contraflow Problem, to build an evacuation plan.

Our results demonstrate that the contraflow strategy can reduce the overall evacuation time by up to 19% when used, demonstrating the approach's significance in the evacuation planning problem. According to our field survey, there is no single place within the Butwal Sub-metropolitan City and Tilottama Municipality at which all the possible victims could be accommodated, due to its space capacity. This fact has been verified by the result we obtained. However, while considering some other places as temporary shelters, besides a single destination, we can accommodate all possible victims. This justifies the inclusion of intermediate storage capability at intermediate vertices in the evacuation model.

To be more succinct, this research recommends the following four points:

(i) Evacuation spaces with highly essential facilities (drinking water, sanitation, medicines, recreational halls, etc.) should be identified. In particular, the existing open space mentioned in this research should be equipped with such facilities.

(ii) One of the most important issues with evacuation zones is that they are frequently swamped by floods during the monsoon season (when a landslide could occur). Thus, evacuation areas must be designed to prevent floods.

(iii) There should be regular rehearsals of the evacuation strategy for potential victims.

(iv) There is no single open space that is suitable and large enough to accommodate all potential victims in the periphery of the landslide area. Thus, technically, the lexicographically maximum flow problem is to be considered to model the evacuation planning problem and is to be implemented. The contraflow approach is obvious in such emergency evacuations.

Finally, we expect that in the coming days, the local and central governments will conduct extensive research (on all aspects of landslides and emergency evacuation) on Jyotinagar landslide and other such landslides within the country. A researcher of the similar field may be interested in finding the optimal evacuation plan for the situation with some of the roads disturbed or even collapsed.

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