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Warehouse location determination for humanitarian relief distribution in Nepal

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Abstract

The use of warehouse for storing emergency relief items has been proven to improve overall responsiveness, efficiency and effectiveness of the humanitarian supply chain while decreasing the cost incurred in the process. Driven by the same goals, this study determines the optimal number and locations of warehouses to be placed in different parts of Nepal for a humanitarian relief chain that would respond to sudden-onset disasters. The study utilizes a modified version of the maximal covering location problem which introduces additional constraints that reflect the real scenario of Nepal. The problem is solved using simplex algorithm with branch and bound applied to the relaxed integer. The novelty of this study lies in the introduction of indexes for development, disaster safety and transportation accessibility constraints to reflect socioeconomic, geo-climatic and topographical features of Nepal respectively. Three scenarios are chosen based on coverage distance. The results show the number and spatial locations of warehouses for each scenario, as well as their maximum and minimum coverages.

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Keywords: Location problem; integer programming; linear solvers; maximum coverage; emergency logistics

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1. Introduction

Disasters destroy the very infrastructure of the country, affecting the social, financial, economic, and physical structure of the society and can be trigger by natural, political, and economic events (Whybark, 2007). Recently, the frequency and scale of disasters have been increasing exponentially, gaining growing attention in the field of disaster response operation. Thus, the role of national and international disaster relief organizations and their disaster response strategies become very important. Depending on the scale of disasters, international relief can play a vital role in building up a country's resilience in advance enabling affected people and countries to get back to normal. The success and failure of disaster response activities highly depends upon the level of preparedness such as building up country's resilience in advance. However, over 90 percent of international relief aid is still dedicated to disaster response and less on advance preparedness. Thus, focus on preparedness activities like emergency planning, construction of emergency operation centers; and prepositioning of emergency supplies could translate to better aid outreach and level of service to beneficiaries. Among the several preparedness activities, this study focuses on warehousing for inventory prepositioning in Nepal which is an integral part of humanitarian logistics. Humanitarian logistics is defined as "the process of planning, implementing, and controlling the efficient, cost-effective flow of and storage of goods and materials as well as related information, from point of origin to the point of consumption for the purpose of alleviating the suffering of vulnerable people" (Thomas and Mizushima 2005). Referring to this definition, for the storage of goods and materials, a pre-determined location plays a vital role which makes facility location an integral part of humanitarian logistics. Warehousing is important because it directly helps reduce suffering of affected people by reducing the time to reach them while also encouraging cooperation and collaboration between large numbers of governmental, non-governmental, national and international organizations working in the field of disaster management.

Located in the central of the Himalaya range, Nepal is prone to various types of natural disasters due to its fragile geophysical structure; characterized by very high peaks, complex geology, active tectonic processes, and unplanned settlement, variable climatic condition, and weak economic and political condition (Nepal Hazard Risk Assessment, 2010). It is a great challenge to the nation to protect infrastructure, property and human lives from frequent landslide and floods. Each year flood, landslide, fire, epidemic, avalanche and various other natural and man-made disasters causes loss of thousands of human lives and destruction of physical properties worth billions of rupees. The earthquake of 1934, 1980, 1988, 2015 and the flood of 1993, and 2008 are devastating natural disasters which not only caused loss of human lives and physical properties but also adversely affected the development process of the country as a whole. Figure 1 and 2 show the statistics of different disasters and number of lives claimed from the year 1900-2014 in Nepal.

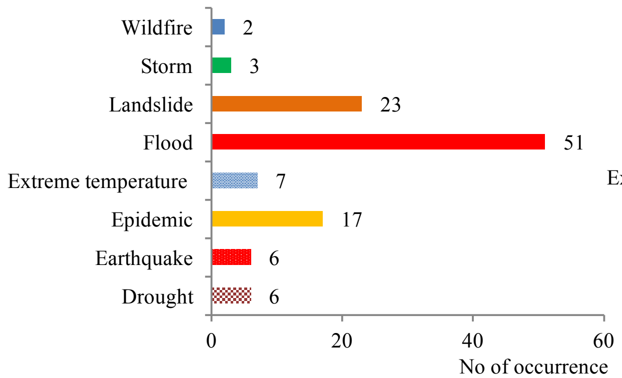

Fig 1: List of disasters with number of occurrence (1900-2014)
Source: Authors made from EM-DAT, 2014

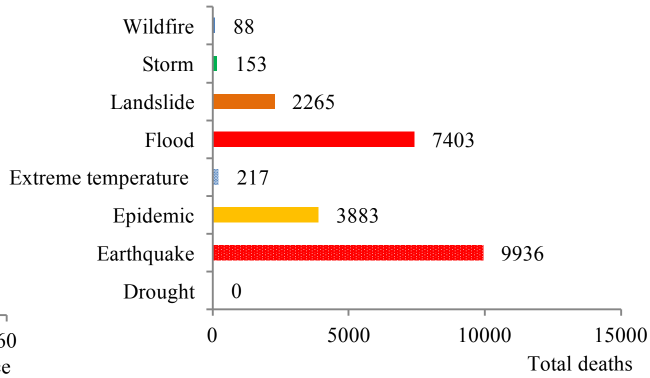

Fig 2: Total deaths claimed by different disasters (1900-2014)
Source: Authors made from EM-DAT, 2014

Disaster management is a difficult task. Due to a disaster's suddenness of occurrence and associated destruction, it is very difficult to cope given a normal administrative set up with its limited funds and resources. On top of the above situation, Nepal is facing a number of severe problems like: lack of preparedness activities, poor public awareness, low literacy rate, mass poverty, difficult and undeveloped physical infrastructure, unplanned settlement, lack of political commitment, slow decision making process and so on. Moreover, lack of cooperation and coordination among various disaster management related agencies, duplication of relief works, inadequate funds and resources and the lack of modern technology especially early warning system have made the disaster situation more complex. As a landlocked country with a rugged landscape, facilitating an incoming humanitarian response from regional and international partners to a major disaster is challenging. Nepal has one international airport in Kathmandu and only three major roads leading to the valley, none of which are resilient to a major earthquake. The difficulty in facilitating international assistance from outside the country would hinder Nepal's ability to effectively respond to a natural disaster. Intuitively, investing all public resources in disaster risk reduction measures would be inefficient, since we could not be certain of the expanse of a disaster's effect, since there would be instances when the effects are small and can be coped with ex post. But neither can society wait until disasters to strike and only deal with them ex post, especially when they can bring about large numbers of deaths and destruction.

Despite the importance of preparedness, less has been done in Nepal in terms of inventory prepositioning. Therefore, this study aims to determine the optimal locations for placing warehouses intended for storage of humanitarian relief. This is among one of the initial steps in building up country's resilience from preparedness perspective. The problem can be categorized as facility location problem. The study takes into consideration factors unique to Nepal such as transportation accessibility, disaster safety and level of development. This study also aims to identify the impact and importance of constraint values on overall output. Several mathematical models could be applied to determine optimal location for warehouses considering the above mentioned factors. Among them is optimization modelling, a powerful tool to tackle emergency logistics problems since its first adoption in maritime disaster situations (Acunhye et al., 2012). Based on data type and number of levels and objectives, structure of facility/warehouse location models can be classified as single-objective or multi-objective and deterministic or stochastic. This study uses a deterministic model with single objective considering accessibility via road, proximity and ease of access to affected people, proximity to disaster prone areas, availability of infrastructural services in the candidate points, and safety of the candidate points from disasters as factors affecting location determination.

2. Literature review

Facility location models determine the most suitable place for inventory prepositioning in the relief network. These models basically deal with determination of appropriate location for prepositioning inventories considering several stochastic as well as deterministic factors like cost, response time, location safety, demand coverage, distance etc. Facility location models are classified either for evacuation operation, stock-prepositioning, or stock prepositioning and relief distribution. Studies use the term facility and warehouse interchangeably. In this study the warehouses serve as places for stock prepositioning and relief distribution. Many studies have addressed the importance of the preparedness phase and the need for pre-positioned warehouses in humanitarian relief logistics, but only a small number of papers are related to the location decision (Dekle et al., 2005; Balcik and Beamon, 2008; Ukkusuri and Yushimoto, 2008; Dessouky et al., 2009; Rawls and Turnquist, 2010; Gatignon et al., 2010; Campbell and Jones, 2011, Roh et al., 2015). Among the different forms of preparedness activities for disaster management, storing disaster relief items in a pre-positioned warehouse is considered to be best for maximizing the effectiveness of humanitarian supply chains (Roh et al., 2015).

Klose and Drexl (2005) summarize various facility location models for distribution system design. They provide the details of continuous location models, network location models, and mixed integer programming models. The authors also classify different types of facility location models based on topological characteristics, objective, capacity constraint, demand, input parameters, and model type. Balcik and Beamon (2008) develop a model that determined the number and locations of the distribution centers in a relief network and amount of relief supplies to be stocked at each distribution center using a variant of maximal covering location model. This linear optimization model integrates facility location and inventory decisions, considers multiple item types, and captures budgetary constraints and capacity restrictions. However, the author suggests the use of real data to support implementation and enhance analysis. Similarly, Akkilal (2006) identifies the optimal locations for warehousing non-consumable inventories required for initial deployment by solving p-median problem. Duran et al. (2011) determine the optimal supply network configuration for CARE International using mixed-integer programming inventory location model using demand, and up-front investment. The supply network configuration consists of the number and the location of warehouse and the quantity and type of relief items held in inventory in each warehouse. Rawls and Turnquist (2010) use a two-stage stochastic mixed integer program to develop an emergency response planning tool that determines the location and quantities of various types of emergency supplies to be pre-positioned, under uncertainty of occurrence of disasters. Basdemir (2004) uses Lingo, to solve MCLP with additional constraints to determine the minimum number of search and rescue stations required to cover all the areas of operation in the Aegean and Western Mediterranean regions of Turkey.

Facility location problems can be formulated either as covering problems or as center problems or as median problems. Covering problems can be solved either as maximal covering location problem (MCLP) or as set covering location problem (SCLP). MCLP and P-median problem deals with similar problem categories. P-median problem attempts to minimize the sum of distances (average distances) between demand nodes and their nearest facilities. So the objective here is to minimize the total demand-weighted distance between each demand node and the nearest facility which can also be interpreted as to find the location of P-facilities on a network so that the total distance is minimized. However, some studies have found that P-median problem approach do not optimize the covered demand as well as site location because in this model distance and time parameters can outweigh the demand values and result in selected locations that are outliers (Lee and Yang, 2009). MCLP approach successfully addresses this shortcoming because the objective is changed from minimizing travel distance to covering maximum population. In addition, coverage models are known to be best for “worst case problem” because we want to ensure good response for even the most remote demand node in the network.

MCLP was first introduced by Church and ReVelle (1974), which maximizes the total demand covered within a maximal service distance subjected to limited number of facilities or resource constraint. Coverage, a notion that is central to facility location models indicates whether a demand location is within a pre-specified radius (measured by distance, travel time, cost or another metric) of its nearest facility. A source of demand is defined as covered if it is located within a specified response distance or time from the facility. The problem can be formulated as static or dynamic, single stage or multi-stage, single period or multi-period. The solution technique used for MCLP varies depending upon the type as well as size of the problem. There exist heuristic methods like Genetic algorithm, Lagrangian relaxation, Ant colony optimization, and Local search heuristics etc. are used which gives near optimal solution within reasonable time limit and exact methods like linear programming with branch and bound when the solution is expected to be global optimal. After the introduction of MCLP by Church and ReVelle (1974), Chung et al. (1983) added a capacity constraint to the MCLP to formulate capacitated maximal covering location problem and solved using heuristic solution. Megiddo et al. (1983) defined the MCLP on a tree-network and presented a solution algorithm for it. Daskin et al. (1988) examined the extensions such as the concepts of multiple, excess, backup, and expected coverage to covering models. Schilling et al. (1993) provide a detailed review of the covering models in facility location followed by Farahani et al. (2012). Boffey and Narula (1997) survey the multi-objective covering and routing problems. However, Farahani et al., (2012) and Balcik and Beamon (2008) are among the few literatures which highlights the lack of application of facility location models in real-world problems and minimal application of facility location models for coverage problems in humanitarian sector unlike in commercial sector until recently.

In an attempt to understand current relief scenario of Nepal, the authors made a field trip to Nepal from 31 May 2015 – 7 June 2015, after the two devastating earthquakes struck Nepal on April 25 2015 and May 12, 2015 leaving more than 8000 people dead and 18000 people affected while more than 2.8 million people in need of humanitarian assistance. The survey identified transportation/logistics problems, lack of technical, administrative and economic resources, lack of coordination as the issues/problems preventing smooth relief response operation. The survey also highlighted the need of warehouses with prepositioned relief materials to reduce transportation cost as well as uncertainty associated with it while improving coordination among several relief partners

Taking into consideration the existing research gaps and current disaster scenario, this study applies modified version of MCLP to determine warehouse locations for disaster relief distribution in Nepal using latest data on demand nodes, population density, distance, road accessibility and connectivity, disaster scenarios of flood, landslide and earthquake, and human development index. The study aims to highlight the applicability of the model in real scenario. Therefore, the paper can be categorized as a case study paper. Hence, the contribution of this paper lies in validating the applicability of already existing model to generate optimal solutions rather than to enlarge contribution in terms of modelling and/or solution technique.

3. Methodology

3.1 Methodology framework

The determination of optimal number and location of warehouses for disaster relief distribution during the immediate aftermath of disaster has been modelled as Maximal covering location problem (MCLP) with additional constraints in this study. The model includes candidate points which can serve as potential locations for warehouses and the demand points that need to be covered. In addition to the coverage distance, the selection of warehouse location is influenced by transportation accessibility, level of development and disaster safety of the respective candidate points and population density of the demand nodes. User accessibility and response time are two key factors that affect selection of facilities in emergency services. Here we use the notion of response distance instead of response time. The threshold values which refers to the minimum value for the three indices are obtained by taking the average of values assigned to each of the districts, and the model is constrained to obey this minimum threshold value. The selection of a candidate point is enabled only when the sum of the candidate point values for each additional constraint is above this threshold. Additional calculations were done with priority values assigned to each demand nodes to see the impact of population size on overall coverage and location selection.

3.2 Mathematical model formulation

The model has been formulated using several assumptions listed below:

- All the warehouses are considered incapacitated, meaning the warehouses have no capacity limitation hence can fulfil all the demands.
- All the demand points have proper road access to and from the candidate warehouse locations.
- There are no existing warehouses in Nepal.
- The demand points are either fully covered or uncovered, there is no provision of partial coverage; the coverage follows binary requirement.

The typical formulation of MCLP has been adapted with additional constraints and variables to meet the requirement of this study whose mathematical formulation is shown as follows;

$$\text{Maximize} \quad \sum a_i y_i \tag{1}$$

$$\text{S.T.} \quad \sum x_j \geq y_i \qquad \forall i \in I \quad j \in N \tag{2}$$

$$\sum x_j \leq P \qquad j \in J \tag{3}$$

$$\sum T_j x_j \geq N_T \sum x_j \qquad j \in J \tag{4}$$

$$\sum V_j x_j \geq N_V \sum x_j \qquad j \in J \tag{5}$$

$$\sum S_j x_j \geq N_S \sum x_j \qquad j \in J \tag{6}$$

$$x_j \in \{0,1\} \qquad \forall j \in J \tag{7}$$

$$y_i \in \{0,1\} \qquad \forall i \in I \tag{8}$$

Where,

I = denotes the set of demand nodes
J = denotes the set of warehouse locations
a_i = demand at node $i \in I$
P = number of warehouses to locate

$x_j = \begin{cases} 1 \text{ if a warehouse is located at candidate site } j \in J \\ 0 \text{ otherwise} \end{cases}$

$y_i = \begin{cases} 1 \text{ if a demand node } i \in I \text{ is covered} \\ 0 \text{ otherwise} \end{cases}$

N_T = the minimum value for transportation accessibility index

N_V = the minimum value for development index

N_S = the minimum value for disaster safety index

T_j = transportation accessibility index value for site j

V_j = development index value for site j

S_j = disaster safety index value for site j

Constraint (2) represents the coverage constraint. Based upon the coverage distance, each candidate location has a certain number of demand nodes it can cover; likewise, each demand node has a set of candidate warehouses which can cover it. In other words demand at node $i \in I$ cannot be covered unless at least one of the facility sites that cover node *i* is selected. Constraint (3) shows that the maximum number of warehouses which can be located, should be less than or equal to the allowable number of warehouses. Constraint (4), (5) and (6) are the limiting constraints for transportation accessibility, level of development and disaster safety associated with each of the districts. It stipulates that the value of transportation accessibility, level of development and disaster safety should be greater than or at least equal to the required minimum values for these indices to be selected as warehouse location. These constraints help to establish minimum standard for selection of warehouse locations.

The model is subject to several restrictions which affect the selection of warehouse locations; first restriction is on the coverage distance which determines the maximum distance within which a candidate warehouse can cover the nearby demand nodes. The coverage distance also determines the maximum number of warehouses that can be opened. Larger the coverage distance smaller will be the number of warehouses that needs to be opened to fulfil all the demand nodes and vice versa. The other restriction is on the maximum number of facilities that can be opened. Increase in the number of warehouses increases the service level provided to the demand points, however this model only allows for single time demand coverage. The third restriction is on the minimum values of transportation accessibility index, development index and the disaster safety index which the candidate points needs to fulfil in order to be selected as the warehouse location. The study considers transport of relief items via road only which in reality may not be applicable all the time and can be considered a limitation of this study.

3.3 Input parameter setting

3.3.1 Demand point selection

Disaster mapping is done to identify the demand points which are essentially the districts highly prone and vulnerable to earthquake, landslide and flood. These three disasters have the highest frequency of occurrence and the ones claiming largest number of damages to human beings and infrastructure. The study only takes into consideration the sudden onset disaster on the assumption that, there remains plenty of time for planning and preparation to respond to slow onset disasters. Data regarding disasters have been referred from Nepal Hazard Safety Assessment report 2010.

Disaster mapping resulted into 55 districts prone to disasters; however due to the lack of distance related data, one of the districts is removed from the list of demand points. Figure 3 shows the spatial distribution of disaster prone districts where each disaster scenario is differentiated by a different colour. Districts coloured light green are subjected to earthquakes, those coloured light red represent districts prone to flood, and districts prone to landslide are represented by light blue colour. While, districts prone to both earthquake and flood are represented by maroon colour, red coloured districts are prone to both earthquake and landslide, and the district prone to flood and landslide is coloured pink. However, there happens to be no district prone to all three types of disasters simultaneously. The rest of the districts without any colour are the ones potentially safe from disasters.

3.3.2 Candidate point selection

All the 75 districts can be considered for candidate point selection, however due to lack of distance related data and possibility of inaccessibility via road network four districts are removed as potential candidate points leaving 71 districts to be selected for warehouse placement. The demand points and candidate points overlap with each other because the disaster safety value weighs the advantage of putting a warehouse in a potentially safe location far from the disaster prone areas (i.e. demand points), with the disadvantage of putting a warehouse in the disaster prone district itself while reducing the overall distance to the demand points. This means that the warehouses could be located either in the disaster prone district or in the potentially safer districts.

3.3.3 Distance calculation

The coverage distance used in this study has been calculated using a web based application called shortest distance calculator, provided by Department of Roads, Nepal. The distance calculator used in the study is unique to Nepal since, it has an updated database of road networks only within the country. Due of the vast diversity in geography and poor infrastructural and economic condition, Nepal's total road network and density are low and as a result only 43 percent of the population has access to all-weather roads (World Bank 2007). Therefore, the calculation of exact distance instead of Euclidean distance is very important in this study to capture the real scenario. In addition, use of other distance calculation like Google maps was inapplicable due to the lack of proper database.

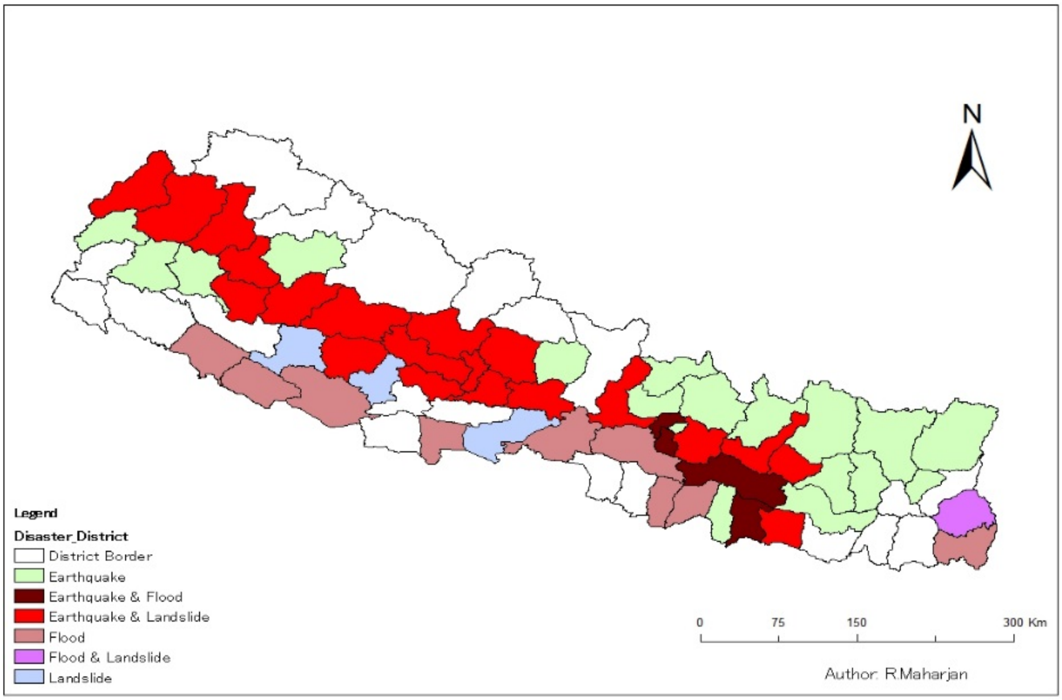

Fig 3: District disaster mapping for Nepal

3.3.4 Index selection

The study uses three indices namely transportation accessibility index, development index and disaster safety index as constraints for model formulation. The selection of these three indices makes this study unique because of their ability to reflect the accessibility of demand nodes from warehouses via road, level of development of each of the candidate points, and disaster safety associated with each candidate points. The main idea behind posing these constraints is to make sure the determined warehouse locations can serve the incoming demands within a short response distance while also making sure the safety of chosen location itself which in turn ensures the safety of emergency relief items stored in the warehouse. The details of constraint selection are explained below;

Transportation accessibility index is a proxy used to represent the accessibility of demand points from candidate points where warehouses are sought to be placed. The index values are derived from road density data which show kilometres of road existing per square kilometre of land for each districts. The model seeks for higher value of this index for candidate points to be selected as warehouse location.

Disaster safety index is a proxy used to represent safety of each district. The term safety here means districts are less vulnerable to disasters, hence safer for placing warehouses. Each district is susceptible to different types of disasters, so are exposed to different degree of risk hence has different values for safety index. The values assigned to each candidate points reflects the three disaster scenarios considered for this study and are derived from Nepal Hazard Risk Assessment report 2010. Some of the districts are prone to two types of disasters at once whereas some are potentially free from disasters. The districts susceptible to fewer disasters are assigned higher values compared to the ones prone to larger number of disasters meaning they are potentially safer. The model seeks for higher values of disaster safety index.

Development index is a proxy used to represent and compare level of development of each candidate points. Data regarding this index is derived from human development index (HDI) which essentially is a measure of life expectancy, education and per capita income indicators. Higher value of development index means the district is more developed hence assumed to have easier and better access to manpower as well as materials for storage and management of warehouse.

4. Calculation results and analysis

Due to the geographic variation in Nepal travel time for covering the same distance in different parts of the country is considerably different. It takes much longer time to travel 100 km in Himalayan Region than in Hilly and Terai region. Normally under standard road condition it takes about 7 hours to travel 200 km in hilly region. Thus, in an attempt to incorporate the varying needs of the response times, three different distances were used for the calculation of demand node coverage subjected to the three considered constraints. A standard criterion was set for all three constraints to calculate the number of demand points covered, wherein the candidate points/warehouses to be selected are required to have the values of transportation accessibility, development and disaster safety higher than 12, 0.345 and 8, respectively. Each scenario determines the maximum coverage obtained with minimum number of warehouses. In each of the scenarios, the demand nodes are treated as binary variables. Binary solution seeks to cover each of the demand nodes at least once. Multiple coverages do not improve quality of the solution. The model was run several times until all the demand points were covered under full coverage constraint. The term full coverage constraint refers to a situation where the P value was increased until all of the demand points were fully covered.

4.1 Scenario dependent solution

Three coverage distances of 100 km, 200 km and 300 km are considered based on authors understanding of the travel time in Nepal. Under normal circumstances, it takes about 7 hours to travel 200 km in hilly region under normal road condition. The travel time varies in each of the regions due to the geographic differences. In addition, there are no set standards for selecting appropriate response time and/or distance in case of disaster, rather it is on earliest possible convenience depending upon the severity of the situation on hand. The objective here is to find the minimum number of warehouses which will provide maximum coverage for all three scenarios. The solution set provides the list of various options with different number of warehouses and their corresponding coverage.

Figure 4 shows the spatial distribution of the warehouses and Figure 5 shows the percentage coverage obtained with varying number of warehouses for all three scenarios throughout Nepal. A total of 26 warehouses need to be located in Nepal to cover all of the 54 demand nodes for 100 km scenario, 12 warehouses for 200 km scenario and 7 warehouses for 300 km scenario. Redundant coverage will be obtained by further increasing the number of warehouses above 26, 12 and 7 in each of the scenarios. However, the solution does not seek for redundant coverage, hence solution was stopped when 100 percent demand coverage was obtained. It is worth to note, when limiting the number of warehouses to only one, the candidate point at Bhaktapur was found to be a significant location as it was common to all three scenarios. Nevertheless, final decision regarding the choice of optimal number of warehouse will depend upon several factors like organization's willingness, available resources, and their capacity etc. If we assume a case when humanitarian organization has resources enough to open six facilities only, then the corresponding coverage obtained will be 44 percent with 100 km coverage distance, 81 percent with 200 km coverage distance and 96 percent coverage with 300 km coverage distance.

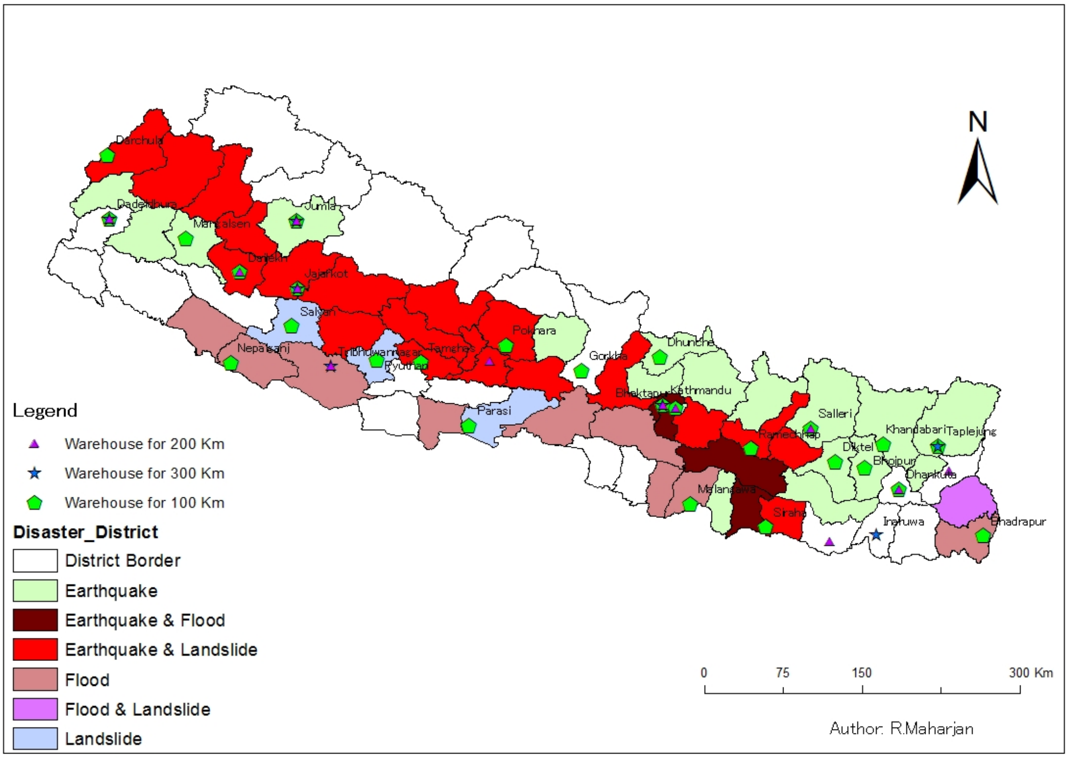

Fig 4: Warehouse locations for 100 Km, 200 Km, and 300 Km scenarios

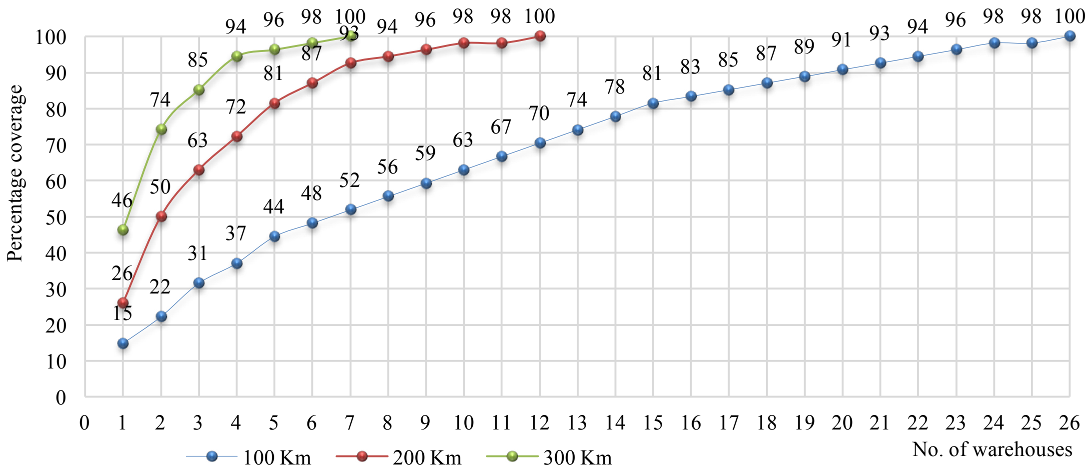

Fig 5: Coverage rates for 100 Km, 200 Km and 300 Km scenarios

4.2 Priority values

Furthermore, the model has been modified to increase its applicability in real life scenario by incorporating population of each of the demand nodes. The modified objective function is;

Maximize $$z = \sum p_i a_i y_i \quad (9)$$

Where,
p_i = priority value for each demand node based on population density

Each of the demand nodes were given a priority value (p_i) based on the population density of each district such that precedence will be given to locations with higher population density. The priority values were assigned based on hierarchy by grouping the entire population size into ten different categories. The higher the population density, the larger are the priority values assigned to each district, hence will ultimately receive more (prior) preference in terms of coverage. Figure 6 shows the details of the calculation for 300 km coverage distance. The objective value in the figure refers to the sum product of demand nodes and their associated priority values. When the number of warehouses were increased further, the objective value remained same but the redundant coverage increased.

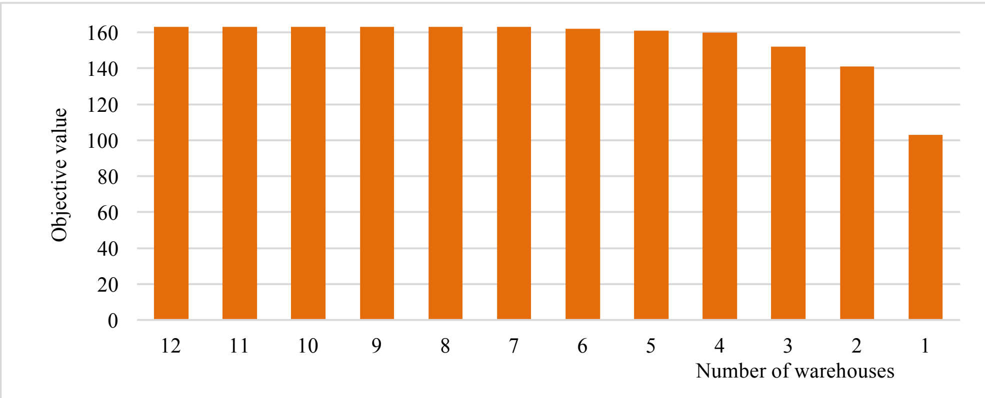

Fig 6: Solution for 300 Km coverage with bonus values

4.3 Sensitivity analysis

Sensitivity analysis, is a technique used to determine how different values of independent variable will impact a particular dependent variable under given assumptions. In this study, sensitivity analysis has been performed to see the impact of changing threshold value of transportation accessibility constraint and transportation accessibility and development index together on overall coverage and location selection. For the single constraint case the locations changed for every ten percent increase in the constraint value, however there was no significant impact on overall coverage. Figure 7 shows the change in location selection when the value of transportation accessibility was varied. The change in location selection can be justified by the model seeking for higher values of transportation accessibility, for example location selection when the constraint value was increased by 30 percent was significantly different from the standard case because the model seeks to maximize the sum total of transportation accessibility of all twelve candidate points. However certain candidate points have been selected as warehouse locations even though they do not comply with the constraint due to mandatory full coverage constraint.

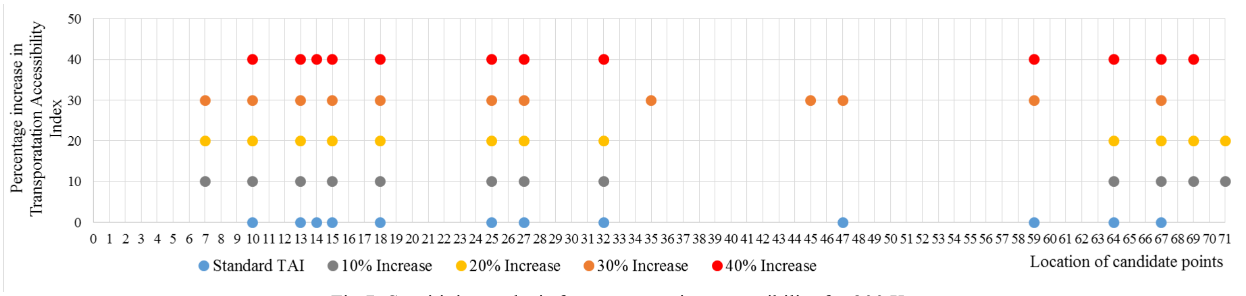

Fig 7: Sensitivity analysis for transportation accessibility for 200 Km

Figure 8 shows the results of sensitivity analysis performed to see the impact of changing two constraints; transportation accessibility and development level on overall coverage for 300 km coverage distance. The impacts on coverage and location choices are different. Every 10 percent increase in constraint values changes the locations significantly; however, change in-terms of coverage is not significant. Coverage decreases for one demand point when both constraint values are increased to 20 percent. Increasing the value of transportation accessibility and development are important to understand the significance of improving infrastructural facilities and its impact on overall coverage.

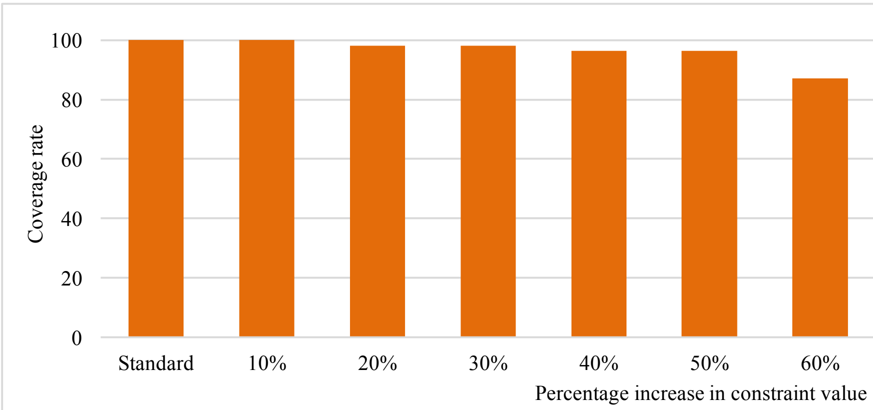

Fig 8: Change in coverage due to change in transport accessibility and development constraints for 300 Km scenario

5. Conclusion

The study determines the optimal number and location of warehouses utilizing the maximal covering location problem (MCLP) as an integer task. The optimal number of warehouses was calculated for different values of coverage distance and their respective locations. Three different scenarios were considered to weigh the pros and cons of having larger number of warehouses versus larger coverage distance. In each case, the main concern is the desired service level, the higher the desired service level, the larger should be the number of warehouses and shorter should be the coverage distance and vice versa. The study also provides several alternative solutions so that decision maker can choose the one which will meet both the desired service level and the organizational resource constraint. While doing so the study assumes that if the relief items are maintained by the host country there will be significant decrease in response time which would enable access to relief materials sooner while also reducing problems related to unsolicited items delivered to the affected people and places. Sensitivity analysis was performed to see the impact of changing the number of warehouses to a fixed value and changing the values of additional constraints on the number of warehouses and their coverage. The number of warehouses and the geographical constraints were found to be important factors affecting overall location decision.

Determining optimal location for establishing warehouses where inventories of emergency relief items can be stored is only a first step in an effort to help build national resilience from preparedness perspective. The significance of this study and more specifically warehousing is highlighted from the recent survey made by authors. It would be worth to note that among the 15 of the most affected districts, 14 of them were among the ones considered vulnerable in this study, which proves that the data used in the study are a close approximate to reality. The contribution of the study is not only limited to determining the warehouse number and location for a disaster prone country like Nepal but also, to the data used in the study which includes, demand nodes, population density, transportation accessibility, human development index, disaster scenarios. This study is the closest we have in terms of application of academic research in real life, which is among one of the aspects lacking in terms of humanitarian field. Despite the attractive results, the contribution of this study in terms of modelling and solution technique is limited except for the additional constraints included.

The authors believe that this model can be easily replicated for other vulnerable countries too with slight modifications. The applicability of the model is not only limited to determining warehouse location for prepositioning inventories for disaster relief distribution, but also to determine the location for search and rescue centers with some adjustments and improvisation. With minor modifications, the same technique can also be applied for determining facility location for both military and civilian purposes, public facilities like fire station location, and health center location etc.

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