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Sustainable Warehouse Location Selection in Humanitarian Supply Chain: Multi-Criteria Decision-Making Approach

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Abstract
The frequency of catastrophic natural disasters is rising, and much emphasis is being given to the Humanitarian Supply chain (HSC). The main goal of relief efforts is to get enough emergency supplies to the area hit by the disaster as quickly as possible. The decision of where to locate warehouses that will store relief supplies presents a significant obstacle for humanitarian relief organizations as they work to enhance their capacity for providing aid and their rescue plan. A non-optimal location could make the search and rescue efforts harder. More importantly, it has been seen that when these kinds of geographical sites are evaluated, social and environmental issues are not considered. This research paper aims to make humanitarian networks more accountable by determining the ideal warehouse site and considering both traditional and sustainable factors. A framework for selecting warehouses to keep relief goods was devised using the Multi-Criteria Decision Making (MCDM) approach. Best-Worst and TOPSIS ("Technique for Order Performance by Similarity to the Ideal Solution") methods were used to rank the potential locations based on Cost, Logistics, Environmental, and Social Criteria. A research study has been done in the State of West Bengal (District Arambagh).

Keywords- Humanitarian supply chain, Warehouse location, Sustainability, MCDM, TOPSIS – BWM.

1. Introduction

Warehouses are an important part of a supply chain because they connect the flows of goods at local and global markets. Recently, companies have been making decisions with customers at the centre of their business. Any firm wants to meet customers' expectations at the lowest possible cost. Hence, a warehouse should be located to maximize the efficiency of the organization's supply chain without causing a delay in the shipment process or increasing the total cost. So far, the location has been chosen based on the usual factors, such as economics, climate, geography, etc. However, in the last ten years, the harmful effects of business activities on the environment and society have been lessened because more attention has been paid to social sustainability and environmental awareness. Therefore, the location selection decisions have now grown to include the sustainability criteria. A sustainable society is built on the three pillars of economic, environmental, and social sustainability. Different industrial activities have done much damage over the years. There are many environmental, climate, energy, and social issues today. The government, customers, and the public are all putting pressure on supply chain managers due to all these issues. The 18 SDGs, or Global Sustainability Goals, must also be addressed towards a more sustainable future. It has also been found that incorporating the sustainability criteria improves the company's competitiveness. It is logical and desirable that the location selection problem includes both the sustainability and traditional aspects.

Humanitarian Supply Chain (HSC) is the flow of relief aid and information between people affected by a disaster and those giving the aid so that as few people as possible die or suffer. Over the years, people have paid attention to HSC because natural disasters are happening more often. India is among the world’s most disaster-prone countries. Climate change and unplanned development are causing unprecedented damage to the country. Also, given the unique topographical and socioeconomic conditions of India, it has been heavily prone to natural disasters, which have a long-term and lingering impact on society. India has witnessed severe and frequent cyclones, floods, droughts and earthquakes. 27 out of 36 states and UTs are disaster-prone, 58.6% of the land mass is prone to earthquakes (differing in intensity); 12% of the land is prone to floods and river erosions; 75.8% of the coastline is prone to cyclones and tsunamis; and 68% of the cultivated land is prone to droughts. India ranked 89th out of 181 countries in the Global Risk Index 2020, mainly because of its soaring vulnerability to extreme natural events and poor preparedness. India’s performance in strengthening its adaptive capacities also plunged, stating a lack of responsiveness to damages and consequences by associated systems, institutions, and other related organizations (Mohanty, 2022). HSC's primary goal is to get enough disaster relief supplies to areas that need them as soon as possible. If they choose the wrong warehouse location, rescue efforts could fail. During the phase of the pre-natural disaster, it is hard to run HSC operations well because it is hard to predict where, how bad, and when a disaster will happen. When resources are unavailable after a natural disaster, it is hard to get relief supplies to the right place on time. So, the humanitarian supply chain needs to put the warehouses where these aid items are stored. Most of the time, the location of a warehouse is chosen based on things like the location's features and economic factors. However, because of the overuse of natural resources and the rise in poverty, HSC must also consider the proper social and environmental criteria. So, making it easier for rescue efforts to work without doing too much damage to the environment and society.

The decision about where to put a warehouse is based on quantitative and qualitative factors, but not all have the same effect on the decision-making process. The problem is making decisions based on more than one factor. An appropriate MCDM framework for the sustainable selection of warehouse locations must be put forward to solve these problems. This study proposes an MCDM framework for choosing warehouse locations for storing relief materials in a sustainable way. A case study of an Indian organization that helps people in need shows that the framework works. Best-Worst Method and TOPSIS techniques are used to find the best place for a warehouse of relief items in Arambagh Block, West Bengal. West Bengal being in the Bay of Bengal Area, is prone to cyclones and floods.

The composition of damages due to floods has changed over the last six decades. From 1953 to 1962, crop damage accounted for 76%, but this fell to 29.7% from 2013 to 2017. During the same time period, the share of public utilities in total damages increased to around 60% (Central Water Commission, 2019). Figure 1 shows the total loss due to floods in India from 1953 to 2017.

Between 1953 to 2017 (65 years), India suffered following losses due to floods

Total damage	₹37,82,47,04,70,000 (₹3,78,247.047 Cr.
Population affected	2,087.60 Million
Lives lost	107,535
No. of houses damaged	80,717,993 *(worth ₹53774.362Cr.)*
Area of crops damaged	256.018 m. hectare *(worth ₹111,225.621 Cr.)*
Cattle lost	6,049,349
Damage to public utilities	₹212,060.003 Cr.

Figure 1. Total loss due to floods in India from 1953 to 2017 (Central Water Commission, 2019).

Figure 2 shows total loss due to floods in India from 1953 to 2017.

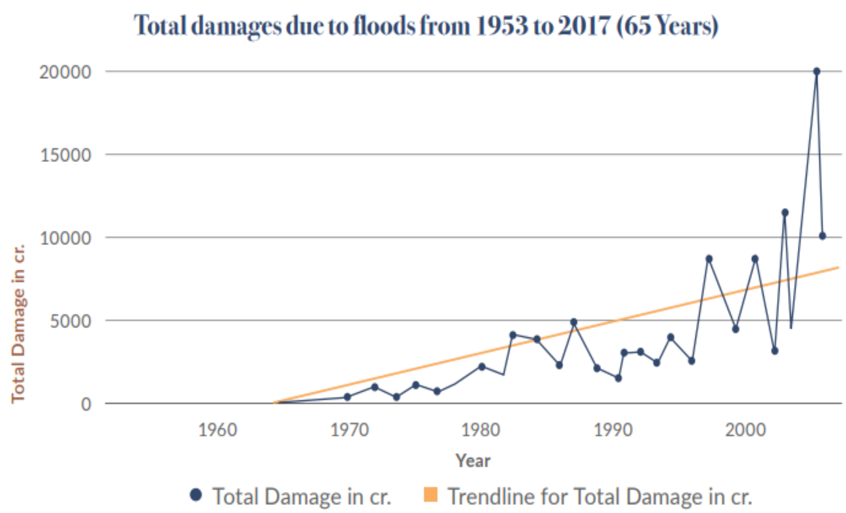

Figure 2. Total loss due to floods in India from 1953 to 2017 (Central Water Commission, 2019).

Looking at the above data and the need of the hour on disaster management the following research question has been formulated.

Q: How do you choose the best location for a warehouse in a humanitarian supply chain, considering location, logistics, and sustainability? The goal is to make the humanitarian supply chain more responsive, efficient, and effective while keeping costs down. The paper deals with solving the above objective in the following way:

The literature review can be found in Section 2. The research methods are discussed in Section 3. In Section 4, we'll look at the specifics of the case and the findings. Sections 5 through 8 present a discussion, a conclusion, and a look ahead at what this research could lead to.

2. Literature Review

Different studies of warehousing addressed in supply chain are storage location planning (Guenov and Raeside, 1992; Vaughan, 1999), inventory management and distribution (Schwartz et al., 2006), order picking (Hsieh and Tsai, 2006; Hwang and Cho, 2006; Bortfeldt and Mack, 2007; De Koster et al., 2007). Weber (1993) initially introduced the concept of warehouse location selection by finding a location so that the total distance travelled between the warehouse and the customers get minimized; (Singh et al., 2018). Warehouse location selection is an essential problem of the supply chain because an inefficient choice of warehouse location can lead to increased transportation costs, loss of qualified labour, and competitive advantage (Stevenson, 1993). So, facilities such as warehouses, distribution centres etc., must be strategically located to optimize a supply chain network (Simchi-Levi et al., 2003). Moghadam and Seyedhosseini (2010) highlighted that proper warehouse location selection results in an adequate and qualified workforce, availability of raw materials, and sufficient transportation facility. Anand et al. (2012) also suggested location decisions as one of the most strategic decisions in supply chain management and operations management.

Meyer and Roubens (2006) presented a 'multiple criteria decision-making' approach to rank and select the best among all available warehouse location alternatives. Sharma and Berry (2007) considered the single-stage capacitated warehouse location problem (SSCWLP) in which some points are selected to set up the warehouse such that the total transportation cost and the warehouse location cost are minimized. Ozsen et al. (2008) considered warehouse location problems and studied them under continuous economies of scale. Keeping in mind the hierarchical structure of the selecting warehouse location problem, Demirel et al. (2010) gathered a number of sub-criteria such as "tax incentives and tax structures", "availability of labor force", "quality and reliability of modes of transportation", and "proximity to customers for location selection problem". Ashrafzadeh et al. (2012), carried out warehouse location selection using fuzzy TOPSIS method.

Since optimal warehouse location requires evaluating alternatives in order to rank them by considering several criteria. Hence multi-criteria decision-making (MCDM) methods are used to choose the best warehouse location by evaluating the available potential alternative locations. Chan and Chung (2004) used AHP-genetic algorithm (GA) approach for warehouse location decision problem. Meyer and Roubens (2006) proposed a multiple criteria decision support approach in order to rank all the alternatives and suggest a best choice within a set of all available alternatives for the location of the warehouse. Korpela et al. (2007) suggested the integration of AHP and data envelopment analysis (DEA) for the decision of optimal warehouse location. Ho and Emrouznejad (2009), used AHP and goal programming to evaluate warehouse alternatives and solve the problem. Demirel et al. (2010), used AHP by selecting various criteria and sub-criteria. Ozcan et al. (2011), applied the TOPSIS and ELECTRE method and Grey theory on a case study of the problem of warehouse location selection in retail sector. Ashrafzadeh et al. (2012), proposed an application of fuzzy TOPSIS method for choosing the warehouse location. Uysal and Tosun (2014), suggested a selection of sustainable warehouse locations in the supply chain by applying the grey method.

The publication of the Brundtland report, "Our Common Future" by Brundtland (1987) marked a watershed for increasing attention towards the concept of sustainable development. The report describes sustainable development as the development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987; Holden et al., 2014). The three main pillars of sustainability are 'economic, environmental and social capital', which should be maintained and developed (Dyllick and Hockerts, 2002; Tahir and Darton, 2010). The economic characteristic is determined by the financial profits that a company is making. The environmental capital includes the negative impacts of business activities on nature (Dyllick and Hockerts, 2002). Social capital is determined by human capital i.e., aspects such as motivation and loyalty of internal and external stakeholders and the societal capital i.e., issues such as quality of public services and cultural offers (Dyllick and Hockerts, 2002; Tahir and Darton, 2010). Many research works' findings also show that better financial benefits are achieved when ecological and social factors are also incorporated (Pagell and Wu, 2009) and successfully implementing sustainable practices leads to competitive advantages (Zailani et al., 2012).

Translating this understanding to the location selection of warehouse problems in the supply chain, companies are adopting the ideas not just to determine the long-term success and competitiveness of the company but simultaneously to minimize the damage caused to nature and society. Özcan et al. (2011) used MCDM techniques such as the Analytic Hierarchy Process (AHP), the technique for order preference by similarity to ideal solution (TOPSIS), elimination and choice expressing reality (ELECTRE), and Grey approach to select the location of a warehouse for a Turkish retail sector. Uysal and Tosun (2014) also used a grey approach to select a sustainable warehouse location for a Turkish pharmaceutical company.

Although a considerable amount of research has been done on warehouse location, implementation of these issues has not received much attention in the field of the humanitarian supply chain. Balcik and Beamon (2008) and Campbell and Jones (2011) assessed the decision of where to pre-position stock in preparation for calamity and how much to stock at the warehouse, taking into account the possibility of it being destroyed. Roh et al. (2013) identified the key factors, i.e., location, logistics, cost, government cooperation, and national stability, and determined their weights for selecting humanitarian relief warehouse aspects. Roh et al. (2015) gave research work to pre-position warehouses at local and regional levels for a humanitarian relief organization, considering location, logistics, cost, government cooperation and national stability aspects. Roh et al. (2018) identified the most appropriate pre-positioned warehouse location for international humanitarian relief organizations considering location, logistics, cost, government cooperation and national stability aspects. Ak and Derya (2021) evaluated the most suitable place as a warehouse for humanitarian aid in Turkey.

In spite of the considerable investigations, very few studies regarding the problem of sustainable DC selection have been done. Most of the literature about warehouse location problems mainly stresses on finding a potential optimal location with optimization models rather than focusing on finding the required necessary characteristics for the location of a warehouse. Besides, mostly research has been conducted including only the traditional criteria or by combining the economic considerations either with environmental or social factors.

Climate change and unplanned development are causing unprecedented damage to the country. Also, given the unique topographical and socioeconomic conditions of India, it has been heavily prone to natural disasters, which have a long-term and lingering impact on society. India has witnessed severe and frequent cyclones, floods, droughts and earthquakes. The objective of research work is to select the most optimal location of a warehouse for a humanitarian supply chain considering the three dimensions of sustainability i.e., economic, environmental and social impact, along with the traditional criteria for improving the overall responsiveness, efficiency and effectiveness of the humanitarian supply chain while decreasing the cost incurred in the process.

3. Methodology

In this paper, an integrated approach of Best-Worst and TOPSIS methods is used to determine the most optimal location of the warehouse among a set of available potential alternative sites. Location selection is influenced by different quantitative and qualitative criteria, but not all of the criteria have the same impact on the decision procedure. Hence, such a selection may lead to additional risks and costs during rescue activities, thus, making it a complex MCDM problem. Therefore, this study utilizes the best-worst method to determine the weights of the criteria and TOPSIS methods to rank the potential locations.

The steps of the methodology can be summarized as follows:

- A set of criteria has been identified with the help of experts on the basis of which location selection has been done.
- A set of potential location alternatives for the warehouse has been selected with the help of experts.
- Weights of the criteria are calculated using the Best-Worst Method (BWM).
- Then, the best alternative was selected among all the potential alternative locations using the Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS).

The schematic presentation of the proposed approach is shown in Figure 3.

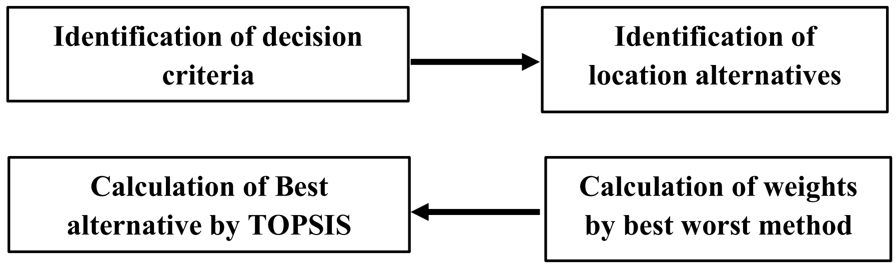

Figure 3. Methodological steps of the procedure.

3.1 Best-Worst Method

Best Worst Method (BWM) is an MCDM method. The method is used to evaluate a set of alternatives with respect to a set of decision criteria. The BWM is based on a systematic pairwise comparison of the decision criteria. After identifying the decision criteria by the decision-maker (DM), two criteria are selected by the DM: the best and worst. The best criterion is the one which has the most crucial role in making the decision, while the worst criterion has the opposite role. In this study, the best-worst method solver has been used. The schematic presentation of steps of BWM is shown in Figure 4:

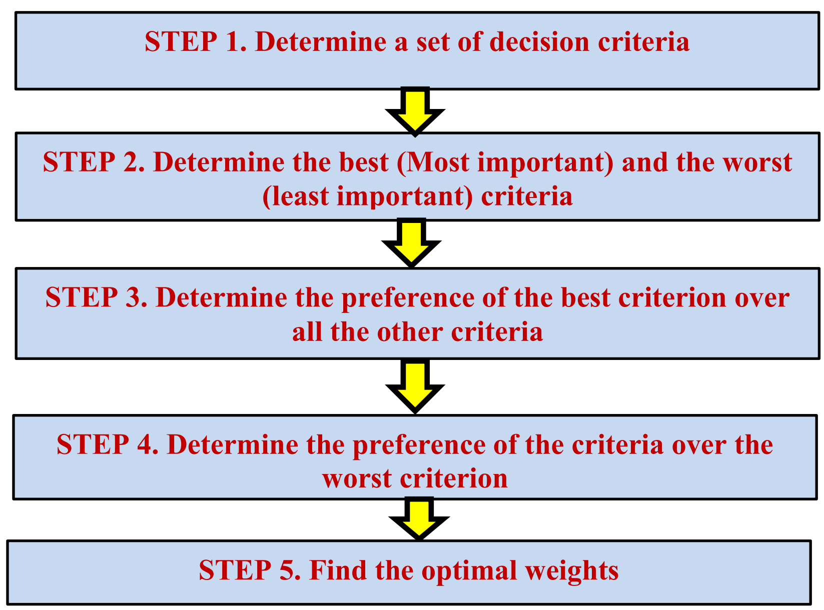

Figure 4. Steps of BWM.

3.2 TOPSIS

This method is used for tackling ranking problems. It is based on the principle that the chosen solution should have the shortest distance from the positive ideal solution and the longest distance from the negative ideal solution.

The steps of TOPSIS method are mentioned in the Figure 5.

Step 1. Form a decision matrix, $(x_{ij})_{mn}(x_{ij})_{mn}$

Step 2. Normalize the decision matrix D by using the following formula:

$$r_{ij} = x_{ij}\left(\sqrt{x_{ij}^2}\right)$$

Step 3. Construct the weighted normalized decision matrix by multiplying the normalized decision matrix by its associated weights. The weighted normalized value v_{ij} is calculated as: $w_{ij}r_{ij}$

Step 4. Determine the positive ideal solution and negative ideal'

$$A^* = \{(\max v_{ij} \mid j\varepsilon J), (\min v_{ij}) \mid j\varepsilon J'\}$$

$$A^- = \{(\min v_{ij} \mid j\varepsilon J), (\max v_{ij}) \mid j\varepsilon J'\}$$

J = 1,2,3,….,n where *J* is associated with the benefit criteria

J'= 1,2,3,….,n where *J* is associated with the cost criteria

Step 5. Determine the positive ideal solution and negative ideal. '‘'solution.‘ ‘'

$$A^* = \{(\max v_{ij} \mid j\varepsilon J), (\min v_{ij}) \mid j\varepsilon J'\}$$

$$A^- = \{(\min v_{ij} \mid j\varepsilon J), (\max v_{ij}) \mid j\varepsilon J'\}$$

J = 1,2,3,….,n where *J* is associated with the benefit criteria

J'= 1,2,3,….,n where *J* is associated with the cost criteria

Step 6. Calculate the separation measure. The separation of each alternative from the positive ideal one is given by:

$$S_i^* = \sqrt{\sum (v_{ij} - v_j^*)^2},$$

$j = 1$ Where $i = 1, 2, \ldots, m$

Similarly, the separation of each alternative from the negative ideal one is given by:

$$S_i = \sqrt{\sum (v_{ij} - v-)^2}, \quad Si = \sqrt{\sum (v_{ij} - v-)^2}, \; j = 1 \text{ where } i = 1, 2, \ldots, m$$

Step 7. Calculate the performance scores/ relative closeness to the ideal solution. The relative closeness of Ai with respect to A* is defined as:

$$C_i^* = S_-^i / (s_i^* + s_i^-), o \le ci^* \le 1 \, where \, i = 1,2,\ldots,m$$

Figure 5. Steps of TOPSIS.

4. Case Study

The framework is validated by considering the case study of Arambagh, West Bengal, India. Arambagh is a town in the Hooghly District in West Bengal, India. The case study of Arambagh has been selected due to the highly flood-prone nature of this region. Massive flooding was recently experienced here in 2017 and 2021. Therefore, firstly key decision factors have been identified, and then the MCDM framework for the sustainable selection of warehouse locations for storing relief material has been proposed.

4.1 Identification of Criteria

Warehouse location selection of a HSC depends on multiple criteria which have different impacts on the decision, hence, making it a complex MCDM approach. The objective of this problem is to select the best location alternative from a set of feasible alternatives. And, these location alternatives are evaluated, ranked and selected on the basis of the importance of the selected criteria. The selection of criteria and the evaluation of the significance of their weights have proportional influence on performance measures while making decisions. Thus, the process of assessing the weights of criteria has a direct impact on the end result of the methodology. So, the process to solve the problem starts with defining decision criteria. The criteria are identified through extensive literature review. Total 25 criteria are identified which are classified into four main categories, ie., Location and Logistics, Cost, Environmental and Social. Hence, all the criteria for warehouse selection are presented as follows in Table 1, Table 2, Table 3 and Table 4.

Table 1. Location and logistics criteria.

Geographical location	"The appropriate physical geographical location of the warehouse."	Malmir et al. (2015), Roh et al. (2018)
Disaster free location	"Location which is not easily affected by disasters should be selected for warehouse construction."	Roh et al. (2013)
Donor's opinions	"Some particular locations for a warehouse are preferred by some donors for political reasons and business relationships with certain governments."	Roh et al. (2018)
Proximity to disaster prone areas	"The distance to frequent disaster occurrence area should be less."	Song et al. (2019)
Climate	"The climatic conditions include temperature, precipitation and humidity in a region which vary from a location to another and play a significant role in warehouse operations."	Jha et al. (2018)
Closeness to other warehouses	"The geographical distance to other regional/local warehouses should be less due to cost and time reduction during the relief operations."	Jha et al. (2018)
Accessibility	"It includes connectivity or transportation facilities such as developed links via roads, nearness to railway stations, airports and seaports."	Jha et al. (2018)
Warehouse Security	"It refers to selecting the location of a warehouse which is secure from accidents, theft, and vandalism."	Rao et al. (2015)
Resource availability	"It refers to the ease and availability of resources such as labour, supply of water, electricity, gas etc in the area where warehouse needs to be located."	Terouhid et al. (2012)

Table 2. Cost criteria.

Sub-Criteria	Description	Source
Procurement Cost	"Ordering and replenishment cost of relief products."	Jha et al. (2018)
Set up cost	"Cost of land and constructing warehouse."	Jha et al. (2018)
Distribution cost	"Cost of distribution of vital materials to the aid recipients in disaster-hit areas."	Jha et al. (2018)
Operating cost	"Maintenance cost of the warehouse."	Jha et al. (2018)

Table 3. Environmental criteria.

Sub-Criteria	Description	Source
Energy saving provisions	"It includes the use of motion sensor lighting, use of photovoltaic or solar cells for the generation of electricity, daylight, sunlight reflecting roof, a prismatic lens for skylights, installation of circulation fans, using high-efficiency drives and motors, use of green cleaning products, etc."	Raut et al. (2017)
Effective water management provision	"This can be achieved by using automatic flushing, sensor-operated taps. The provision of rainwater management in a warehouse is also a significant selection factor. The usage of rain-water for lawn care and in toilets helps in saving considerable potable water."	Jha et al. (2018)
A provision for storage and disposal of toxic substance	"A sustainable warehouse should safely store and dispose of hazardous/harmful/toxic materials. So, the selected location should have safe waste storage and disposal provision."	Raut et al. (2017)
Ecosystem vitality	"The location selection of a warehouse must consider how to reduce urban pollution as much as possible and to protect the natural environment. Pollution includes construction waste pollution, water pollution, vehicle noise and air pollution caused by vehicular emissions."	Rao et al. (2015)
Environmental health	"The location selection of a warehouse must consider environmental health factors such as environmental burden of disease, air pollution related to humans and water quality related to humans."	Chen et al. (2014)

Table 4. Social criteria.

Sub-Criteria	Description	Source
Comply with environmental laws and regulations	"The location selection of a warehouse must comply with local laws and regulations and comprehensively consider the city and region's overall planning and resource space, and the selected location must conform to the city spatial structure and land use planning."	Jha et al. (2018)
Impact on nearby residents	"The location selection of a warehouse must consider the social environment. It should reduce the disturbance to city life and also relieve the pressure on urban congestion and promote healthy development for urban residents."	Rao et al. (2015)
Impact on ecological landscape	"To make the warehouse architecture merge into the living environment of the local residents, and to maintain or improve the original landscape without damaging a city's image."	Rao et al. (2015)
Availability of the safety measures	"Provisions like CO_2 cylinders, fireproof walls, fireproof electric cables, sand bed, smoke and heat alarms, sprinkler systems and eye wash station."	Jha et al. (2018)
Impact on traffic congestion	"To operate the warehouse smoothly, we must plan for the surrounding traffic environment."	Rao et al. (2015)
National Stability	"A stable political situation is important for the operation of the warehouse. If the political, economic, and social state of a country is very fragile and unstable, it will be difficult for a humanitarian organization to operate their supply chain in a risky and dangerous environment."	Roh et al. (2018)
Cooperation	"Cooperation in information, facilities and personnel sharing, etc. in the country by host government, United Nations, neighbour countries, logistics agents."	Roh et al. (2018)

4.2 Identification of Potential Locations

Following are the potential locations identified in the Arambagh region:

- Arandi
- Arandi
- Batanal-G.P.
- Madhabpur-G.P.
- Moloypur-I
- Horinkhola-II
- Mayapur-I
- Tirol G.P.
- Horinkhola-I
- Harinkhola-I

4.3 Best-Worst Method

Step 1. Determine a set of decision criteria and determine the Best and the Worst criteria

In this study, there are 25 total criteria. These criteria have been divided into four subsets: location and logistics aspects, economic aspects, environmental aspects and social aspects. So firstly, a pairwise comparison is done among the subsets i.e., four analyses are done. So, determine a set of decision criteria and the best and the worst criteria for each subset. The best and the worst criteria are mentioned in Table 5.

Pairwise Comparison among the Criteria:

The first pairwise comparison among the criteria is done. Both best and the worst criteria are selected, which are 'Proximity to disaster-prone areas' and 'Closeness to other warehouses' respectively.

Pairwise Comparison among the Cost Criteria:

A pairwise comparison among the cost criteria is done. Both best and the worst criteria are selected, which are 'Set up cost' and 'Procurement Cost' respectively.

Pairwise Comparison among the Environmental Criteria:

Pairwise comparison among the environmental criteria is done. Both best and the worst criteria are selected, which are 'Ecosystem vitality' and 'Energy saving provisions' respectively.

Pairwise Comparison among the Environmental Criteria and Social Criteria:

Pairwise comparison among the environmental criteria is done. Both best and the worst criteria are selected, which are 'Comply with environmental laws and regulations and 'Impact on traffic congestion' respectively.

Pairwise Comparison of 4 Main Categories:

A pairwise comparison of 4 main categories is done. Both best and the worst criteria among them are selected, which are 'Cost' and 'Location and logistics' respectively.

Table 5. Best and worst criteria.

Criteria	**Best Criteria**	**Worst Criteria**
Location and Logistics Aspects	Proximity to disaster prone areas	Closeness to other warehouses
Cost Aspects	Set-up Cost	Procurement Cost
Environmental Aspects	Ecosystem vitality	Energy saving provisions
Social Aspects	Comply with environmental laws and regulations	Impact on traffic congestion
Technical Aspects	Technology capability	Forecasting ability
Main Aspects	Location and logistics	Technical factors

Step 2. Enter the preferences (Best to others and Others to the Worst)

The preferences of the best criterion are given over all the other criteria and also the preferences of all the criteria over the worst criterion are given using a number from a predefined scale. Preferences with respect to Closeness to other warehouses, Proximity to Disaster Prone Areas, Set up cost, Procurement Cost, Ecosystem vitality, Energy Saving Provisions, Comply with Environmental Laws and Regulations, Impact on traffic congestion, cost and Location and logistics are given in Table 6, Table 7, Table 8, Table 9, Table 10, Table 11, Table 12, Table 13, Table 14 and Table 15 respectively.

Table 6. Preferences with respect to closeness to other warehouses.

Others to the Worst	**Closeness to other warehouses**
Geographical location and climate	5
Disaster free location	8
Donor's opinions	3
Proximity to disaster prone areas	9
Closeness to other warehouses	1
Accessibility	7
Warehouse Security	2
Resource availability	6
Closeness to other warehouses	9
Accessibility	3
Warehouse Security	8
Resource availability	4
Availability of technology	6

Table 7. Preferences with respect to proximity to disaster prone areas.

Best to Others	**Proximity to Disaster Prone Areas**
Geographical location and climate	5
Disaster free location	2
Donor's opinions	7
Proximity to disaster prone areas	1

Table 8. Preferences with respect to set up cost.

Best to Others	**Set up cost**
Procurement Cost	**4**
Set up cost	**1**
Distribution cost2	**2**
Operating cost	**3**

Table 9. Preferences with respect to procurement cost.

Best to Others	**Set up cost**
Procurement Cost	1
Set up cost	4
Distribution cost2	3
Operating cost	2

Table 10. Preferences with respect to ecosystem vitality.

Others to the Worst	**Ecosystem vitality**
Energy saving provisions	5
Effective water management provision	4
A provision for storage and disposal of toxic substance	3
Ecosystem vitality	2
Environmental health	1

Table 11. Preferences with respect to energy saving provisions.

Others to the Worst	Energy saving provisions
Energy saving provisions	1
Effective water management provision	2
A provision for storage and disposal of toxic substance	3
Ecosystem vitality	5
Environmental health	6

Table 12. Preferences with respect to comply with environmental laws and regulations.

Best to Others	Comply with environmental laws and regulations
Comply with environmental laws and regulations	1
Impact on nearby residents	2
Impact on ecological landscape	3
Availability of the safety measures	4
Impact on traffic congestion	7
National Stability	6
Cooperation	5

Table 13. Preferences with respect to impact on traffic congestion.

Best to Others	Comply with environmental laws and regulations
Comply with environmental laws and regulations	7
Impact on nearby residents	6
Impact on ecological landscape	5
Availability of the safety measures	4
Impact on traffic congestion	1
National Stability	6
Cooperation	3

Table 14. Preferences with respect to cost.

Best to Others	Cost
Location and logistics	4
Cost	1
Environmental Aspects	2
Social Aspects	3

Table 15. Preferences with respect to location and logistics.

Others to the Worst	Location and logistics
Location and logistics	1
Cost	4
Environmental Aspects	3
Social Aspects	2

Preferences with respect to Weights of the Criteria is mentioned in Table 16.

Table 16. Preferences with respect to weights of the criteria.

	Weights	Sub-Criteria	Weights	Global Weights
Location and logistics	0. 103448276	Geographical location and Climate	0. 076607387	0. 079249021
		Disaster free location	0. 191518468	0. 019812253
		Donor's opinions	0. 054719562	0. 005660644
		Proximity to disaster prone areas	0. 314637483	0. 032548705
		Closeness to other warehouses	0. 027359781	0. 002830322
		Accessibility	0. 127678979	0. 01320817
		Warehouse Security	0. 047879617	0. 004953064
	Weights	**Sub-Criteria**	**Weights**	**Global Weights**
		Resource availability	0. 095759234	0. 009906128
		Availability of technology	0. 063839489	0. 006604085
Cost	0. 465517241	Procurement Cost	0. 103448276	0. 048156956
		Set up cost	0. 465517241	0. 216706302
		Distribution cost	0. 25862069	0. 12039239
		Operating cost	0. 172413793	0. 080261593
Environmental Aspects	0. 25862069	Energy saving provisions	0. 071684588	0. 018539118
		Effective water management provision	0. 11827957	0. 030589544
		A provision for storage and disposal of toxic substance	0. 157706093	0. 040786059
		Ecosystem vitality	0. 415770609	0. 107526882
		Environmental health	0. 23655914	0. 006117909
Social Aspects	0. 172413793	Comply with environmental laws and regulations	0. 352603526	0. 060793711
		Impact on nearby residents	0. 209102091	0. 036052085
		Impact on ecological landscape	0. 139401394	0. 024034679
		Availability of the safety measures	0. 104551046	0. 018026042
		Impact on traffic congestion	0. 04100041	0. 007069036
		National Stability	0. 069700697	0. 012017362
		Cooperation	0. 083640836	0. 014420834

4.4 TOPSIS

The description of the TOPSIS method is mentioned in section 3.2. Following are the steps of the method.

Step 1. Rank the criteria on the 5-point scale to form the decision matrix.

The following criteria have been measured on a scale of 1 to 5, where *1 stands for good, 3 stands for very good, and 5 stand for extremely good.*

- Geographical location
- Climate
- Accessibility
- Warehouse Security
- Energy saving provisions
- Effective water management provision
- A provision for storage and disposal of toxic substance
- Environmental health
- Impact on traffic congestion
- National Stability
- Cooperation

The following criteria have been measured on the scale of 1 to 5, where,
1 stands for Less Probable, 3 stands for Highly Probable and 5 stands for Extremely Highly Probable.

- Disaster-free location
- Resource availability
- Availability of technology

Following criterion has been measured on the scale of 1 to 5, where,
1 stands for Supportive, 3 stands for Very Supportive and 5 stands for Highly Supportive.

- Donor's Opinions

Following criteria has been measured on the scale of 1 to 5, where,
1 stands for Close, 3 stands for Very Close and 5 stands for Extremely Close.

- Proximity to disaster-prone areas
- Closeness to other warehouses

Following criterion has been measured on the scale of 1 to 5, where,
1 stands for High, 3 stands for Very High and 5 stands for Extremely High.

- Procurement Cost
- Set up cost
- Distribution cost
- Operating cost
- Comply with environmental laws and regulations
- Impact on nearby residents
- Impact on ecological landscape
- Impact on traffic congestion
- National Stability
- Cooperation

Then decision matrix is formed using the above defined 5-point scale. Table 17 represents the decision matrix for the criteria; Geographical location and Climate, Disaster free location, Donor's opinions, Proximity to disaster prone areas and Closeness to other warehouses.

Table 17. Decision matrix.

Alternative Locations	Geographical location and Climate	Disaster free location	Donor's opinions	Proximity to disaster prone areas	Closeness to other warehouses
Arandi-I	1	3	3	5	1
Arandi	5	1	3	1	5
Batanal-G.P	5	3	5	3	3
Madhabpur-G.P.	1	5	1	1	1
Moloypur-I	3	1	5	1	1
Horinkhola-II	5	5	5	5	3
Mayapur-I	3	1	3	3	5
Tirol G.P.	5	3	1	1	5
Horinkhola-I	1	5	3	3	3
Harinkhola-I	3	5	5	1	1

Similarly, decision matrices are formed for rest of the criteria as well.

Step 2. Normalize the decision matrix

The decision matrices are then normalized using the formula mentioned in the section 3.2, step 2. Normalized Decision Matrix is presented in the Table 18 for the criteria; Geographical location and Climate, Disaster free location, Donor's opinions and Proximity to disaster prone areas.

Table 18. Normalized decision matrix.

Alternative Locations	Geographical location and Climate	Disaster free locations	Donor's opinions	Proximity to disaster prone area
Arandi-I	0.00695059894	0.005212948613	0.001445598053	0.01797201582
Arandi	0.0347529947	0.001737649538	0.001445598053	0.003594403165
Batanal-G.P.	0.0347529947	0.005212948613	0.002409330088	0.01078320949
Madhabpur-G.P.	0.00695059894	0.008688247688	0.0004818660175	0.003594403165
Moloypur-I	0.02085179682	0.001737649538	0.002409330088	0.003594403165
Horinkhola-II	0.0347529947	0.008688247688	0.002409330088	0.01797201582
Mayapur-I	0.02085179682	0.001737649538	0.001445598053	0.01078320949
Tirol G.P.	0.0347529947	0.005212948613	0.0004818660175	0.003594403165
Horinkhola-I	0.00695059894	0.008688247688	0.001445598053	0.01078320949
Harinkhola-I	0.02085179682	0.008688247688	0.002409330088	0.003594403165
Ideal Best (VJ*)	0.0347529947	0.008688247688	0.002409330088	0.01797201582
Ideal Worst (VJ-)	0.00695059894	0.001737649538	0.0004818660175	0.003594403165

Similarly, normalized decision matrices are formed for rest of the criteria as well.

Step 3. Form the weighted normalized decision matrix.

It is formed by multiplying the normalized decision matrix by its associated weights, i.e., the global weights of the criteria calculated by BWM method.

Step 4. Calculate Euclidean distance from positive ideal and negative ideal solutions and calculate performance scores

Euclidean distance from positive ideal and negative ideal solutions and performance scores are calculated using the formulae mentioned in the section 3.2.and are presented in the Table 19.

Table 19. Euclidean distances from positive ideal and negative ideal solutions and performance scores.

Alternative Locations	Si+ (Euclidean distance from positive ideal solutions)	Si- (Euclidean distance from negative ideal solutions)	Si+ + Si-	Ci* (Performance Score)
NormailArandi-I	0.05910549747	0.08637210267	0.1454776001	0.5937141016
Arandi	0.09652727835	0.05905667368	0.155583952	0.3795807531
Batanal-G.P.	0.06691993391	0.06499345757	0.1319133915	0.4926979501
Madhabpur-G.P.	0.05150179042	0.08877403085	0.1402758213	0.632853403
Moloypur-I	0.09354095947	0.04228558619	0.1358265457	0.3113204859
Horinkhola-II	0.06960353603	0.06251981328	0.1321233493	0.4731927673
Mayapur-I	0.07701932839	0.05029536284	0.1273146912	0.3950475971
Tirol G.P.	0.04586238809	0.09702770282	0.1428900909	0.6790373091
Horinkhola-I	0.08734461333	0.06948196193	0.1568265753	0.4430496669
Harinkhola-I	0.08396041668	0.07256011206	0.1565205287	0.4635820786

Step 5. Final Ranking

Final ranking of the potential location alternatives is done according to their performance scores, presented in Table 20.

Table 20. Final ranking.

Alternative Locations	Ranks
Arandi-I	3
Arandi	9
Batanal-G.P.	4
Madhabpur-G.P.	2
Moloypur-I	10
Horinkhola-II	5
Mayapur-I	8
Tirol G.P.	1
Horinkhola-I	7
Harinkhola-I	6

5. Discussion

In this study, the best and most sustainable place for an HSC warehouse in West Bengal's Arambagh block has been identified. Because this area is prone to flooding, a warehouse needs to be set up to store items that can be used to help people during and after a flood. It is a decision that is affected by both quantitative and qualitative factors. There are various factors of differing weightage, making it a difficult **Multi-Criteria Decision Making (MCDM) problem.** A literature review was done to find a set of criteria for making decisions. In the end, 4 main criteria and 25 sub-criteria were found that affect how humanitarian supply warehouses are chosen. These are shown in tables 1, 2, 3, and 4 in Section 4.1. Usually, the location of a warehouse is chosen based on things like the characteristics of the area and economic factors. But to make these research projects more responsible, social and environmental factors are also taken into account. Then, with the help of experts, a list of possible locations for the warehouse has been made and is shown in section 4.2. The best location option is then chosen by taking all the criteria into account. The BWM method, which is explained in section 4.3, is used to figure out each decision criterion's weight, or how important it is. After figuring out how important each decision criterion is, the TOPSIS method, which is explained in section 4.4, is used to rank the possible locations. Table 20 shows the final rankings of the different possible locations. Table 20 shows that Tirol G.P. is the best and most practical place for a warehouse in the Arambagh block of West Bengal.

6. Conclusions

Given the exponential rise in the incidence of natural disasters, interest in HSC has skyrocketed in recent years. Having a warehouse for storing emergency relief supplies in a central place has been shown to increase the HSC's speed, efficiency, and efficacy. It is challenging to efficiently manage HSC operations in the pre-natural disasters phase due to uncertainty regarding the location, severity, and timing of disaster. In the aftermath of natural disasters, it can be challenging to get relief supplies where they need to go on time due to a lack of available resources. The dilemma of where to put the warehouses holding the supplies for the relief efforts takes on added significance for humanitarian groups. Strategic stockpiling for humanitarian reasons is crucial for ensuring a steady flow of relief supplies to the affected area. To ensure that people have access to necessary goods as quickly as possible during an emergency, this research examines the optimal "where" for stockpiling. Arambagh block, West Bengal, is a very flood-prone area, hence this research proposed using a BWM - TOPSIS integrated framework to determine the best possible place to store relief supplies. These criteria were narrowed down after an extensive review of the relevant literature and consultation with a group of decision-makers. Based on the results of this study, Tirol G.P. is the best possible location for a warehouse in this area.

The new component of this study is that it takes into account all three dimensions of sustainability (economic, environmental, and social) at once (thus the term "triple bottom line"). A warehouse's site is typically chosen in accordance with a variety of factors, including those related to the location's qualities and economic considerations. It has been noted, however, that when such geographical sites are considered, the social and environmental considerations that are so important are often overlooked. However, selection based on applicable social and environmental criteria becomes necessary in order to make research activities more responsible. So, in this research, we choose the best place to put a warehouse by factoring in a variety of environmental considerations, such as access to renewable energy sources, efficient water management, and safe disposal of hazardous materials.

7. Limitation and Future Scope

In this study, 25 decision criteria which include an important aspect, i.e., sustainability has been considered. However, there can be a number of other aspects, for instance; lean, agile and resilient criteria (LAR), that are omitted from this research work. The inclusion of these criteria will help the HSC organizations even better to formulate resilient and robust strategies to minimize risks and efficiency and effectiveness. In future, authors would like to consider LAR and sustainability simultaneously while making optimal warehouse location decisions for HSC.

8. Research Contribution and Implications

This research adds to the existing body of knowledge by providing an in-depth analysis of the decision factors involved in selecting a warehouse location; it also sheds light on how humanitarian relief organizations can incorporate both conventional and sustainability criteria into their warehouse selection processes; it provides guidance on how to choose the best location out of a set of alternatives with respect to a number of decision criteria. Local governments must invest in studying this topic at a deeper level and define a model to calculate the cost and impact of strategically placed warehouse to provide relief material. According to scientists, similar research can be used for other types of calamities, such as deadly pandemics. The previous two years have seen the biggest global outbreak in recorded history. When the rapid outbreak of COVID occurred, no supplies were on hand to deal with it, the paper provides a helpful guideline for selecting the location of warehouses from which medicines, paramedics, or vital oxygen cylinders can be supplied rapidly to the most affected locations. When every second counts and hundreds of lives are at stake, properly placing these is of utmost importance. Maintaining a strategic stockpile for humanitarian purposes is crucial to provide a steady flow of aid supplies to the affected area as soon as possible.

Conflict of Interest

The authors confirm that there is no conflict of interest to declare for this publication.

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