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Multimodal Logistics in Disaster Relief

Syed Tariq, Muhammad Naiman Jalil and Muhammad Adeel Zaffar

Introduction

A disaster is defined as a major ecological breakdown between man and the environment (Gunn 2003). Disasters can be natural like earthquakes, floods, hurricanes, or man-made like chemical leakages or terrorist attacks. The number of natural disasters has increased in an exponential manner in the past few decades (see Fig. 15.1). Damages caused by disasters amounted to USD 155.8 billion from 2005 to 2014 (Guha-Sapir et al. 2014). Logistics is an important element of disaster operations, accounting for close to 80 percent of relief efforts (Trunick 2005). For example, in the 2010 Earthquake in Haiti, both sea and airports were damaged. Portable air traffic control equipment was brought in to make the airport functional. However,

S. Tariq (✉)
Suleman Dawood School of Business, Lahore University of Management Sciences, Lahore, Pakistan
e-mail: 14080009@lums.edu.pk

M.N. Jalil
Rotterdam School of Management, Erasmus University, Rotterdam, The Netherlands
e-mail: muhammad.jalil@lums.edu.pk

M.A. Zaffar
Information Technology, University of North Carolina, Chapel Hill, NC, USA
e-mail: adeel.zaffar@lums.edu.pk

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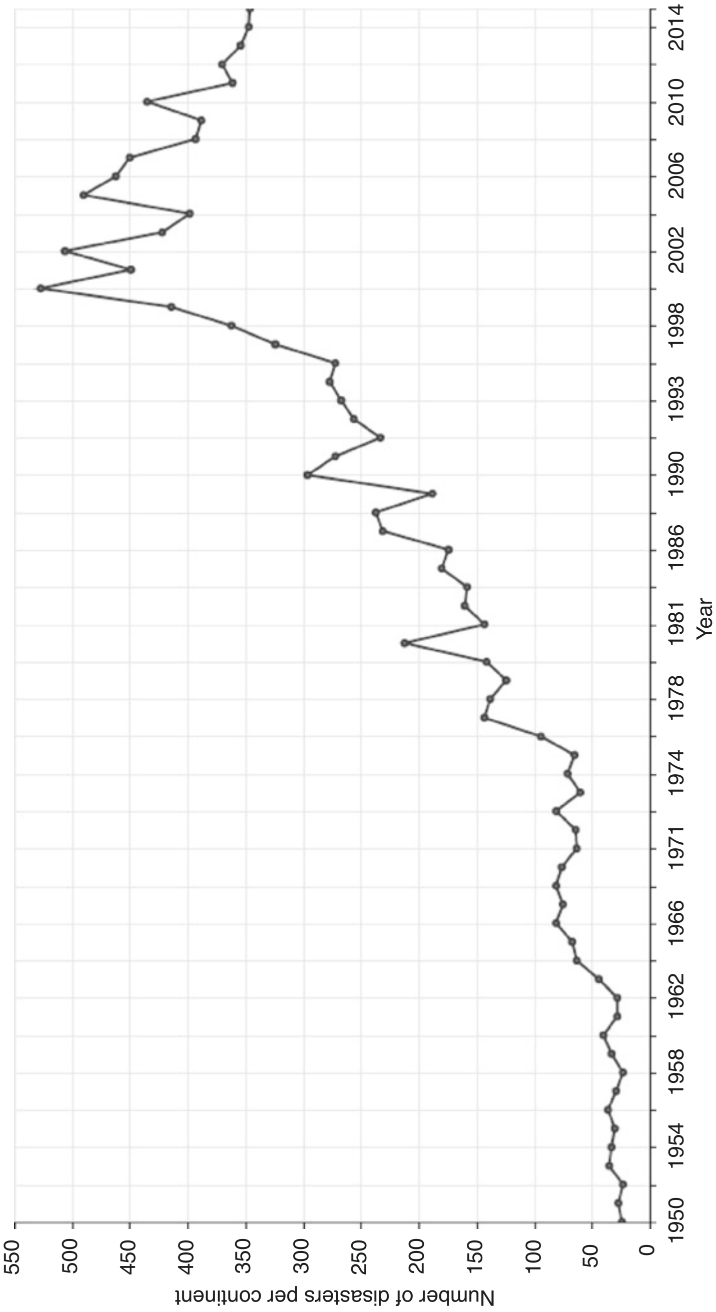

Fig. 15.1 Trend of reported disasters 1950–2015 (With permission from EM-DAT 2016)

the seaport could not resume function for weeks as the piers and two cranes had been destroyed. Alternate logistics arrangements and emergency equipment were deployed to resume the flow of relief goods and medical teams (Holguín-Veras et al. 2012a). Such disruption of logistics infrastructure is one of the reasons for the utilization of alternative modes of transportation in disaster operations. This chapter is concerned with multimodal transportation during disasters and the elements of logistics that enable its use in disaster response.

Multimodal transportation of freight is defined as the utilization of more than one transportation mode in delivering a shipment of goods (UNECE 2009). The objective of this chapter is to review and understand problem settings in disaster scenarios concerned with multimodal logistics in order to provide areas of future research. This review includes a comparison of literature with cases from practice to glean interesting future areas of research. Literature relevant to multimodal planning in disaster operations is discussed in section "Literature Review". Section "Case Methodology" discusses the research methodology of two case studies—the 2005 Kashmir Earthquake and the 2010 Pakistan Floods. The cases are presented in sections "Kashmir Earthquake 2005" and "Pakistan Floods 2010", respectively, from a relief logistics viewpoint. Finally, in section "Analysis and Conclusions", we analyze the logistics problems faced in the two cases to obtain insights for future research in the field.

Literature Review

Disaster Operations Management

Humanitarian operations are geared toward alleviating suffering in general and helping people survive. These can be divided into two streams of activities: relief activities and development activities (Beamon and Balcik 2008). Relief activities alleviate suffering in large-scale emergencies. Disaster response is a relief activity targeted toward affectees of natural or man-made disasters. The purpose of relief activities is to provide immediate response to minimize human suffering and loss of life. Development activities—sometimes called continuous aid work—are long-term commitments toward the development of infrastructure, self-sufficiency, and sustainability in a community. These activities are sometimes conducted after disasters. However, their core purpose is to provide long-term stability and introduce self-sufficiency in an affected area.

The process of disaster operations management consists of four distinct phases: mitigation, preparedness, response, and recovery (McLoughlin 1985). Mitigation is concerned with reduction in disaster risk through steps in advance that reduce impact on populations. Preparedness phase facilitates disaster response through training personnel, deploying disaster response facilities, evacuating vulnerable population, and pre-stocking goods in preparation for the disaster. Disaster response phase occurs after a disaster has struck. The response phase is focused on minimizing human suffering through delivery of relief goods and medical assistance to the affectees. The recovery phase is a long-term effort to provide economic stability and resume daily activities in the affected area.

Disaster logistics problems occur in the last three stages, that is preparedness, response, and recovery stages (Özdamar and Ertem 2015). Certain characteristics of disaster logistics planning as highlighted by Sheu (2007) are:

1. Challenges in coordination and communication during disaster response arising from damaged communication infrastructure and increased complexity of communication due to multiple stakeholders.
2. Difficulties in achieving efficiency and timeliness in logistics.
3. Scarce resource availability given the magnitude of the impact.
4. Increased sources of uncertainty including high demand uncertainty as well as uncertainty due to impact of disaster on infrastructure capabilities of the region.

Caunhye et al. (2012) mention that recovery takes place after the chaotic environment of disaster response subsides. Hence, we focus on logistics planning during preparedness and response stages of disaster operations management which are more focused on the chaotic nature of disaster operations.

Multimodality of Logistics in Disaster Operations

Multimodal transportation of freight is broadly defined as the utilization of more than one transportation modality to ship goods (UNECE 2009). Other terminologies have also been introduced in the literature that refer to shipment of goods through multiple modes of transportation. They represent concepts that qualify multimodal transportation planning according to techniques employed for improving efficiency or flexibility in the system. We will discuss three terms here: intermodal transportation, co-modal transportation, and synchromodal transportation. Intermodal transportation refers to the transportation of goods through at least two transportation modes over the travel itinerary (Crainic and Kim 2006). Co-modal transportation refers to the consolidation of shipments from a consortium of shippers utilizing smart methods to maximize benefit for the entire group (Verweij 2011). Synchromodal transportation is less clearly defined in literature. However, there is agreement that it introduces the element of real-time flexibility in multimodal transportation planning (Behdani et al. 2014; Verweij 2011). SteadieSeifie et al. (2014) discuss multimodal transportation planning in detail in their literature review and conclude that the terms multimodal and intermodal are often used interchangeably in academic literature.

This chapter differentiates between multimodality and intermodality in light of the definitions presented earlier. The intermodal problem here involves more than one vehicle selection decision for the travel itinerary between supply and demand points. Facilities are required in this scenario to connect the different vehicle routes and shift the goods from one transportation mode to the other if required. The multimodal problem is considered as the choice of transportation mode between origindestination pairs. The last mile distribution problem, for example, can be described as a multimodal problem where vehicles of multiple transportation modalities deliver goods from a supply location to a demand point without shifting their load to another vehicle.

The logistics aspect is introduced when we define an intermodal logistics network. Intermodal logistics networks are characterized by transportation through two or more modes on a network that contains facilities that enable modal switch during transportation from an origin to a destination (Woxenius 2007). Hence, consolidation of shipments and modal shift introduce facility and inventory-related problems.

We divide the work on multimodal logistics in disaster operations into three key areas based on the nature of multimodality in the problem: (1) multimodal transportation, (2) intermodal transportation, and (3) intermodal logistics problem. Transportation and logistics problems in disaster operations undertaking co-modal or synchromodal work are scarce. The key reason for this is the dearth of sophisticated coordination models in literature which is discussed in detail in section "Analysis and Conclusions". Table 15.1 provides an overview of key papers based on the types of logistics problems and multimodality. In the following section, literature is discussed with relevance to the phase and type of the problem. Section "Preparation Phase" provides problem aspects relevant to the preparation phase, while section "Response Phase" presents problem aspects relevant to the response phase of disaster operations. We summarize the concepts presented in these sections in section "Literature Summary".

Table 15.1 Literature map based on problem type and type of multimodality

Paper	Problem type	Type of multimodality	Preparation	Response
Nolz et al. (2010)	Location-routing	Intermodal logistics	√	√
Rennemo et al. (2014)	Location-routing	Intermodal logistics	√	√
Bozorgi-Amiri and Khorsi (2015)	Location-routing	Intermodal logistics	√	√
Zhu et al. (2008)	Resource allocation	Intermodal logistics	√	√
Adivar and Mert (2010)	Vehicle requirement-routing	Intermodal logistics	√	√
Yi and Özdamar (2007)	Location-Routing	Intermodal transportation		√
Afshar and Haghani (2012)	Location-routing	Intermodal logistics		√
Ruan et al. (2014)	Location-routing	Intermodal logistics		√
Haghani and Oh (1996)	Routing	Intermodal transportation		√
Barbarosoglu and Arda (2004)	Routing	Intermodal transportation		√
Özdamar et al. (2004)	Routing	Intermodal transportation		√
Ye and Liu (2011)	Routing	Intermodal transportation		√
Özdamar and Demir (2012)	Routing	Intermodal transportation		√
Najafi et al. (2013)	Routing	Intermodal transportation		√
Battini et al. (2014)	Routing	Intermodal transportation		√
Zhao and Qian (2014)	Routing	Intermodal transportation		√
Ozkapici et al. (2016)	Routing	Intermodal transportation		√
Wang et al. (2015)	Routing and scheduling	Multimodal transportation		√
Zheng and Ling (2013)	Routing and scheduling	Multimodal transportation		√
Hu (2011)	Routing and scheduling	Intermodal transportation		√

Preparation Phase

The disaster logistics problem in the preparation phase of disaster operations management includes locating response facilities and pre-stocking relief goods. The preparation phase problems relevant to multimodal logistics often include response phase vehicle routing in addition to facility location and/or stock pre-positioning.

Location-Routing Problems

Facilities for disaster relief include permanent distribution centers, warehouses, and temporary response facilities (Afshar and Haghani 2012). All of these facilities receive and dispatch relief goods. The intermodal logistics of disaster relief goods requires facilities that can handle multiple modes of transportation to assist in shipment consolidation and transshipment between nodes and transportation modalities. Temporary response facilities are often deployed in the response phase to assist in relief goods distribution.

The facility location problem is related to the vehicle routing problem. The integration of the two problems provides significant gains in productivity (Min et al. 1998). The location routing problem is faced with a number of uncertainties including uncertain supply, uncertain demand, and uncertain facility capacities after a disaster strikes (Rennemo et al. 2014). Hospitals and clinics in disaster-struck areas have uncertain capacities and processing capabilities as a result of the disaster (Najafi et al. 2013).

Stock Pre-positioning

Pre-positioned relief goods provide a hedge against possible shortages. The disaster preparation planning must also be sensitive to possible vulnerabilities to transportation infrastructure after a disaster. Zhu et al. (2008) consider stock pre-positioning in preparation for disasters. The transportation network connecting warehouses to affected areas is vulnerable to disaster-related damage. The response phase multimodal logistics is accounted for in the problem through scenario analysis. Location-routing problems also consider pre-positioning of stock in the facilities (Nolz et al. 2010; Rennemo et al. 2014; Bozorgi-Amiri and Khorsi 2015).

Vehicle Requirement Problem

Vehicle requirement planning calls for assessing each link in the transportation network for its transportation mode requirement and the amount of commodity that would traverse the link. Adivar and Mert (2010) present a problem that plans for international response to a disaster scenario with vehicle requirement decision. Response phase damage to the network makes the vehicle requirement and routing decisions more difficult.

Response Phase

Temporary Facility Location

Temporary facilities are located closer to affected areas to assist in the distribution of goods and the provision of shelter and medical attention for affectees. Ruan et al. (2014) discovered that greater numbers of temporary facilities often increase the efficiency and utility of medical supplies due to decreased distance between affected areas and temporary facilities. They also discovered that more vehicles are required to serve the increased number of temporary facilities.

One way of locating temporary facilities is seabasing. It originates from the military where a container ship forms a floating warehouse to deliver supplies where required. The application of seabasing provides flexibility in facility location to enable better response time. The floating warehouse can be anchored at a single point or move to other locations as required. Seabasing expands the horizon of multimodal logistics from transportation multimodality toward multimodality of warehouse facilities. Ozkapici et al. (2016) applied the seabasing concept for intermodal transportation in a disaster response scenario.

Routing

Disasters may cause massive damage to transportation networks. This impacts the amount of goods that can be transported through a transportation mode in time for the response efforts (Barbarosoglu and Arda 2004). The damage to transportation infrastructure can also cut off some affected areas from access through some transportation modes. This results in the need for alternative modes of transportation.

Disasters like earthquakes are difficult to predict and plan for. This leads to scenarios where both demand and consequently supply of relief goods is not easy to plan (Barbarosoglu and Arda 2004). The affected areas have to be surveyed after the disaster in order to assess the damage. The survey process takes time to calculate actual demand figures. This leads to the possibility of a mismatch between supply and demand in disaster-affected areas. Some demand points may be overstocked initially while other demand points may be realized later. The supply-demand mismatch results in ineffective response due to increased response time (Ye and Liu 2011). As a clearer demand picture is received, transportation between demand nodes may occur in order to resolve the initial mismatches (Özdamar et al. 2004). Another approach to tackle the demand-supply mismatch is to calculate demand in the form of a cluster. Since the areas affected by a disaster can generate several demand points, the problem becomes easier to solve when the demand is clustered (Özdamar and Demir 2012).

Vehicles involved in disaster response activities may or may not start travelling from supply points. The supply of vehicles may originate from points other than those for relief goods. This is especially true for disasters like earthquakes which are difficult to predict (Özdamar et al. 2004).

Human lives are at stake in disaster response efforts. This makes delivery speed an important aspect of the problem for medical supplies in particular. Damage to the transportation network aggravates the problem for some transportation modes. Helicopters are utilized for their capability to take off and land vertically in relatively small places. They are also able to avoid some disruptions in the transportation network and take a more direct route via air. However, helicopters are often in short supply and must be utilized efficiently. Ruan et al. (2014) found that as the difference between travel times of road vehicles and helicopters increased, intermodal transportation of medical supplies became more advantageous. Having said that, once the difference in speeds exceeded a threshold, intermodal transportation became less effective because of superior helicopter speeds and comparatively inferior road transportation speed. This implies that when roads are severely damaged, the use of helicopters is a better choice.

A number of different commodities are required to provide an effective response in disaster-affected areas. These include food, clothing, medicine, medical supplies, and machinery. Different commodities may require different modes of transportation (Haghani and Oh 1996). Fragile and temperature-sensitive medicine and medical supplies may require a transportation mode that can ensure better handling and speed of delivery than, for example, transportation for clothing.

Multimodal logistics involve the transfer of shipments from one mode of transportation to the other. The transshipment time and cost and accidents during transshipment are important considerations in multimodal logistics planning. All transportation modes are vulnerable to accidents. This problem is further aggravated in disaster scenarios when networks are damaged. Accidents can happen during transportation or during transshipment of goods. Zhao and Qian (2014) present an analytical approach to plan for minimum accidents, cost, and time.

Casualty transportation during non-disaster times is usually done through specialized vehicles like ambulances. Some transportation modes can be adapted in disaster scenarios to transport both goods and casualties in some sequence leading to a pickup and delivery-type scenario (Yi and Özdamar 2007). The injured people are spread in the affected areas in a similar fashion as the demand for relief goods. The extent of injuries also varies among affectees (Najafi et al. 2013).

Scheduling

The uncertainties encountered in disaster response make disaster transportation planning a complex problem. The problem is aggravated when multimodal transportation is considered. Hence, the scheduling of multimodal vehicles in disaster response planning is tackled through heuristics, fuzzy optimization, and an immune-based model (Zheng and Ling 2013; Wang et al. 2015; Hu 2011).

Literature Summary

The multimodal logistics literature in disaster management has improved from routing decisions to decisions spanning multiple phases of disaster operations management. The key area where the literature lacks is in accommodating the complex interactions of humanitarian actors in the multimodal logistics planning problem. Applications of co-modal and synchromodal transportation require attention due to their potential for greater efficiency and flexibility in dealing with the problem. Battini et al. (2014) tested their model for a possible co-transportation scenario and inferred that such a possibility would improve cost performance. They also mentioned the lack of such arrangements in the humanitarian community. Rodriguez et al. (2007) mentioned a number of tangible and intangible factors that can inhibit the utilization of co-transportation. They recommended the use of techniques like the analytic hierarchy process to resolve conflicts between potential partners. The efficiency and effectiveness of co-modal and synchromodal transportation networks in disaster scenarios require further exploration.

There are some general limitations of optimization models. The amount of data required may not be available in large-scale emergencies or may be difficult to communicate. Optimal solutions might take very long even when sufficient data are available. Disaster scenarios require urgent directives rendering improvement in solution algorithms important. Better solution algorithms are critical to making large, realistic models practical.

After discussing select papers from literature, we now focus our attention on the cases.

Case Methodology

Sample

Kashmir earthquake 2005 and Pakistan floods 2010 were selected for study on the basis of their impact. Table 15.2 highlights their impact among similar incidents in the history of the country by mortality count. The two disasters are among the top ten disasters by fatality counts and the number of people affected. The earthquake tops the list in mortality count and the floods top the list in the number of people affected. As recent events that caused large-scale destruction, both serve as instructive cases for our study.

Our distinct advantage in studying these cases lies in first-hand access to experts and individuals who were involved during disaster logistics operations. Both disasters occurred in terrains that, to a great extent, involved

Table 15.2 Top 10 natural disasters in Pakistan by mortality count for the period 1900–2011

Disaster	Date	Casualties	No. total affected	Damage (000 USD)
Earthquake	8-Oct-05	73,338	5,128,000	5,200,000
Earthquake	31-May-35	60,000		
Storm	15-Dec-65	10,000		
Earthquake	28-Dec-74	4,700		
Earthquake	27-Nov-45	4,000		
Flood	1950	2,900		
Flood	28-Jul-10	1,985	20,202,327	9,500,000
Flood	8-Sep-92	1,334	6,655,450	1,000,000
Flood	2-Mar-98	1,000		
Flood	Sep-12	571	4,849,841	

Source: SAARC (2016)

extreme conditions and damaged infrastructure. Such conditions are commonly observed in large-scale disasters (Ferris 2010). All these aspects combined presented significant challenges during the disaster logistics operations management of the cases.

Methodology

The case study method was employed in assessing the state of practice in planning, coordinating, and managing the logistics of disaster operations. The research framework was primarily exploratory and explanatory in nature.

We decided to base our research on primary and secondary data by utilizing a mixed method research design. We collected primary data by interviewing key officials to understand on-ground realities of disasters operations. These expert interviews facilitated our understanding of intra- and interorganizational dynamics and structural dependencies during disaster operations that transpired in a rather chaotic and time-pressured environments. We shall discuss these aspects in greater detail later.

In addition to this, archives, organizational documents, and academic literature were used to understand and present a deeper understanding of disaster logistics operations of the chosen cases. The archival and literature research was also used to triangulate the findings of expert interviews. We used these sources to create a chronological depiction of the events and their logistics. The chosen sample and its analysis are discussed later in the chapter. The focus of the cases was toward understanding the logistics and coordination problems in the two disasters. The coordination problem was included due to the interesting co-modal possibilities that can be utilized to improve productivity.

Data Collection

The data for case studies were collected through two methods—key respondent interviews and archival research. For detailed interviews, two respondents were selected. Lt. Col. (R) Raza Iqbal was interviewed. He is working in the UN-OCHA as Humanitarian Affairs Officer. He has also worked with the National Disaster Management Authority (NDMA), Pakistan, as Director Response. The second interview was with Lt. Col. (R) Ali Haider Kazi who worked as Director Coordination for the Earthquake Reconstruction and Rehabilitation Authority (ERRA) and was Logistics Head at the NDMA during the 2010 floods. The interviews were semi-structured and explored the coordination of multiple vehicle modes during the two disasters and relevant logistics elements. Interview data were utilized to understand: (1) the background of the disaster; (2) the intra- and inter-organizational contexts of logistic function during disaster preparedness and response phases; and (3) the nature of decisions taken during disaster relief efforts.

Both academic and practitioner literature were utilized for data collection. Academic literature included published work from journals like *Natural Hazards, Disasters*, and the *International Journal of Emergency Management*. Unpublished papers and theses were also utilized to triangulate interview data. Practitioner literature includes reports by the Asian Development Bank, the World Bank, the United Nations, the NDMA, the ERRA, and other government agencies as well as news items. Literature was searched using "2005 Kashmir Earthquake response," "2005 Kashmir Earthquake logistics," and similar keywords for the 2010 floods. The data obtained in literature were utilized for: (1) accurate descriptions of the disasters; (2) coordination setup during the disasters; (3) preparation and response phase logistics; and (4) supporting evidence for the interviews. Methodological primacy was given to literature which ensured that the biases of the interviewees or the researchers did not impact the study.

Overview of the Cases

There are some similarities between the two cases. Both cases pertain to the same country and are among the worst disasters faced by it. Disaster operations were in a developing state throughout the two cases. A sophisticated and systematic approach to disaster operations planning was not fully functional. Coordination aspect of the logistics problem did not accommodate all stakeholders at a similar level throughout the two disasters.

Disaster logistics planning demonstrated improvement from the 2005 case to the 2010 case. The 2005 earthquake presented a challenge for which the country was not prepared. Logistics plans were developed and certain elements of coordination were established during the disaster. This was partly because earthquakes are difficult to forecast. The terrain was mountainous and made road transportation less viable. The NDMA had established better coordination mechanisms before the 2010 floods hit the country. Floods can be forecasted with reasonable accuracy, but the forecast in this case arrived late. Hence, the advantage that could have been attained due to a timely forecast of the flood was lost. The terrain was more diverse in this scenario as the floods originated from mountains and the waters travelled downstream to plains and desert areas.

The cases present scenarios which are somewhat similar to responses to other disasters. The disaster response efforts were on a massive scale in both scenarios. Hence, problems faced by logistics planners were vivid. The two cases may provide little help in disaster relief planning for man-made disasters like terrorist attacks or chemical spills.

Kashmir Earthquake 2005

Background of the Disaster

Northern Pakistan was struck by a 7.6 Mw earthquake on October 8, 2005. This earthquake caused a surface rupture 70 km long and up to 7 m wide that ran from Bagh in Kashmir to Balakot in the Khyber Pakhtunkhwa (KPK) province, then called the North-West Frontier Province (Kaneda et al. 2008). The main affected region was in the Lesser Himalaya which had main valley floor altitudes at a height of approximately 500 m to more than 2,000 m above sea level and peaks rising up to more than 3,000 m above sea level. The Jhelum River and its tributaries, the Neelum and the Kaghan Rivers, flow in these areas. The lower slopes of the valley reach 10–25° and toward the peaks the slopes rise to more than 50° (Owen et al. 2008).

Snowfall in this region occurs at altitudes greater than 1,500 m above sea level December through March. At the peaks the snow drifts exceed several meters in thickness. The earthquake occurred in the post-monsoon period when the weather was mild. A timeline of the 2005 Kashmir Earthquake response is given in Table 15.3.

Coordination

"Logistics is a very precise activity…one cannot have too much coordination in disaster logistics"—Lt. Col. (R) Ali Haider Kazi

The interviewees emphasized that coordination is a key element in logistics in general and disaster logistics in particular. The resource shortages faced in disasters can be avoided or reduced through effective coordination of relief logistics. Hence, we also discuss coordination aspect in our case studies.

Table 15.3 Timeline of 2005 Kashmir Earthquake response

8:50 October 8, 2005	October 9, 2005	October 10, 2005	October 24, 2005	March 31, 2006
Earthquake occurs	United Nations Disaster Assessment and Coordination team arrives	Federal Relief Commission is formed	Earthquake Reconstruction and Rehabilitation Authority formed	Government of Pakistan announces end of relief, Federal Relief Commission subsumed into Earthquake Reconstruction and Rehabilitation Authority

Pre-disaster

Government Structure

The roles of government departments when the 2005 earthquake struck are summarized in Table 15.4. The Pakistan Meteorological Department (PMD) was responsible for predicting weather and geophysical phenomena. In coordination with the Geological Survey of Pakistan, the PMD had formulated a seismological map.

The key stakeholders under the National Calamity (Prevention and Relief) Act 1958 for relief provision are the Provincial relief departments. The Directorate General Civil Defense has to work under the supervision of the provincial governments. The Emergency relief cell of the Cabinet Division works directly under the Prime Minister. This cell was responsible for coordinating between donors and provincial relief departments.

Table 15.4 Roles of government departments

Prediction/ confirmation	Pakistan Meteorological department (PMD)	
Response lead institution	Provincial Relief Department-**Provincial**	Emergency Relief Cell-**National**
Support institutions	SUPARCO-**Geographic Information System/Mapping**	Civil Defense-**Response**
Provider of last resort	Pakistan Army	

Another key stakeholder is the Space and Upper Atmosphere Research Commission (SUPARCO) that utilizes satellite imaging techniques to assist in disaster management. The Pakistan Army's role in disaster operations includes inspection, assessment, and the last line of resort for relief work. All corps headquarters are equipped for emergency relief in times of disaster (GoP 2005).

Structure of the United Nations

United Nations was working on the pilot for the cluster approach to operating in disaster scenarios. The cluster approach was formulated as a response to the Darfur crisis 2004–2005. The UN Emergency Relief Coordinator Jan Egeland commissioned a report evaluating the global humanitarian system prevalent up to 2004–2005. The report concluded that the prevalent coordination mechanisms operated independently of each other (Adinolfi et al. 2005). It identified a need for closer coordination and proposed specialization in certain areas/clusters for disaster response. The proposed cluster approach was bolstered by the lead agency approach prevalent within the UNHCR in the mid-1990s. Nine clusters were implemented for the pilot project. The Kashmir Earthquake was identified as the pilot project for the cluster approach. The cluster lead agencies (CLAs) for each cluster in the earthquake are listed in Table 15.5.

The coordination mechanism for the cluster approach was such that the CLAs would coordinate between various international non-governmental organizations (NGOs) operating in the clusters. The UN Emergency Relief Coordinator was to coordinate between the clusters. Given its responsibility to coordinate between various organizations, the cluster lead was to be the provider of last resort in its cluster.

Table 15.5 Cluster lead agencies for earthquake 2005

Cluster	Cluster Lead Agency
Logistics	WFP
Emergency shelter	IOM
Camp management	UNHCR
Food and nutrition	WFP
Water Sanitation and Hygiene (WASH)	UNICEF
Protection	UNICEF
Health	WHO
IT and telecommunication	OCHA

Adapted from Stoddard et al. (2007).

After Disaster Occurrence

The president and the prime minister set up the Federal Relief Commission (FRC) on 10 October 2005, 2 days after the disaster, to further streamline the operations. The FRC proceeded to communicate with two primary stakeholders: the military and the civilian stakeholders. The military relief work was coordinated through a dedicated wing responsible for the execution of rescue and relief operations. Similarly, there was a dedicated wing for civilian stakeholders which managed inter-agency coordination between the various civilian departments and the NGOs.

Qureshi (2006) found that civilian institutions were not emphasized in the disaster response. Local government representatives and the civilian structure of the government worked with little support from the army and the international NGOs. The army representatives were of the opinion that the civilian institutions had failed to provide relief during the disaster response phase. The Federal Relief Commission was headed by Major General Farooq Ahmed Khan which led Qureshi (2006) to believe that FRC legitimized the military's role in disaster response. Thompson (2008) is of the view that the Emergency Response Cell was untested in large-scale disaster scenarios. This inexperience might be the reason why the Pakistan Army General Headquarters took charge of response efforts.

An NGO staff member reported for the Kashmir earthquake 2005: "If we had good maps, we would be on top of things" (Curion 2005, p. 17). Thompson (2008) noted that the implications of this observation are the lack of situational awareness and inability to provide a common operational picture to all stakeholders. The United Nation's Humanitarian Information Centre (HIC) introduced their "Who is doing what where?" maps and related products through relief improve coordination.

Logistics Structure

The logistics coordination structure that emerged during the disaster relief was such that an Army Logistics Cell coordinated the collection and receipt of all incoming relief materials and dispatched them to the humanitarian hubs as indicated by their demands. Another cell was formed to coordinate all the air traffic flowing within the country as well as from abroad. This Air Operations Center worked under the General Officer Commanding Military Aviation and comprised the Pakistan Army Air Wing, the UN Helicopter Air Service, and the United States Navy (Cahill 2007).

The principle by which the Army and the local authorities coordinated with the humanitarian agencies was that of "non-interfering coordination". This meant that the information and the assessment of the damage would be disbursed to all humanitarian stakeholders as transparently as possible and would allow them to make their choices in relief participation. The only action required of them was to report their decisions to the Pakistani authorities. This led to better relief provision as the humanitarian actors chose the areas they were most competent in while the Army and the government agencies filled up remaining gaps (MacLeod 2007).

Preparedness

Facility Location

According to a report by the Government of Pakistan (2005), the emergency relief cell operated a warehouse in Islamabad when the earthquake occurred. Islamabad, being the federal capital, was to be the last resort for relief goods. However, Islamabad was also affected by the earthquake and the respondents report some damage at the relief cell warehouse as well.

Stock Pre-positioning

The details of stocks pre-positioned in the emergency relief cell warehouse at Islamabad could not be acquired. However, according to the interviewees, the stocks were insufficient for disaster response. The key reason why preparedness was so low was because the last earthquake that caused similar destruction in this region had occurred about four centuries ago (Thakur 2006).

Vehicle Requirement Planning

An Aviation Squadron comprising four helicopters was at the emergency relief cell's disposal to assist in rescue operations and to provide logistics to disaster struck areas. This was an insufficient amount of transportation as discovered after the disaster. A number of deficiencies in planning were also discovered by Alexander (2006, p. 1) including the "lack of preparedness", as well as the untrained and unequipped state of local first responders.

Response

According to a joint report by the Asian Development Bank and the World Bank (2005), the disaster event resulted in direct damages of USD 2.3 billion. The top three sectors that bore the damage were private housing, transportation (roads and bridges), and education. The damage to private housing amounted to USD 1.03 billion which was the major portion of damage sustained in the earthquake. The second largest component of the damage was sustained by roads and bridges which amounted to USD 340 million. The education sector was the third highest component of the damage amounting to USD 335 million. The damages to the education sector primarily comprised school buildings. Schools were in session on the day the disaster struck, leading to a high casualty count of school-going children.

Temporary Facility Location

The president requested the UNDAC (UN Disaster Assessment and Coordination) to assist in damage assessment and coordination of international relief organizations. A UNDAC team was on ground within 24 hours of the disaster and set up an On-Site Operations Coordination Centre (OSOCC) at Muzaffarabad. Further humanitarian hubs were set up in the disaster region as shown in Fig. 15.2 with Civil Military Liaison officers in each (Cahill 2007). The interview respondents were of the opinion that the temporary facilities were located keeping in view alternative road routes and helicopter landing areas. The redundancy of road and helicopter access was necessary because of excessive road damage that was causing major problems in relief delivery. Helicopter access was not a major problem for hub facilities, but in smaller clusters of population the heavily forested mountainous terrain caused some difficulty.

Routing

The coordination and cooperation aspects were not evident in routing relief goods. The Edhi Foundation, the largest NGO in Pakistan, responded by directing all of its ambulances in the Punjab and KPK toward the disaster region. They filled their ambulances with wheat flour and burial shrouds. They later introduced lentils, oil, and drinking water in their relief items.

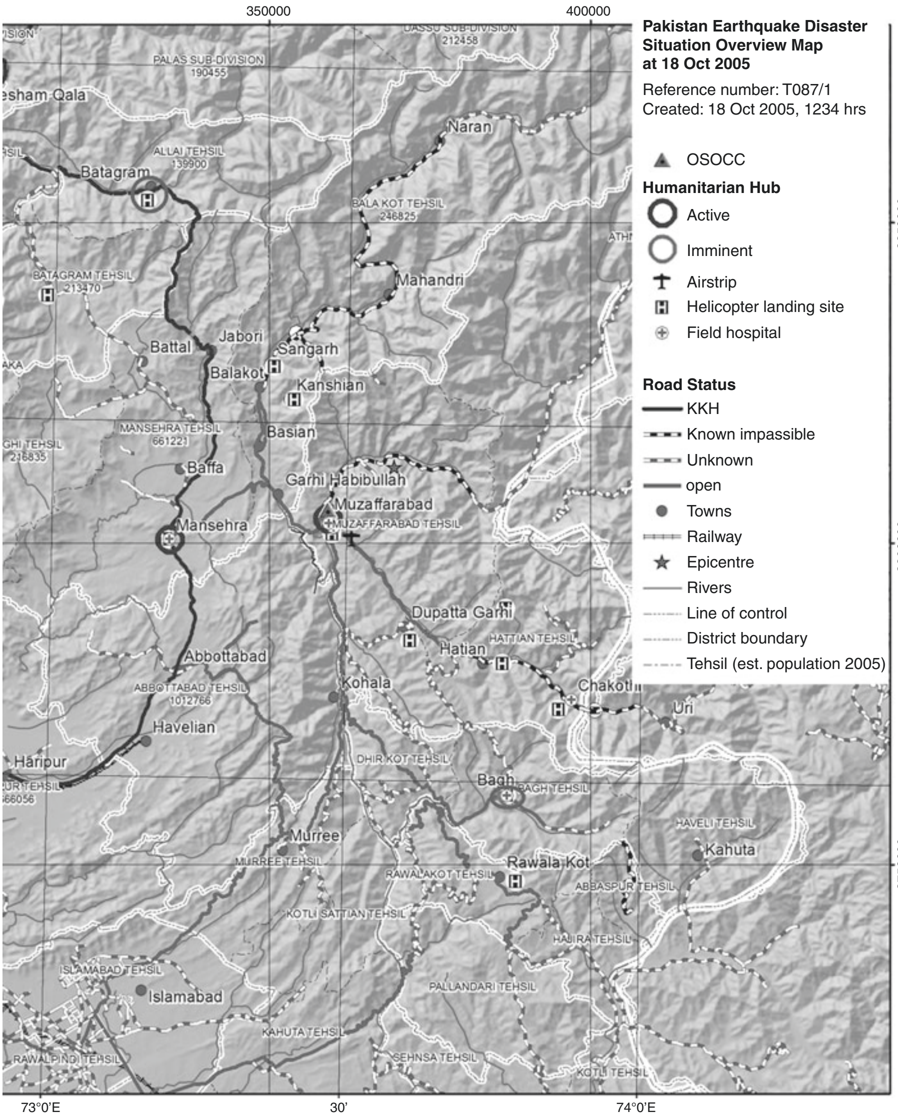

Fig. 15.2 UN OSOCC and Humanitarian Hubs as placed on the map (With permission from MapAction 2005)

Their transportation mode included inflatable boats for evacuation of affectees and transportation of relief goods across rivers (Syed 2015). Although they set up their relief network at a quick pace, there is not much evidence of their coordination with other stakeholders. This was not a stand-alone case as indicated by the interview respondents. Most of the local NGOs and independent volunteers adapted their own strategies to route their relief vehicles. This led to a lot of stress on the road network in particular.

ADB-WB (2005) reported strong response from the civil society including local and international NGOs such as the Edhi Foundation, Islamic Relief, the Red Crescent Society, the Agha Khan Foundation, Oxfam, and the Rural Support Program Network. They also reported a large number of self-help groups supported by several thousand people collecting relief goods for the earthquake affectees. The donations amounted to USD 100 million excluding in-kind items and services. Interview respondents noted that the in-kind donations were excessive and included material that did not meet any requirements. This led to the problem of material convergence where unusable items were sorted out. However, some material went through the relief chain to the affectees causing nuisance for them.

A total of approximately 6,440 km of roads were damaged in the disaster region. This included a total of 175 km of national highways, cutting off road access to the Kashmir region from Pakistan (ERRA 2006). This led to a greater need for other modalities of transportation, especially helicopters and other air assets. The interview respondents noted that volunteer road vehicles aggravated the problem. The mountainous terrain of the affected region was already limited in its capacity to handle road vehicles. Evacuating traffic and excessive independent volunteer vehicles chocked what remained of the road network. This led to early efforts in restoring road infrastructure to ease the traffic.

As winters were about to begin and the vulnerability to extreme colds in the mountains was termed as the second impending disaster, the relief operation was dubbed Operation Winter Race. The operation started as a race against time. Extensive use of aircraft led to around 500 sorties by the Pakistan Air Force, about 30,000 helicopter sorties by the Pakistan Army Aviation, and around 11,000 sorties by the United Nations for rescue, relief, and evacuation. According to the United Nations Joint Logistics Committee (UNJLC) data, 75 percent of the cargo coordinated through the Cargo Movement Coordination Cell (CMCC) was moved through the UN Humanitarian Air Service (UNHAS) and the rest was moved through road transportation (Benini et al. 2009). The UNJLC prioritized food and shelter and utilized air transportation for the same. Construction material was delivered through road transportation as road network became usable. Trucks were owned by independent transporters. The truck drivers were familiar with the mountainous terrain and the interview respondents regard their driving skills highly.

Helicopters-Fleet Management

Helicopters are a terrain-independent mode of transportation and a key-transportation resource in many disasters. The Pakistan Army Air Operations Centre (AOC) coordinated and approved all helicopter missions in the disaster area. The AOC determined appropriateness of a mission through urgency and accessibility of the region through other modes of transportation. Urgency meant the immediacy of the requirement and accessibility meant whether the area could be covered through ground vehicles or not. Most of the aviation units operated primarily at the Chaklala airbase with the AOC (Thomspon 2008).

Efficient usage of air assets involves minimizing ground time to improve work achieved per blade hour. Thompson (2008) notes that in the first week after the disaster, several aircrews sat idle due to lack of situational awareness by the planners. The information asymmetry continued later into the disaster when relief was dispatched to locations which were already well-supplied. The inefficient usage of helicopters coupled with the high costs of operating them led to a cash crisis threatening further usage of this transportation mode (BBC 2005). The employment of helicopters for scouting ground routes and assessing relief provision situation proved useful. The AOC maintained a map of this information.

Mules

In the disaster area, road boundaries were classified by the ease with which various ground vehicles could move on them. These comprise road head and jeep head. A road head is the limit up to which normal road transportation can travel. A jeep head is a path beyond the road head up to which a jeep can travel. The area beyond a jeep head cannot be accessed through most vehicles. In the earthquake, mountainous terrain presented areas where jeep heads ended. Such areas were accessed through the army Animal Transportation Units (ATUs). These units comprised trained mules deployed by the Pakistan Army. These mules could carry up to 72 kg load and travel up to 26 km without rest (BBC 2005). About 250 mules were deployed by the Army while the extent of

Table 15.6 2005 Earthquake case summary on developed framework

Preparedness	Response
Facility location Emergency Relief Cell operated a central facility in Islamabad for disaster relief.	*Temporary facility location* Four facilities located in disaster area by the government and UN.
Stock pre-positioning Centralized stocks at Islamabad warehouse of Emergency Relief Cell.	*Routing* Routes were surveyed by Pakistan Army and decided based on their recommendation for military and international NGO response. However, independent volunteers and local NGOs decided routes by themselves.

the civilian usage of mules is unknown. The usage of mules in the Ganul/Ghanoul valley near Mansehra in KPK was reported by *The Telegraph UK* (Wilkinson 2005).

Case Summary

The 2005 earthquake case employed an intermodal logistics approach in the response phase with collection and distribution of relief goods performed in an intermodal fashion. Response phase logistics included temporary facility location and routing. Key transportation modalities included trucks and helicopters in distribution. A summary of the earthquake case is presented in Table 15.6.

Pakistan Floods 2010

Background of the Disaster

The monsoon rains began around 18 July and lasted till 10 September 2010. The intensity of rainfall reached a peak on 28–29 July 2010. A secondary peak in rainfall was observed on 5–9 August 2010. The flooding began from River Swat in the northern region of Khyber Pakhtunkhwa in the last week of July. Fatality reports from heavy rains and flooding were first reported on 22 July 2010, from Khyber Pakhtunkhwa, the Punjab, and Balochistan provinces. The overall impact of the flood was such that 6 million ha of land were inundated out of which 3.3 million ha were cultivated land (Iqbal et al. 2015).

Coordination

Pre-disaster

Government Structure

The provincial governments were responsible for dealing with floods through the National Calamity Act 1958. The provincial government requested federal level planning and mitigation of floods after the heavy floods in 1973 and 1976 (Rahman 2010). This led to the establishment of the Federal Flood Commission (FFC) in 1977. The FFC is responsible for planning flood protection at the national level. It reviews damage assessment and plans for reconstruction when flooding occurs (GoP 2011).

The National Disaster Management Ordinance was promulgated in 2006 in an effort to avoid the stress faced in the 2005 earthquake. The National Disaster Management Authority (NDMA) led the preparation for the floods of 2010. The guidelines on disaster management were detailed in the National Disaster Response Plan 2010 and the National Monsoon Contingency Plan 2010. The Emergency Relief Cell was operative in parallel with the NDMA. The cell's role was important in obtaining funds and procuring relief goods. However, the cell was undermined in the planning process leading to difficulties in implementation. A timeline of the 2010 floods and their response is given in Table 15.7.

The Federal Flood Commission prepares National Flood Protection Plans on ten-year horizons. The practice began in 1978 and the 2010 floods happened during the 4th planning horizon. The 3rd plan 1998–2008 included the development of the first computer-based flood early warning system. The 4th plan had been submitted to the Ministry of Water and Power in November 2006 for approval, but awaited approval by the Planning Commission until after the 2010 floods (GoP 2011).

The National Disaster Response Plan 2010 prepared by the NDMA outlined major institutions and their broad responsibilities in a disaster scenario (see Table 15.8). The Hyogo Framework for Action inspired the organizational structure for disaster coordination in Pakistan. The structure in which these institutions were to coordinate is captured in Fig. 15.3.

The NDMA captured most of these planning elements in 2007 through the National Disaster Risk Management Framework (NDMA 2007). The National Disaster Response Plan 2010 provided standard operating procedures

Table 15.7 Timeline of 2010 Pakistan floods

July 18–24, 2010			
July 21: First Monsoon rainfall	Swat, Kabul and Indus Rivers started rising	Flooding in Mianwali and Layyah districts	
July 28–30, 2010			
July 29: Torrential rainfall	Rivers started spilling over embankments	In the northern region Swat valley and Charsadda/Nowshera districts affected through rivers Kabul and Swat, respectively	Mianwali, Layyah, D.G. Khan, and Rajanpur districts affected through River Indus
August 2–9, 2010			
Incessant rains for 8 days: August 2–9 in the catchment areas of the rivers	Breaches in Indus River on August 2 at Mulanwala and Dibwala, Southern Punjab causing 3–4 m high waves flooding Muzaffargarh district	Peak flood in Indus River extending beyond Sukkur Barrage, Sindh	
August 10–20, 2010			
Floods peaked in Punjab	Breaches of Indus River in Tori and Ghuaspur exposing further areas in Balochistan and Sindh to flooding	Two discharge peaks observed at Sukkur Barrage one on August 12 and the other on August 17	
August 21–September 18, 2010			
KPK and Punjab provinces cleared of flood water, except low-lying pockets	Flood water receded toward Dadu district, Sindh	Deltaic region in Thatta district inundiated	
September 19–30, 2010			
Large areas in Sindh and some in Balochistan under deep flood water	Sowing of Rabi crop season not possible in the affected region		

Table 15.8 Institutions and their functions in a disaster scenario

Institution	Responsibilities
NDMA	National planning, coordination, monitoring and technical assistance
PDMA	Provincial planning, coordination, monitoring, evaluation, technical assistance, and direction to provincial departments
DDMA	District planning, coordination, monitoring, implementation, monitoring, community training, early warning system implementation and maintenance, establish relief centers and relief stock
Local authorities	Training employees for disaster management, resource maintenance, construction monitoring, carrying out relief, rehabilitation and reconstruction
Armed forces	Support civil administration in relief, rescue and evacuation; search and rescue; provision of helicopters, airplanes, ships, etc. for evacuation; assist in flood contingency planning; security provision
Provincial Relief Departments	Relief Commissioner is responsible for coping with disaster situation; disbursal of funds and relief goods
Civil Defense	Assist in rescue, evacuation and relief; formation and training of search and rescue teams in all districts; first aid training; maintenance of volunteers database at district level; community awareness
Pakistan Red Crescent Society (PRCS)	Disaster preparedness and response
Punjab Emergency Services (Rescue 1122)	Handling all types of emergencies
Local Charity Organizations (Edhi, etc)	Ambulance services, evacuation, food and nonfood items
NGOs	Provision of relief services and promotion of recovery
Community Based Organizations	Local-level disaster risk management and relief activities
UN Agencies	Capacity building, technical support, and coordination of International NGOs (INGOs) through Inter Agency Standing Committee (IASC)
Media	Disseminating information about early warnings, relief, recovery and gaps

Adapted from NDMA (2010).

and job descriptions for emergency operation centers at district, provincial, and national levels. The emergency operation centers (EOCs) were hubs for coordination and management of relief operations at respective levels. The provincial and national-level EOCs were to be activated as the district and province authorities became overwhelmed by the disaster needs, respectively.

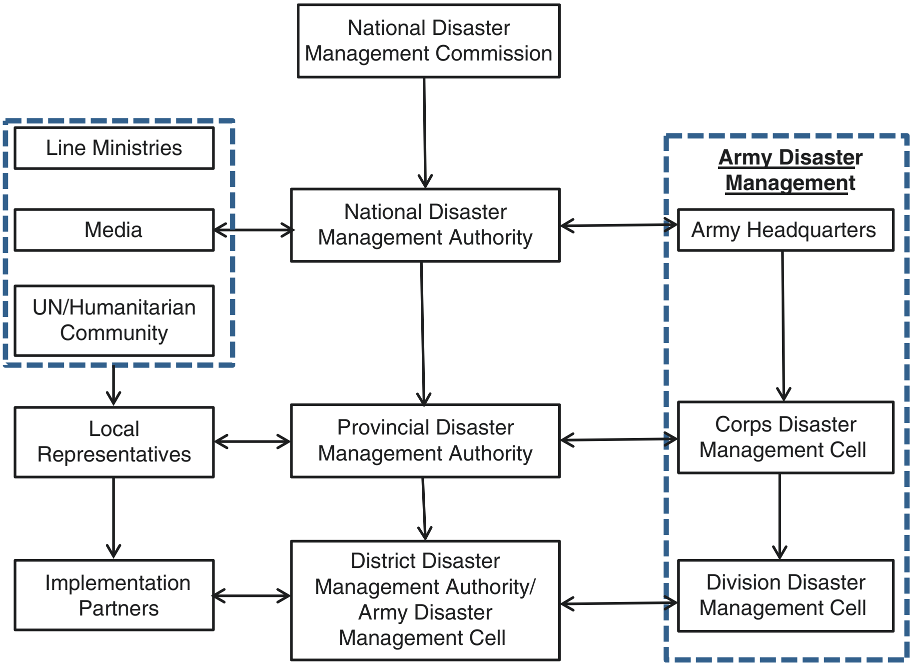

Fig. 15.3 Disaster management organizational structure (Adapted from NDMA 2010)

UN Structure

The UN cluster approach had evolved since its deployment as a pilot during the 2005 Kashmir earthquake. The number of clusters had increased from the pilot number of 9 to 11. The list of clusters and their lead agencies is given in Table 15.9.

After Disaster Occurrence

SUPARCO had become the regional support office for the UN Space-based Information for Disaster Response program on 12 February 2010. The UN and the Pakistan government worked together to create maps for the disaster region. These included damage assessment maps, daily updates, thematic mapping, and time series analyses through maps of the disaster region. The information contained in the maps was utilized by the NDMA, the UN, the INGOs, and some local NGOs to plan their response for the disaster scenario (Iqbal et al. 2015).

Table 15.9 UN clusters and cluster lead agencies

Type	Cluster	Cluster lead agency
Response	Agriculture	Food and Agriculture Organization (FAO)
	Camp Coordination, Camp Management (CCCM)	International Organization for Migration (IOM)
	Early Recovery	United Nations Development Programme (UNDP)
	Nutrition	United Nations Children's Emergency Fund (UNICEF)
	Emergency Shelter	International Federation of Red Cross and Red Crescent Societies (IFRC)
	Health	World Health Organization (WHO)
	Education	UNICEF/Save the Children
	Protection	United Nations High Commissioner for Refugees (UNHCR)
	Water, Sanitation and Hygiene (WASH)	UNICEF
Service	Logistics	World Food Programme (WFP)
	Emergency Telecommunications	Office for Coordination of Humanitarian Affairs (OCHA)/WFP/UNICEF

Adapted from Steets et al. (2010)

Logistics Coordination

The NDMA (2011) reported a total of 316 foreign relief flights, 6 relief trains, and 5 shipments through the sea. Almost half of the flights were received at the Main Operating Base at Chaklala, Rawalpindi. The remaining relief flights were received in the five Forward Operating Bases.

A Joint Aviation Coordination Cell (JACC) was formed between the Pakistan Army, the Pakistan Air Force, the UN Helicopter Air Service (UNHAS), the US Air Force, the US Marines, the USAID, the WFP, and the NDMA. This cell was chaired by the General Officer Commanding of the Pakistan Army Aviation. The cell places special emphasis on managing fixed wing and rotary wing flying crafts for relief operations. According to the NDMA (2011), helicopter support included 48 helicopters from Pakistan, 24 from the US, 5 from China, 4 from Japan, 4 from Afghanistan, 3 from the UAE, and 8 from UNHAS/WFP. In addition to rotary wing resources, 16 fixed wing flying aircraft were dispatched to Pakistan for relief operations. The US provided 2 C17s and 3 C-130s while Turkey and Egypt provided a C-130 each for relief operations. The US fixed wing aircraft were the first to arrive in Pakistan on 4 August 2010.

The Pakistan Navy established Emergency Response and Coordination Centers at Head Quarters of commander north in Islamabad and naval headquarters Karachi for water-based transportation. Teams were deployed in KPK and Sindh. The navy employed 3 hovercraft and more than 200 boats in the relief effort over flood waters. Almost 1,000 boats were deployed by other institutions of the Pakistan government (UN-OCHA 2010).

Preparedness

Facility Location

Before the 2010 floods, the NDMA had formed ad hoc warehouses at the federal and provincial capitals with the help of other government agencies. In the federal capital, Islamabad, four warehouses were present. Two of these warehouses were operated by the Pakistan Army which allowed some space to the NDMA to store relief goods. One was operated by the Emergency Relief Cell and another warehouse was owned and operated by the NDMA. Two warehouses were present in Karachi, the provincial capital of the Sindh province. One was an army warehouse with space allocation for relief goods, and the other was operated by the Relief Goods Dispatch Organization which came under the Emergency Relief Cell. The Army Ordinance Depot in Quetta and the Army Engineer Store Depot in Lahore were also engaged with an allocated area for disaster relief goods. The WFP was running a warehouse in Pir Piai, KPK province.

Stock Pre-positioning.

The PMD forecasted normal monsoon rains in 2010. This forecast was revised on June 21st, 2010, when the PMD issued a warning for flash floods in the northern region of the country. The warning announced an additional 10 percent rain with "few very heavy rainfall events" (GoP 2011, p. 30). Rahman and Khan (2011) explain this as a defect in the early warning system as the catchment area of Kabul and Swat rivers was outside its coverage. This led to a higher number of mortalities and damages in the Kabul and Swat river basins. Out of 1,961 deaths, 1,156 were reported in the Khyber Pakhtunkhwa province where the Kabul and Swat river basins are situated (Rahman and Khan 2011). Another cause of the flood was snowmelt (Rasul and Ahmad 2012) generated by high snowfall during 2004–2009 (NDMA 2009) and aggravated by record high summers in 2010 (Vidal and Walsh 2010). Once the record high rainfalls had occurred in the northern areas, the

PMD provided a reasonably accurate picture of flooding for the rest of the country with 2–3 days warning (NDMA 2011). This resulted in a short window for relief agencies to pre-position an adequate amount of relief stocks.

Relief good stocks were acquired and placed in accordance with the flood forecast. There was severe shortage of relief items especially at the beginning of the disaster response. Polastro et al. (2011) attributed this to the shipment of locally produced relief items to Haiti for earthquake relief since Pakistan produces 85 percent of the world's emergency tents. However, international NGOs were able to cope with the situation through national and regional contingency stocks.

Response

Temporary Facility Location

The map of the disaster region with the NDMA operating bases and the UN provincial/area hubs as of 6 September 2010 is given in Fig. 15.4. The UN humanitarian coordinator and Country Team were located with the NDMA Main Operating base (MOB). The UN was focused toward creating humanitarian hubs closer to disaster struck communities. In Sindh, the UN formed the first hub in Sukkur to cater for northern Sindh and later established another one in Hyderabad. The Provincial Disaster Management Authority (PDMA) Sindh is based in Karachi, but the NDMA created Forward Operating Bases (FOBs) in Sukkur and Hyderabad. The PDMA structure favored MOB in provincial capital and forward bases closer to disaster-affected regions. The UN presence in Karachi increased over time due to better cargo handling capabilities of this port city. This also improved coordination between the UN and the PDMA Sindh. The Pakistan government and the UN worked in tandem on the cluster-based coordination pattern. The clusters were assigned governmental counterparts to interact with, as shown in Table 15.10.

Routing and Resource Allocation

The 2010 flood response provides a better case for multimodal logistics in both the receipt and the disbursal of relief goods. The improvements happened as the result of a better coordination structure. The NDMA

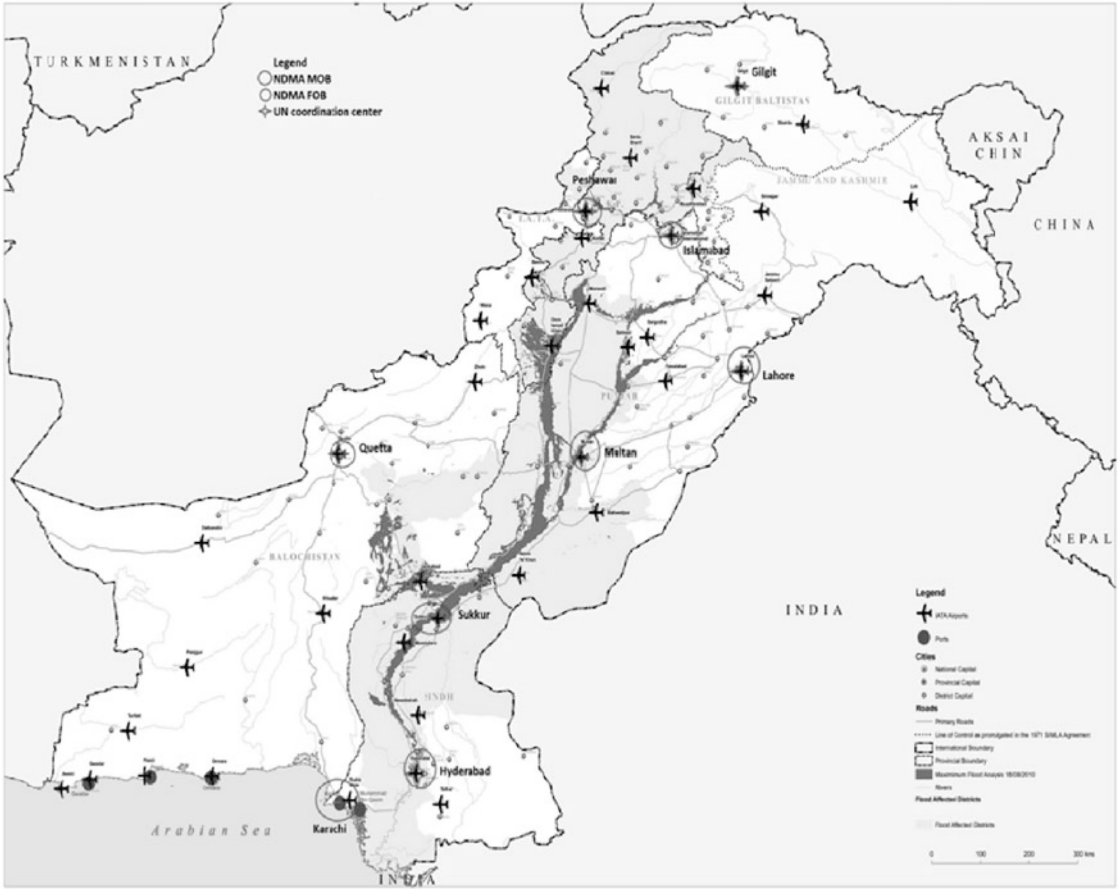

Fig. 15.4 Location of NDMA MOB/FOBs and UN hubs as of September 6th, 2010 (Adapted from MapAction 2010; NDMA 2011 and UN-OCHA 2010)

Table 15.10 Clusters, cluster lead agencies and governmental counterparts

Cluster	Primary Governmental Counterpart	Cluster Lead Agency
Agriculture	Ministry of Agriculture	FAO
Community Restoration	NDMA/PDMAs	UNDP
Food	NDMA/PDMAs	WFP
Health	Ministry of Health	WHO
Shelter and NFIs	NDMA/PDMAs	IOM
WASH	Ministry of Environment, Provincial Public Health Engineering Departments	UNICEF
Logistics, Emergency Telecommunications	NDMA/PDMAs	WFP
Coordination	NDMA/PDMAs	OCHA
Nutrition	Ministry of Health	UNICEF
Education	Ministry of Education	UNICEF/Save the Children
Protection	Ministry of Social Welfare	UNHCR
Camp management/ Camp Coordination	NDMA/PDMAs	UNHCR

Source: UN-OCHA (2010)

coordinated the international- and federal-level relief response. This led to the NDMA handling relief goods in bulk. Interview respondents informed that the NDMA handled relief goods procured by them or donated to them through multiple ways: (1) receiving goods at one of their warehouses; (2) receiving goods at the airport; or (3) redirecting relief goods toward other warehouses where demand was urgent.

The goods shipped by the NDMA were mostly directed to provincial relief departments in bulk to enable response at the provincial level. The NDMA's role in this situation was to route goods to provincial warehouses from where the goods could be dispatched to district warehouses. However, at times goods were shipped by the NDMA directly to the districts as a result of dire need. The hierarchical distribution of responsibilities resulted in a hierarchical level of networks. This hierarchical approach to relief goods distribution reduced the size of the logistics network and reduced the logistics planning burden on the coordinating bodies.

Helicopters were deployed in a centrally coordinated manner. The Joint Aviation Coordination Cell cleared the helicopters for their pickup and drop off points as well as the routes to travel. This special treatment was due to the strategically important terrain-independent characteristic of helicopters and to avoid any air traffic-related accidents. Road and water-based transportation were less systemically routed. Transporters were identified for shipment through trucks. Independent volunteers and NGOs provided relief supplies based on their own knowledge of the transportation networks.

Case Summary

The case of the 2010 floods employed an intermodal logistics approach in the preparation and response phases with collection and distribution of relief goods performed in an intermodal fashion. The logistic problems of the preparation phase included locating disaster response facilities and stock pre-positioning. Response phase logistics included temporary facility location and routing. Key transportation modalities included airplanes and ships in collection and trucks, boats, and helicopters in distribution. A summary of the 2010 floods case is presented in Table 15.11.

Analysis and Conclusions

The 2005 Kashmir earthquake was a wake-up call for disaster management institutions in Pakistan in a number of ways. There was no planning or preparation for this disaster or any disaster of a similar nature. There was a complete lack of logistics planning in the preparedness phase. The planning elements in disaster management emerged slowly during the response phase. The terrain was already difficult to navigate and became more difficult to work with as a result of the disaster. This required extensive use of helicopters which the country did not possess in sufficient numbers. The number of aircraft serving the area by November 2, 2005, rose to 125 through assistance

Table 15.11 2010 Floods case summary on developed framework

Preparedness	Response
Facility location One warehouse each was being operated by World Food Programme, National Disaster Management Authority and Emergency Relief Cell	*Temporary facility location* Ad hoc facilities were arranged with Pakistan Army
Stock pre-positioning Stocks were available in the warehouse facilities, but were not sufficient for a disaster of such a scale	*Routing* Helicopter routes were decided by Joint Aviation Coordination Cell. Road and water-based transportation problem was not decided centrally.

from other nations (ADB-WB 2005). Lack of funds and accessibility issues led to the utilization of mules as an alternative mode of transportation. However, the abruptness of the disaster, the lack of preparedness and mostly ad hoc response led to a situation where the different modes of transportation were not efficiently utilized.

The response to floods in 2010 improved through lessons learned from the earthquake. The most important development was the establishment of an institution for coordinating and monitoring disaster operations management, that is the NDMA. This institution led the efforts for the establishment of functioning warehouses with pre-positioned relief goods stock. The last mile distribution problem was decentralized through the framework of this institution. As small autonomous bodies became responsible for their areas, improvements in relief goods distribution were realized. The logistics problem was split into several hierarchies. At the national level, the distribution problem was to deliver to the provinces only. The provinces were in turn responsible for supplying district demands. The districts were then responsible for delivering supplies to affectees in their areas. A centralized coordination mechanism for last mile distribution would have heavily taxed the resources of the central coordinating body leading to inefficiencies. As a result the logistics problem was broken down into smaller problems at different hierarchical levels; however, the utilization of some logistics modes—helicopters, for instance—remained centralized. The assignment of governmental counterparts to the UN clusters was another mechanism that synchronized coordination between international NGOs and the distribution of the workload. A major weakness of the system was the delay in the deployment of a sophisticated warning system. Table 15.12 summarizes research ideas gleaned from the two cases.

In light of the literature and analysis of the two disasters, it is obvious that there is a gap between research and practice. The response teams are overwhelmed with operational tasks and have little time for systematic planning during the response phase. This increases the importance of planning tools that can provide solutions in a quick and efficient manner. However, we find that multimodal logistics models are computationally difficult to solve and Özdamar and Ertem (2015) conclude that these models are not integrated into decision support systems. Furthermore, these multimodal logistics solutions are difficult to implement in the chaotic environment of disaster response due to inherent issues in coordination and information asymmetry.

Table 15.12 Comparison of literature and implementation in the two disasters

Preparedness	Response
Facility location: (1) Facilities as alternative to costly transportation modalities, (2) inclusion of forecasting to improve short-term location problem, (3) coordinated facility location by multiple humanitarian actors	*Temporary facility location*: (1) Inclusion of multimodal accessibility score, (2) consideration beyond distribution point
Stock pre-positioning: (1) Lot-size planning, (2) multimodal sourcing transportation for short-notice stocking	*Routing*: (1) Planning for congestion/returning traffic, (2) hierarchical transportation planning in practice, (3) modeling the transportation coordination incentives/contracts to enable co-modal and synchromodal transportation, (4) introduction of volunteer vehicles, (5) consideration of material convergence

Preparation

Facility Location Problem

The interview respondents viewed warehouse facilities as an alternative to the acquisition of costly vehicles. Locating permanent facilities closer to disaster-prone areas and pre-stocking them with relief goods can be costly exercises. However, the trade-off between facility acquisition and vehicle procurement needs to be explored for an efficient and effective disaster response.

The inclusion of forecasting and risk assessment elements in stock pre-positioning makes it easier to plan for future requirements. Garrido et al. (2015) included a flood forecasting model in their study on emergency preparation and response during flood disasters. The model improved the pre-stocked inventory and vehicle allocation for disaster response. The integration of forecasting/risk assessment and multimodal access to facility location decisions requires further research. Models considering risk assessment with pre-planned accessibility of facilities through multiple modes of transportation can improve response time logistics.

The warehouse sharing arrangements observed in the response to the 2010 floods provide hope for possible co-modal planning of logistics. The trust and credibility established while sharing permanent facilities can be utilized in sharing transportation vehicles of various modes to deliver goods owned by different humanitarian actors.

The problem of facility location could also be planned in a coordinated manner to minimize costs and human suffering while maximizing coverage and cooperation between humanitarian actors. Formation of contracts that offset expensive capital investment through rent agreements with multiple parties is an observable phenomenon in the field.

Stock Pre-positioning

The pre-positioning of stocks provides a hedge against sourcing costs during the disasters. There is a tradeoff between sourcing and transportation costs during the disaster and costs of obsolescence, material management, and maintenance of pre-positioned stocks. Problems of lot-sizing for procurement are relevant to the problem of pre-positioning.

The multimodal logistics problem in stock pre-positioning is not usually pressed for delivery time performance. However, delivery time performance becomes relevant in late warnings when the stock pre-positioned in warehouses needs to be augmented before the disaster. Pre-positioning stock during these late warnings might face delays due to evacuating traffic congestion. Development of models for routing and scheduling vehicles of multiple modes to pre-position stocks in a timely fashion is another area for future research.

Response

Temporary Facility Location

Temporary facilities include distribution centers, evacuation shelters, and medical camps closest to the affectees. Location planning for the temporary facilities is possible after the disaster has struck and the affected locations have been identified. However, since these temporary facilities are last mile distributions points, better accessibility needs to be ensured for them.

There can be situations where the temporary facility is not the actual consumption point for relief goods. In the case of the Kashmir earthquake, certain affected areas were so remote that distribution points were also further from their location. Another reason for the distance between distribution centers and affected areas was a lack of accessibility to a feasible location in that area. The last mile problem begins at such temporary facilities. Transportation through mules was one such example in the case of the Kashmir earthquake.

Multimodal Routing

The routing problem is linked to vehicle allocation, scheduling, and coordination problems. The damaged links in the network are not identified immediately after the disaster has occurred. The condition of some routes might be updated much later. The condition of the routes is also dynamic as some repair begins during the disaster to facilitate routing.

Relief distribution can be hampered by transportation bottlenecks on some routes due to evacuating traffic. The Kashmir earthquake is an illustration of this with mountainous terrain and scarce road capacity. Few attempts have been made to model congestion in relief distribution with Wang et al. (2015) modeling it as arc capacity constraint.

The logistics decision-making setup that emerged in the 2010 floods—and is prevalent in Pakistan today—was hierarchical and distributed in most cases. This despite the fact that the majority of multimodal routing literature for disaster scenarios assumes a central planner who decides for all the goods movement and location decisions. The hierarchical logistics model observed in the 2010 case separates bulk movement from last mile distribution. The planners for routing are different and in some cases they are independent agents. The centralized coordination of helicopters presents a further complexity in modeling this system. However, for almost all other transportation modalities the routing decision is decentralized. A hierarchical model of the disaster routing problem with multiple transportation modes may be an area of future research. Applications of agent-based models for multimodal routing in a decentralized network can also be promising areas of research.

The key challenge is to improve multimodal routing in the disaster context to co-modality and eventually to synchromodality. The application of a co-modal system in a disaster context is often difficult due to severe coordination problems inherent in humanitarian relief chains. Balcik et al. (2010) discovered that transportation is an area where coordination mechanisms in relief chains need to be improved. They suggest that incentives and contracts for transportation-based collaboration are a future area of research in disaster logistics.

The role of volunteer vehicles is often overlooked in disaster operations management. A number of independent volunteers come forward to assist in disaster settings. These volunteers may be able to own and operate vehicles of different modalities. This exogenous supply of vehicles can be directed by humanitarian actors to assist in disaster response. Technologies like crowd-mapping can provide valuable data and improve utilization of volunteer vehicles, but sophisticated mechanisms are required for establishing the credibility and believability of the data (Poblet et al. 2012).

Material convergence is a phenomenon in disaster relief where a lot of unsolicited goods are accumulated at the relief distributor's facility. These materials contain a large proportion of goods not suitable for use. Material convergence was observed in the 2005 earthquake where large amounts of in-kind donations required processing. The planners had not foreseen this issue which resulted in less-effective utilization of transportation (Wilder 2008). Although a major problem, the literature is scarce in this area (Holguín-Veras et al. 2012b).

Scheduling

The two case studies present similar problems in scheduling. The centrally coordinated helicopters were scheduled in a more systematic manner compared to road and water-based transportation. Articles addressing the scheduling aspect of multimodal vehicles in disaster response are scarce. We came across only three such articles as shown in Table 15.1. This dearth of articles can be attributed to the need for more effective and efficient solution algorithms to solve this complex problem (Wang et al. 2015).

Multimodal scheduling problems need to schedule heterogeneous products with different vehicle requirements. Fragile and temperature-sensitive medical products cannot be transported alongside tents and other nonperishables. Similarly, other products have different transportation requirements. Scheduling problems must consider the product-vehicle match.

The scheduling problem also needs to take into consideration the prevalent status of the network. Bad weather might ground helicopters just like land-sliding might stop ground vehicles. A dynamic program which updates these conditions during disaster response might improve scheduling.

References

Adinolfi, C., Bassiouni, D. S., Lauritzsen, H., and Williams, H. R. (2005). Humanitarian response review. Retrieved from *ALNAP*, April 1, 2016, from http://www.alnap.org/pool/files/adinolfi-et-al-(2005)-humanitarian-response-review.pdf

Adivar, B., & Mert, A. (2010). International disaster relief planning with fuzzy credibility. *Fuzzy Optimization and Decision Making, 9*(4), 413–433.

Afshar, A., and Haghani, A. (2012). Modeling integrated supply chain logistics in real-time large-scale disaster relief operations. *Socio-Economic Planning Sciences*, *46*(4), 327–338.

Alexander, D. (2006). *Earthquake in Kashmir: A Question of Responsibilities*. An unpublished paper. Retrieved April 1, 2016, from http://www.radixonline.org/resources/kashmiralexander.doc

Asian Development Bank and World Bank (ADB-WB). (2005). Preliminary Damage and Needs Assessment—Pakistan 2005 Earthquake.

Balcik, B., Beamon, B. M., Krejci, C. C., Muramatsu, K. M., and Ramirez, M. (2010). Coordination in humanitarian relief chains: Practices, challenges and opportunities. *International Journal of Production Economics*, *126*(1), 22–34.

Barbarosoglu, G. and Arda, Y. (2004). A two-stage stochastic programming framework for transportation planning in disaster response. *Journal of the Operational Research Society*, *55*(1), 43–53.

Battini, D., Peretti, U., Persona, A., and Sgarbossa, F. (2014). Application of humanitarian last mile distribution model. *Journal of Humanitarian Logistics and Supply Chain Management*, *4*(1), 131–148.

BBC. (2005, October 28). Cash crisis for quake helicopters. Retrieved April 1, 2016, from *BBC News*: http://news.bbc.co.uk/2/hi/south_asia/4384204.stm

Beamon, B. M., and Balcik, B. (2008). Performance measurement in humanitarian relief chains. *International Journal of Public Sector Management*, *21*(1), 4–25.

Behdani, B., Fan, Y., Wiegmans, B., and Zuidwijk, R. (2014). Multimodal schedule design for synchromodal freight transport systems. Available at SSRN *2438851*.

Benini, A., Conley, C., Dittemore, B., and Waksman, Z. (2009). Survivor needs or logistical convenience? Factors shaping decisions to deliver relief to earthquake affected communities, Pakistan 2005–06. *Disasters*, *33*(1), 110–131.

Bozorgi-Amiri, A., and Khorsi, M. (2015). A dynamic multi-objective location–routing model for relief logistic planning under uncertainty on demand, travel time, and cost parameters. *The International Journal of Advanced Manufacturing Technology*, *85*(5-8), 1633–1648.

Cahill, K. M. (2007). *The Pulse of Humanitarian Assistance*. Oxford, UK: Oxford University Press.

Caunhye, A. M., Nie, X., and Pokharel, S. (2012). Optimization models in emergency logistics: A literature review. *Socio-Economic Planning Sciences*, *46*(1), 4–13.

Crainic, T. G., and Kim, K. H. (2006). Intermodal transportation. *Transportation*, *14*, 467–537.

Currion, P. (2005). Assessment report: Pakistan Earthquake Response. Inter-agency Working Group on Emergency Capacity, Retrieved April 1, 2016, from ALNAP: http://old.alnap.org/resource/3381.aspx.

EM-DAT. (2016). Number of disasters reported: 1950–2015. EM-DAT: The OFDA/CRED International Disaster Database – www.emdat.be – Université

Catholique de Louvain – Brussels – Belgium. Retrieved April 1, 2016, from http://www.emdat.be/disaster_trends/index.html

ERRA. (2006). *Annual Review 2005–2006*. Islamabad: Government of Pakistan.

Ferris, E. (2010). *Earthquakes and floods: Comparing Haiti and Pakistan*. Brookings Institution, 26.

Garrido, R. A., Lamas, P., and Pino, F. J. (2015). A stochastic programming approach for floods emergency logistics. *Transportation Research Part E: Logistics and Transportation Review*, *75*(C) 18–31.

Government of Pakistan (GoP). (2005). A review of disaster management policies and systems in Pakistan. UN-World Conference on Disaster Reduction. Retrieved April 1, 2016, from http://presidentofpakistan.gov.pk/gop/index.php?q=aHR0cDovLzE5Mi4xNjguNzAuMTM2L2dvcC8uL3BkZnMvZGlzYXN0ZXIgbWFuYWdlbWVudCBwb2xpY3kucGRm

Government of Pakistan (GoP). (2011) *Annual Flood Report 2010*. Government of Pakistan, Ministry of Water and Power, Federal Flood Commission, Islamabad

Guha-Sapir, D., Hoyois, P., and Below, R. (2014). *Annual Disaster Statistical Review 2013: The Numbers and Trends*. Brussels: CRED.

Gunn, S. W. A. (2003). The language of disasters: A brief terminology of disaster management and humanitarian action. *In Basics of International Humanitarian Missions*, 37–40. New York City, New York, USA: Fordham University Press.

Haghani, A., and Oh, S. C. (1996). Formulation and solution of a multi-commodity, multi-modal network flow model for disaster relief operations. *Transportation Research Part A: Policy and Practice*, *30*(3), 231–250.

Holguín-Veras, J., Jaller, M., Van Wassenhove, L. N., Pérez, N., and Wachtendorf, T. (2012a). On the unique features of post-disaster humanitarian logistics. *Journal of Operations Management*, *30*(7), 494–506.

Holguín-Veras, J., Jaller, M., Van Wassenhove, L. N., Pérez, N., and Wachtendorf, T. (2012b). Material convergence: Important and understudied disaster phenomenon. *Natural Hazards Review*, *15*(1), 1–12.

Hu, Z. H. (2011). A container multimodal transportation scheduling approach based on immune affinity model for emergency relief. *Expert Systems with Applications*, *38*(3), 2632–2639.

Iqbal, I., Iqbal Z., and Ravan, S. (2015). Effective use of Space-based information to monitor disasters and its impacts: Lessons Learnt from Floods in Pakistan. Retrieved April 9, 2016, from *UN-SPIDER.org*: http://www.un-spider.org/sites/default/files/150112_SUPARCOBooklet_online.pdf

Kaneda, H., Nakata, T., Tsutsumi, H., Kondo, H., Sugito, N., Awata, Y., Akhtar, S. S., Majid, A., Khattak, W., Awan, A.A. and Yeats, R.S. (2008). Surface rupture of the 2005 Kashmir, Pakistan, earthquake and its active tectonic implications. *Bulletin of the Seismological Society of America*, *98*(2), 521–557.

MacLeod, A. (2007). *ERRA Annual Review 2006–2007*, 119–132. Islamabad: Government of Pakistan.

MapAction. (2005). Pakistan Earthquake Disaster Situation Overview Map, T087/1, 18 October 2005. Retrieved from MapAction.org, April 1, 2016, from http://maps.mapaction.org/dataset/7-1293.

MapAction. (2010, September 9). Pakistan-Overview-Transport, PAK215, v2_A0, 19 August 2010. Retrieved from MapAction.org, April 1, 2016, from http://maps.mapaction.org/dataset/196-2111/resource/97b59d32-d56d-4323-8675-df54e9406ee7

McLoughlin, D. (1985). A framework for integrated emergency management. *Public Administration Review*, *45*, 165–172.

Min, H., Jayaraman, V., and Srivastava, R. (1998). Combined location-routing problems: A synthesis and future research directions. *European Journal of Operational Research*, *108*(1), 1–15.

Najafi, M., Eshghi, K., and Dullaert, W. (2013). A multi-objective robust optimization model for logistics planning in the earthquake response phase. *Transportation Research Part E: Logistics and Transportation Review*, *49*(1), 217–249.

NDMA. (2007). *National Disaster Risk Management Framework*. Islamabad: Government of Pakistan.

NDMA. (2009). *Annual Report 2009*. Islamabad: Government of Pakistan.

NDMA. (2010). *National Disaster Response Plan 2010*. Islamabad: Government of Pakistan.

NDMA. (2011). *Pakistan Floods 2010: Learning from Experience*. Islamabad: Government of Pakistan.

Nolz, P. C., Doerner, K. F., & Hartl, R. F. (2010). Water distribution in disaster relief. *International Journal of Physical Distribution & Logistics Management, 40*(8/9), 693–708.

Owen, L. A., Kamp, U., Khattak, G. A., Harp, E. L., Keefer, D. K., and Bauer, M. A. (2008). Landslides triggered by the 8 October 2005 Kashmir earthquake. *Geomorphology*, *94*(1), 1–9.

Özdamar, L., and Demir, O. (2012). A hierarchical clustering and routing procedure for large scale disaster relief logistics planning. *Transportation Research Part E: Logistics and Transportation Review*, *48*(3), 591–602.

Özdamar, L., and Ertem, M. A. (2015). Models, solutions and enabling technologies in humanitarian logistics. *European Journal of Operational Research*, *244*(1), 55–65.

Özdamar, L., Ekinci, E., and Küçükyazici, B. (2004). Emergency logistics planning in natural disasters. *Annals of Operations Research*, *129*(1–4), 217–245.

Ozkapici, D. B., Ertem, M. A., and Aygüneş, H. (2016). Intermodal humanitarian logistics model based on maritime transportation in Istanbul. *Natural Hazards*, *83*(1), 1–20.

Poblet, M., Leshinsky, R., and Zeleznikow, J. (2012). Digital neighbours: Even Good Samaritan crisis mappers need strategies for legal liability. *Planning News*, *38*(11), 20.

Polastro, R., Nagrah, A., Steen, N., and Zafar, F. (2011). *Inter-Agency Real Time Evaluation of the Humanitarian Response to Pakistan's 2010 Flood Crisis*. Madrid: DARA.

Qureshi, J. H. (2006). Policy briefing Pakistan: Political impact of the earthquake. Crisis Group Asia Briefing No. 46. Retrieved April 10, 2016, from crisisgroup.org: http://www.crisisgroup.org/~/media/Files/asia/south-asia/pakistan/b046_pakistan_political_impact_of_the_earthquake.pdf

Rahman, A. (2010) *Disaster Risk Management: Flood Perspective*. VDM Verlag Publishing: Saarbrücken, 192 pp. *ISBN 978-3-639-29891-8*

Rahman, A., and Khan, A. N. (2011) Analysis of flood causes and associated socio-economic damages in the Hindu Kush region. *Natural Hazards 59*(3): 1239–1260.

Rasul, G., and Ahmad, B. (2012). *Climate change in Pakistan*. Focused on Sindh Province, Pakistan Meteorological Department Report.

Rennemo, S. J., Rø, K. F., Hvattum, L. M., and Tirado, G. (2014). A three-stage stochastic facility routing model for disaster response planning. *Transportation Research Part E: Logistics and Transportation Review*, *62*, 116–135.

Rodriguez, R. R., Saiz, J. J. A., and Bas, Á. O. (2007). Tangible and intangible factors for supply chain co-transportation practices. In *XI Congreso de Ingeniería de Organización: Madrid, 5-7 de Septiembre de 2007*, 923–927. Madrid, Spain: Asociación para el Desarrollo de la Ingeniería de Organización (ADIGNOR).

Ruan, J., Wang, X., and Shi, Y. (2014). A two-stage approach for medical supplies intermodal transportation in large-scale disaster responses. *International Journal of Environmental Research and Public Health*, *11*(11), 11081–11109.

SAARC. (2016). Disaster profile of Pakistan. Retrieved April 1, 2016, from http://www.saarc-sadkn.org/countries/pakistan/disaster_profile.aspx

Sheu, J. B. (2007). Challenges of emergency logistics management. *Transportation Research Part E: Logistics and Transportation Review*, *43*(6), 655–659.

SteadieSeifi, M., Dellaert, N. P., Nuijten, W., Van Woensel, T., & Raoufi, R. (2014). Multimodal freight transportation planning: A literature review. *European Journal of Operational Research*, *233*(1), 1–15.

Steets, J., Grünewald, F., Binder, A., De Geoffroy, V., Kauffmann, D., Krüger, S., Meier, C. and Sokpoh, B. (2010). Cluster approach evaluation 2 synthesis report. IASC Cluster Approach Evaluation 2nd Phase, Groupe URD and the Global Public Policy Institute.

Stoddard, A., Harmer, A., Haver, K., Salomons, D., and Wheeler, V. (2007). Cluster approach evaluation—Final. *Development*, 10121, 10150.

Syed, S. (2015, October 4). 10 years on, we have learnt no lessons from the earthquake. Retrieved April 1, 2016, from Dawn: http://www.dawn.com/news/1210665

Thakur, V. C. (2006). Lessons learnt from the 8 October 2005 Muzaffarabad earthquake and need for some initiatives. *Current Science-Bangalore*, *91*(5), 566.

Thompson, W. C. (2008). *Practitioner's Hands and Academic Eyes: A Practical Approach to Improving Disaster Preparedness and Response* (Doctoral dissertation). Corvallis, Oregon, USA: Oregon State University.

Trunick, P.A. (2005). "Special report: Delivering relief to tsunami victims", *Logistics Today*, *46*(2), 1–3.

UNECE. (2009). Illustrated glossary for transport statistics. ISBN: 978-92-79-17082-9.

United Nations Office for the Coordination of Humanitarian Affairs (UN-OCHA). (2010) Pakistan floods emergency response plan, September revision. UN-OCHA

Verweij, K. (2011). Synchronic modalities – Critical success factors. In P. J. van der Sterre (Ed.), *Logistics Yearbook Edition 2011*. Rotterdam (pp. 75–88). ISBN: 978-90-79470-00-6.

Vidal, J. and Walsh D. (1 June 2010). "Temperatures reach record high in Pakistan". *The Guardian*, London.

Wang, L., Song, J., and Shi, L. (2015). Dynamic emergency logistics planning: Models and heuristic algorithm. *Optimization Letters*, *9*(8), 1533–1552.

Wilder, A. (2008). Perceptions of the Pakistan earthquake response: Humanitarian agenda 2015—Pakistan country study. Medford, MA: Feinstein International Center, Tufts University.

Wilkinson, I. (2005, November 7). Mules provide constant hope for villages cut off by quake. Retrieved April 1, 2016, from *The Telegraph*: http://www.telegraph.co.uk/news/worldnews/asia/pakistan/1502434/Mules-provide-constant-hope-for-villages-cut-off-by-quake.html

Woxenius, J. (2007). Generic framework for transport network designs: Applications and treatment in intermodal freight transport literature. *Transport Reviews*, *27*(6), 733–749.

Ye, Y., and Liu, N. (2011, June). A sequential approach for emergency logistics planning in natural disasters. In *International Conference on* Service Systems and Service Management (ICSSSM), 2011 8th (pp. 1–6). Tianjin, China: IEEE.

Yi, W., and Özdamar, L. (2007). A dynamic logistics coordination model for evacuation and support in disaster response activities. *European Journal of Operational Research*, *179*(3), 1177–1193.

Zhao, Y., and Qian, Y. (2014). The construction of emergency logistics and integrated transport system based on "Scenario-Response" mode. *International Journal of Control and Automation*, *7*(3), 359–370.

Zheng, Y. J., and Ling, H. F. (2013). Emergency transportation planning in disaster relief supply chain management: a cooperative fuzzy optimization approach. *Soft Computing*, *17*(7), 1301–1314.

Zhu, J., Huang, J., Liu, D., and Han, J. (2008). Resources allocation problem for local reserve depots in disaster management based on scenario analysis. In *The 7th International Symposium on Operations Research and its Applications,* 395–407. Beijing, China: World Publishing Corporation.