Flood Risk Assessment in Humanitarian Logistics Process Design

C. Díaz-Delgado*[1] and J. Gaytán Iniestra[2]

[1] Centro Interamericano de Recursos del Agua (CIRA)
Facultad de Ingeniería
Universidad Autónoma del Estado de México
Cerro de Coatepec, Ciudad Universitaria s/n, Toluca, C.P. 50110
Estado de México, México
*cdiazd@uaemex.mx
[2] Facultad de Ingeniería
Universidad Autónoma del Estado de México
Cerro de Coatepec, Ciudad Universitaria s/n, Toluca, C.P. 50100
Estado de México, México

ABSTRACT
This article deals with the relationship between a flood risk assessment and the humanitarian logistics process design related to emergency events caused by flooding. The magnitude and timing of the flooding is estimated using a forecasting model that requires a hydrologic component to convert rainfall into runoff as well as a hydraulic component to route the flow through the stream network predicting time and severity of the flood wave. Once these components are known, and with the intention of mitigating the impact of the flood wave on the population, we provide the relevant aspects to define humanitarian aid and evacuation plans including processes and metrics of it. Finally, an example that integrates both methodologies is included.

Keywords: flood early warning system, humanitarian logistics, flood risk assessment, evacuation plan.

1. Introduction

Flood is the flow of an excess of water that submerges land usually not covered by water. Floods are the most frequent disasters worldwide and they mostly affect people who have a low social and economic status as they tend to live in the flood-prone areas of the cities (Sodhi and Tang, 2013) (see figure 1). In June 2012, there were 17.4 million victims caused by the flood that affected China. Additionally, this country was affected by another flood in April (13.1 million victims) and two storms in August (9.8 million victims), contributing to a worldwide total of 44.6 million flood victims (EM-DAT, 2013). In figure 2 it can be observed that hydrological disasters (including floods) are responsible for the greatest number of people affected worldwide by natural disasters between the years 1900 to 2012. Natural disasters are considered random events due to its complexity and the need for several other incidents to occur simultaneously. If the actual trend continuous, more natural disasters such as floods will continue to happen. It is thus important to highlight that floods and storms are responsible for more than 55% of all natural disasters (EM-DAT, 2013). Furthermore, Palmer and Raïsänen (2002) specify that climate change will affect the probability of atypical seasons of high intensity rainfall in the next hundred years in such a way that it will be five times the current probability. Mexico, through its history, has been immersed in several meteorological phenomena, which marked and forced the population to enhance hydrological and hydraulic techniques to cope with floods. In fact, since the era of Tenochtitlan, its inhabitants experienced the frequent increment in height of lakes and rivers which provoked floods and forced them to build hydraulic structures as magnificent as the ones made by other developed cultures of that era (Gonzalez et al., 2012).

Number of natural disasters reported 1900-2012 (square rooted)

EM-DAT: The OFDA/CRED International Disaster Database - www.emdat.be - University Catholique de Louvain. Brussels - Belgium
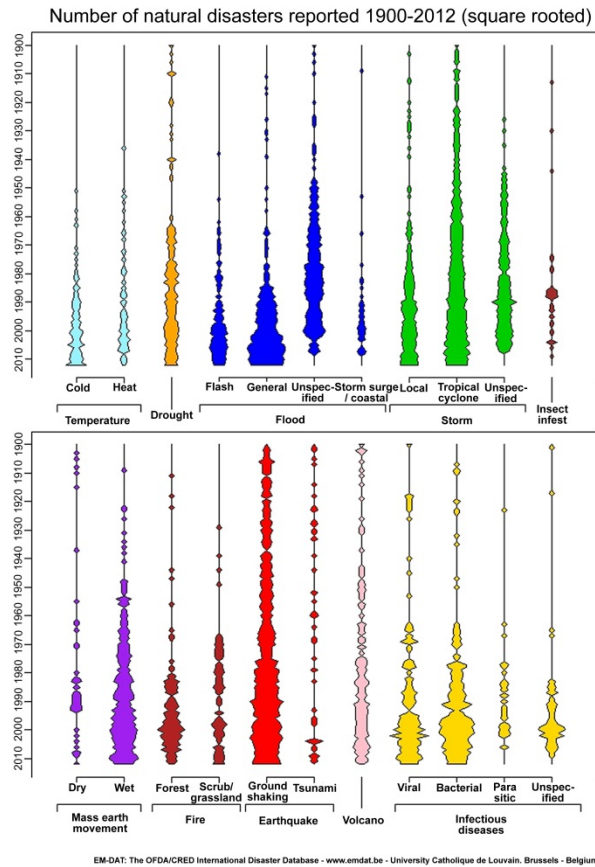
Figure 1. Number of natural disasters reported
for the period 1900-2012 (EM-DAT, 2013).

Mexico is affected annually by an average of 8 hurricanes on the Atlantic coast and at least two of them go inland while the Pacific Ocean coast is struck annually by an average of 13 hurricanes and at least 4 of them reach land and cause severe damage (Bitrán, 2001). To demonstrate the significance of damage caused by floods the following events are accurate examples: a) the flood generated by one of the most important tropical depression of the last 40 years in the country, occurred on October 1999 in the Tehuantepec Isthmus region and it was responsible for more than 260 human casualties and huge damage across 81 municipalities (Bitran, 2001), b) the State of Tabasco, in 2007, was affected by an extraordinary precipitation in the middle watershed of the Grijalva river which caused floods in more than 70% of its territory with water levels up to 4 meters in urban areas (Bitran, 2001), and c) in September 2013

Mexico's Pacific and Gulf coasts were both flooded simultaneously by deadly hurricanes (Ingrid and Manuel) causing at least 23 deaths and more than 1,5 U$ billion of economic losses in the Pacific coast and 169 casualties and more than 4,2 U$ billions in damage in the Mexican Gulf coast (AONbenfield, 2013). Moreover, it is worth to stress that the previous simultaneous occurrence of two hurricanes in Mexico was held in 1958 (NASA, 2013). Figure 3 depicts Ingrid and Manuel hurricanes affecting both Mexican coasts (NASA, 2013).

Mexican authorities are continuously working on emergency plans and hydro-meteorological alert systems, but up until now, in the presence of an extreme flood, the major set of activities to help people affected is the Plan DNIII used to evacuate and rescue the population involved. However that plan is only applied once the event had occurred and is not designed specifically for flooding events. Therefore, it is necessary to count with an early flood warning system and evacuation plan that includes its logistics and supply chain support. As a result, this paper aims to analyze the relationship between flood risk assessment and the humanitarian logistics tasks concerned with these kinds of events in order to identify the main gaps that remain unaddressed in the Mexican emergency plans, which could presents itself as a great opportunity for research and a very good way to contribute to the effort to protect and ensure the society's wellbeing.

Number of people reported affected by natural disasters 1900 - 2012 (square rooted)

EM-DAT: The OFDA/CRED International Disaster Database - www.emdat.be - University Catholique de Louvain. Brussels - Belgium
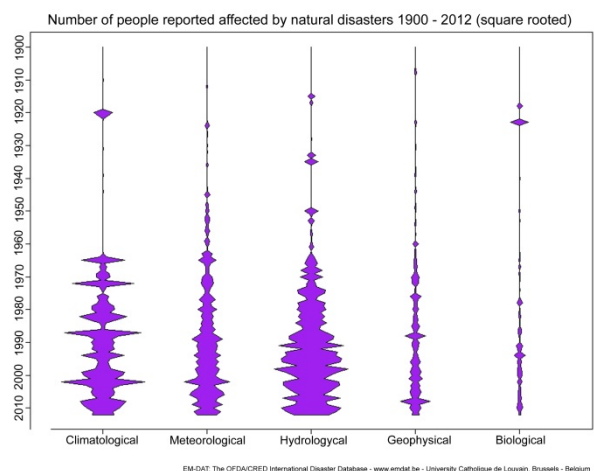
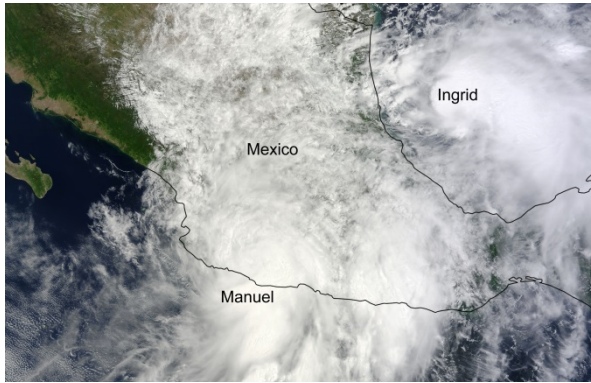Figure 2. Reported number of people affected by natural disasters for the period 1900-2012 (EM-DAT, 2013).

Figure 3. View of Manuel and Ingrid hurricanes affecting both Pacific and Gulf of Mexico coasts (NASA, 2013).

2. Flood early warning system

2.1 Flood early warning system (FEWS)

A FEWS (GnbH, 2009), consists of four elements: a) risk identification, b) monitoring and warning services, c) dissemination and communication, and d) response capability. It must be understood that the initial purpose of this system is to help people cope effectively with the flooding and subsequently to maximize their safety with a minimal economical impact. Thus a flood warning system will be used to let people know of expected flooding and encourage them to take action to protect themselves and their assets. This kind of system can be analyzed through three major components: hardware, software and orgware. The hardware of a FEWS is the ensemble of physical devices which allows the monitoring and warning diffusion of a particular situation. The software is the ensemble of knowledge, methods and techniques to make decisions in a FEWS framework. The Orgware (humanitarian logistics and its supply chain) is a set of rules, order of actions, and assignment of responsibilities, amongst other concepts, which become the protocol to build an effective response capability against floods.

2.2 Flood risk assessment

The flood risk assessment should provide several answers in order to take them into account to build the different phases of a FEWS. Hence the flood risk assessment consists in evaluating: a) the causes of the flood hazard, b) the frequency of extreme flood events, c) the identification and

location of flood prone areas, d) the depth of floods, e) the duration of the flood, f) the velocity of the peak flow of the flood, g) the elements at risk (people and valuable materials) and its vulnerabilities. Therefore, all the previous variables become the main input for the design of a strategic plan against floods. In consequence, flood risk assessment should investigate the flood process and this could be done through the following two analysis: 1) Hazard: which consist in hydrological / hydraulic analysis and morphological analysis, and b) vulnerability: consist in analyzing census data and other complementary data to estimate physical, health and social vulnerability to flooding.

The hydrological analysis entails the chain from precipitation and runoff generation to water concentration in different points of the main river, while the hydraulic analysis deals with flood routing through the river network, possible failure of protective flood measures, and the obtaining of flood extent and water levels. Moreover a flood risk assessment should take into account all relevant flooding scenarios, their associated probabilities and possible damages as well as a thorough examination of the uncertainties related with the risk analysis. In fact, the extent and severity of flood damage are defined by the water depth. As can be seen in figures 4 to 6, such an inundation analysis can be carried out effectively and efficiently by using numerical modeling tools on Geographical Information System platform as has been proposed by (Diaz-Delgado, et al., 2012).
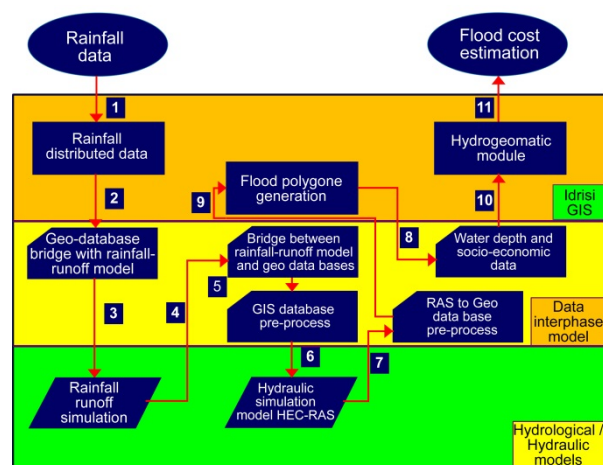

Figure 4. Framework for a flood risk assessment (Diaz-Delgado et al., 2012).
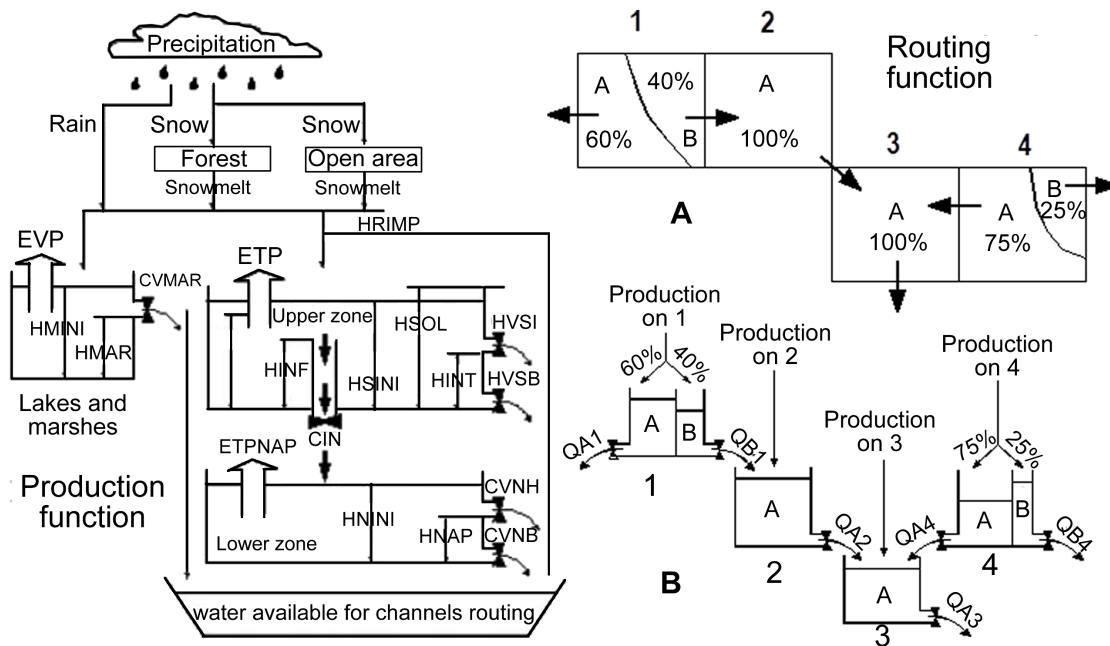
Figure 5. Schematic of a hydrological model for the process of rainfall runoff (modified from Eluch et al., 2009).

The "production function" represented in fig. 5 (left side), deals with the vertical flow, the scheme depicting the transfer of water among rain, snow-melt, evapo-transpiration, infiltration and variations of near-surface and deeper water reserves. The "routing function" (right side figure 5) deals with water flow transfer in the drainage network, taking into account the influence of lakes, marshes, artificial water supply reservoirs such as dams, deviations, canals, water intakes, etc (Eluch et al., 2009).
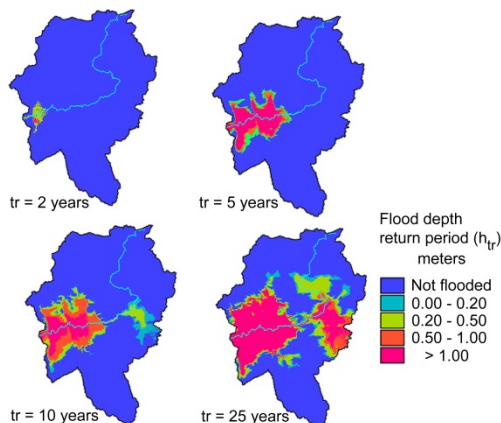

Figure 6. Example for flood risk analysis for several return periods in a watershed.

3. Humanitarian logistics and supply chain

Despite the fact that the number of floods has been increasing exponentially since 1900, there is very little research information in humanitarian logistics and its supply chain to deal with floods (Sodhi and Tang, 2013).

Humanitarian logistics could be defined as the set of activities of planning, implementing, and controlling the flow and storage of goods and materials in an efficient and cost-effective manner; as well as its related information, from point of origin to point of consumption for the purpose of alleviating the impact on vulnerable people (Thomas and Kopczak, 2005).

Humanitarian logistics differs fundamentally from commercial supply chains. The ultimate goal of commercial supply chains (Beamon and Balcik, 2008) is to deliver the right supplies in the right quantities to the right location at the right time, while the humanitarian aid chains objective is to provide humanitarian support in the form of medicine, food, shelter and water, and other supplies to the area affected by a large scale emergency.

The cycle for disaster management is often described as a process with four stages: 1) Mitigation, 2) Preparedness, 3) Response, and 4) Reconstruction. Flood logistics oversees mainly the preparedness, response and reconstruction phases.

For the purpose of this article, emphasis is made on the preparedness and response phases for the flood. The preparedness phase refers to several operations that should occur during the period before disaster strikes, unlike the response phase which deals with various operations that are simultaneously implemented just after a flood occurs. The preparedness phase is crucial and it consists in the physical network design, the information and communications technology systems, and the building of bases for institutional collaboration in order to ensure people know evacuation options, location of pre-positioned emergency response supplies, and shelter's capacity to respond to disasters. In the response phase, coordination and collaboration among all the players involved in the humanitarian flood emergency deserves particular attention (Cozzolino et al., 2012).

Moreover, at this stage activities are primarily focused on saving lives and preventing or mitigating further damage. Here the humanitarian operations rely mostly on logistics because they consider the distribution of food, medical supplies and other necessities on which human lives depend on, and thus the importance of how quickly the logistics tasks are performed.

In the literature about disaster logistics, several authors highlight as a key issue the "last mile relief distribution" concept which involves the ultimate connector of humanitarian activities with the victims. This concept refers to the supply of relief items from the local distribution centers to the people affected by the natural disaster (Balcik et al., 2008).

3.1 Last mile relief distribution

The last mile relief distribution is the ultimate stage of disaster relief operations, which is associated with the delivery of relief supplies from field warehouses to the affected people taking into account the key factors affecting such delivery.

Priyanka et al. (2013) says that four logistical decisions could influence this last mile relief distribution. These include facility location (identifying the most suitable place for inventory in the relief network), inventory management (efficiently manage the inflow and outflow of the relief materials), transportation mode (how to move the relief to the area in need) and distribution decision (to quickly and efficiently distribute the relief materials to the suffering population). It is clear these four decisions are sequentially related. Moore (2000) and Cedillo-Campos and Sánchez (2013) have all proposed methodologies to cover these factors in an integral way. In the following sections we discuss these four factors as an integrated process.

3.2 Facility location decisions

The facility locations decisions should take into account the next key components Priyanka et al. (2013):

• Number of facilities: It is necessary to determine the number and location of distribution centers in the relief network.

• Location of facilities: The location of relief camps during a flood situation.

• Capacity of the facility: The available capacity of the facility.

• Factors affecting the facility location decision: a) quality of infrastructure, b) different facility areas for segregation and packing, c) setting up the distribution center, d) accessibility and location safe against flood.

3.3 Inventory decision

The inventory decisions should take into account the next key components Priyanka et al. (2013):

• Inventory types: What inventory should be stored in each facility related to the requirements of beneficiaries for the purpose of fixing lifetime commodities

• Inventory policy: The target inventory levels, minimum and maximum inventory levels, stock replenishment policy, order quantity and safe stock levels.

• Factors affecting the inventory decisions: a) regional restrictions regarding food and clothes that can be employed, b) accurate assessment of the flood disaster situation, c) cultural requirements, d) capacity to potentially manage the donated relief, e) safety and security (particularly with young girls and women), e) ability to supply lead time with perishable items.

3.4 Transportation decision

The transportation decisions should take into account the next key components Priyanka et al. (2013):

• Transportation policy: Number of vehicles, route planning, capacity of the vehicles, and vehicle scheduling.

• Age groups of people affected by flood who need to be rescued as well as those who need to be transported to shelters taking into account their mobility capacity.

• Factors affecting transport decision: a) geographical area of the disaster, b) potential for collaboration and coordination, c) flood magnitude, d) weather situation and associated forecast, e) volume of items and allowed time frame for transportation.

3.5 Distribution decisions

The distribution decisions should take into account the next key components Priyanka et al. (2013) and also a specific methodology for the strategic plan implementation as has been mentioned by Rojas-Arce et al. (2012):

• Transport network which remains available for any type of flood, supply of relief, number of volunteers and prioritization of the affected areas.

• Factors affecting distribution decision: a) communication plans with local authorities and population, b) safety and security, c) time required for distribution, c) enough volunteers for distribution, d) time for the day of distribution, e) strong control mechanism during distribution and f) transparency of distribution.

4. Performance measurement of relief operations

Several supply chain performance measures have been proposed for different perspectives, depending on the type of supply chain ((Moore, 2000; Cedillo-Campos et al. (2013); Beamon and Balcik (2008) and Santarelli et al. (2013)). For example, the performance measurement of Commercial supply chains are more related to financial metrics, since they are indicators of market-need satisfaction and an organization´s ability to operate efficiently in cost and responsiveness (Kanter and Summers, 1987). For nonprofit supply chains, performance measurement is more related to intangible aspects such as alleviate human suffering and reduce human fatalities. For example, Santarelli et al. (2013) evaluate the performance of humanitarian supply chains, considering five categories and for each of them several key performance indicators (KPIs), for quantitative and qualitative, financial and no-financial. Han et al. (2007) proposed as measures of effectiveness (MOE) for an effective evacuation plan: evacuation time, cumulative exposure, and temporal/spatial risk factors. The equity of the evacuation plan is considered by Gaytán et al. (2013) who consider as MOE maximum distribution time of the supplies to shelters, total cost of the plan, and maximum evacuation time. These measures are used to define critical decision including shelters to be opened, population to be transported to each shelter, transportation modes, distribution centers to be opened, and number of vehicles required to distribute humanitarian aid from distribution centers to shelters. The performance of humanitarian logistics effort is also related to the last mile distribution from distribution center to beneficiaries. Huang et al. (2012) study the impact of the efficacy and equity of the distribution on the number and type of service vehicles, and structure of vehicles routes.

5. Study case. Villahermosa, Tabasco, México

Villahermosa, the capital of the state of Tabasco, is located 904 km from Mexico City and is situated at an average of 10 m AMSL where the flow of three important rivers converges: the Grijalva River, the

De la Sierra River and the Usumacinta River. Its geographical situation contributes to the propensity of flood risk. In fact The National Risk Atlas classifies this municipality as one with high vulnerability (CENAPRED, 2012). During the flood event that took place during 2007, the floods covered near 70% of the state, and the water level rose up to cover 80% of the city of Villahermosa. Estimated affected people were around 196,682 (SEGOB, 2008).

A GIS was built to include road and altitude maps, street network and infrastructure in order to locate possible shelters and distribution centers. Combining the GIS and developing hydrological and hydraulic analysis, simulated flooding maps were constructed for different flooding times for the conditions of the 2010 scenario. The corresponding map for a 2 m flooding scenario, at the lowest point of the watershed, is shown in figure 7. Once the flooding zone and affected population are known, the information gathered is fed to a multi-objective optimization model (Mejía et al., 2012) that considers equity of distribution aid, evacuation time, and evacuation costs as criteria. Pareto front for the three criteria is constructed with a heuristic algorithm developed, which is based on the SSPMO procedure (Molina et al., 2007). The Pareto front is submitted to the decision makers. Each point of Pareto front corresponds to the most convenient number of shelters, distribution centers, evacuation points, and vehicles required to evacuate the affected population.
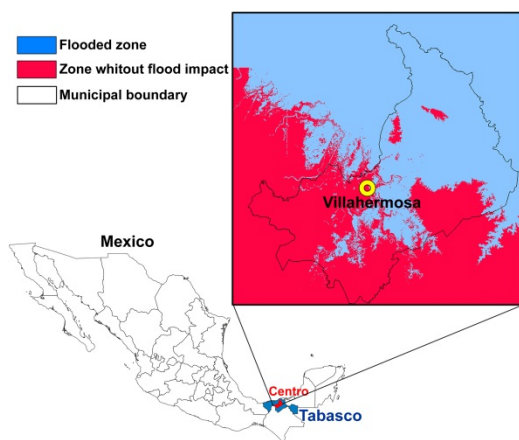

Figure 7. Flooded area of Villahermosa, Tabasco Mexico under a 2 m flooding scenario at the lowest point of the watershed (Mejía et al. (2012)).

6. Discussion and conclusion

Floods are more predictable, or can be simulated with an acceptable degree of accuracy (unlike other kind of natural disasters such as earthquakes) in terms of timing, magnitude and location. Hence, nowadays with the available knowledge and technology there is an opportunity for a much better preparedness, response, and mitigation against this natural phenomena.

Therefore it is important to create the database needed for forecasting floods and also to make contributions to strengthening a multidisciplinary and multi-sectorial teamwork, which will be responsible for finding practical solutions against flood disasters in the country. However, to optimize the logistic performance it is required that all the relationships among the stakeholders are managed under an integrated approach and an efficient coordination for a good performance.

Humanitarian logistics is a very important research field that requires attention in order to develop tools and decision support systems that when used they facilitate the decision making process, and in practice help to save human lives and avoid significant negative economic impact for the stakeholders involved in a flood. Another gap that remains unaddressed is the development of metrics for all phases of a disaster cycle in order to monitor and improve all processes involved.

In this analysis the main logistical decisions and the factors which affect these decisions for the last mile relief distribution were synthesized stressing the need to tackle all these as a whole integrated process. Moreover, it was identified that there is a need for a multidisciplinary and multi-stakeholder participation to guarantee the emergency response services are prepared against floods. And finally, it should be understood that a flood hazard mitigation situation needs to shift from only a disaster reactive response system to a more preparedness based system on flood risk assessment, and to an improved humanitarian logistics and its supply chain programs which must include an effective flood early warning system.

References

[1] M.S. Sodhi and C.S. Tang, "Buttressing supply chains against floods in Asia for humanitarian relief and economic recovery," http://www.cassknowledge.com/-sites/default/files/article-attachments/supply-chains-floods-asia-relief-cass-knowledge-upd.pdf (retrieved September 12th 2013).

[2] EM-Dat, "The OFDA/CREDT International Disaster Database," http://www.emdat.be/. Retrived September 10 2013.

[3] T. Palmer and J. Raïsänen, "Quantifying the risk of extreme seasonal precipitation events in a changing climate," Nature Publishing Group, New York, pp. 512 - 514. 2002.

[4] E. Gonzalez, C. Diaz-Delgado, V.H. Guerra, M.A. Gutierrez and N.M Ramos, "The importance of floods in the Integrated Water Resources Management in Mexico, " (La importancia de las inundaciones en la gestión integrada de los recursos hídricos en México, in spanish), pp. 92-176.Universidad Autónoma de Querétaro, 2012.

[5] Bitrán, "Socio-economical characteristics of impacts of the main disasters occurred in Mexico for the perid 1980 – 1999," (Características del impacto socioeconómico de los principales desastres ocurridos en México en el período 1980-199, in spanish), Centro Nacional de Prevención de Desastres (CENAPRED), México. 2001.

[6] AONbenfield, "Global catastrophe recap 2013, impact forecasting",http://thoughtleadership.aonbenfield.com/Documents/20140107_if_december_global_recap.pdf, (retrived January 22th 2013.).

[7] NASA-National Aeronautics and Space Administration (USA), "Satellite image showing Tropical Storm Manuel and Hurricane Ingrid simultaneously affecting Mexico",http://www.weathercast.co.uk/weather-news/news/ch/841689901323acfc53cf8a289b30e110/article/mexico_hit_by_tropical_storms.html, (retrived January 23th 2013).

[8] GnbH (GTZ), "Local flood early warning systems. Manual: Experiences from the Philippines," Tacloban City, October. pp. 1-100. 2009.

[9] C. Diaz-Delgado, M.A. Gómez-Albores and J.A. Hernández-Pérez, "Hydrological/hydraulic flood modelling with direct tangible damage estimation" (Modelado hidrológico-hidráulico de inundaciones con estimación de daños directos tangibles, in spanish).[XXII Congreso Nacional de Hidráulica, noviembre 2012], Acapulco, Guerrero, Mexico, 2012.

[10] S. Eluch, S., A. Carsteanu, K.M. Bâ, R. Magagi, K. Goïtia and C. Díaz-Delgado, "Validation and use of rainfall data to simulate water flows in the rio Escondido basin," Sctochastic Environmental Research and Risk Assessment Journal, Vol 24, num. 5, 2009 pp 559-565.

[11] A. Thomas and L.R. Kopczak, "From logistics to supply chain management: the path forward in humanitarian sector," white paper, Fritz Institute, San Francisco, C.A., 2005, http://www.fritzinstitute.org/pdfs/whitepaper/fromlogisticsto.pdf retirved September 5 2013. Retrieved on September 1st 2013.

[12] B. Beamon and B. Balcik, "Performance measurement in humanitarian relief chains". International Journal of Public Sector Management. Vol. 21 No. 1, pp. 4-25. 2008.

[13] A. Cozzolino, S. Rossi and A. Conforti, "Agile and lean principles in the humanitarian supply chain. The case of the United Nations world food programme," Journal of Humanitarian Logistics and Supply Cahin Management, Vol. 2, No. 1, pp. 16-33. 2012.

[14] B. Balcik, M.B. Beamon and K. Smilowitz, "Last mile distribution in humanitarian relief," Journal of Intelligent Transportation Systems, Vol. 12, No. 2, pp. 51-63. 2008.

[15] R. Priyanka, P. Albores and C. Brewster, "Logistical framework for last mile relief distribution in humanitarian supply chains: considerations from the field",http://windermere.aston.ac.uk/~kiffer/papers/Roy_ICMR12.pdf , (retrieved 15th August 2013).

[16] M.H. Moore, "Managing for value: organizational strategy in for-profit, nonprofit, and governmental organizations", Nonprofit and Voluntary Sector Quarterly, Vol. 29 No.1, pp. 183-204. 2000.

[17] M. Cedillo-Campos and C. Sánchez, Model for Dynamic Evaluation of Logistics Performance of Supply Chains Operating in Emerging Markets. JART. Journal of Applied Research & Technology, Vol. 11, No. 3, pp. 338-347. 2013.

[18] J. Rojas-Arce, O. Gelman and J. Suárez-Rocha, The Methodology for Strategic Plan Implementation. JART. Journal of Applied Research & Technology, Vol. 10, No. 2, pp. 248-261. 2012.

[19] G. Santarelli, H. Abidi, A. Regattieri and M. Klumpp, "A performance measurement system for the evaluation of humanitarian supply chains", POMS, 24th. Annual Conference of the Production and Operations Management Society, May 6, 2013.

[20] R.M. Kanter and Summers, D.V. "Doing well while doing good: dilemmas of performance measurement in nonprofit organizations and need for multiple-constituency approach", In Powell, W.W. (Ed.), The Nonprofit Sector: A Research Handbook, Yale University Press, New Haven, CT, pp. 154-66. 1987.

[21] L.D. Han, F. Yuan, T. Urbanik, "What Is an Effective Evacuation Operation?, Journal of Urban Planning And Development, vol. 133, no. 1, March 1, 2007.

[22] J. Gaytán, J. García, G. Vertiz, I. Serrano, V. Ortíz, "Methodology for designing evacuation plans based on GIS and optimization models", International Congress on Logistics & Supply Chain,(CILOG). Instituto Mexicano del Transporte, Sanfandila, Qro. 2013.

[23] [M. Huang, K. Smilowitz, B. Balcik, "Models for relief routing: Equity, efficiency and efficacy", Transportation Research Part E, vol. 48, pp. 2-18. 2012.

[24] CENAPRED, Basic guide for the making of Hazard and Risks State and Municipal Atlas: hydrometeorologic phenomena. 1st Edition. Disaster Prevention National Center, México D.F., 2012.

[25] SEGOB, "Tabasco: characteristics and socioeconomic impact of the floods at the end of October and beginning of November 2007 by the cold front number 4". No. LC/MEX/L.864. p. 231, 2008, Mexico.

[26] C. Mejía, O. Rodríguez, J. Gaytán, "Optimization models for humanitarian logistics operations during floodings in Villahermosa, Tabasco", (Modelos de optimización en operaciones de logística humanitaria durante inundaciones en Villahermosa, Tabasco, in spanish), XXII Congreso Nacional de Hidráulica, Acapulco, México, Asociación Mexicana de Hidráulica, Noviembre 6-9, 2012.

[27] J. Molina, M. Laguna, R. Martí, R. Caballero, "SSPMO: A Scatter Tabu Search Procedure for Non-Linear Multiobjective Optimization", INFORMS, Journal on Computing, vol. 19, no. 1, pp. 91-100, 2007.