



Geographic Information Systems (GIS) in Humanitarian Assistance: A Meta-Analysis

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Abstract: Every year natural and man-made disasters cause mass population displacement, loss of lives, and human suffering. On a given disaster several international or non-profit organizations will respond depending on the region in need as well as media and donor attention Olsen, Gorm Rye, et al (2003). Because of the extreme unique difficulties found in each disaster zone such as infrastructural damages, uncertain demand and supply, geographical challenges and time pressures, it is imperative that humanitarian organizations have readily available and applicable response methodologies as well as information technologies to increase their relief impact. In regards to the latter Geographic Information Systems (GIS) has proven to be an indispensable tool in the humanitarian sector.

However, despite there being great recognition in regards to the importance of geospatial information in relief operations there is still a knowledge gap in regards to all the different tasks and uses of GIS in the humanitarian sector. For example, Espindola et al (2016) lament that despite the recent increase in literature which utilizes GIS for humanitarian logistics most of the research is limited to net-work analysis and also that GIS's full potential for disaster relief has not been fully tapped. This meta-analysis, for the first time, seeks to address such gap of knowledge by achieving two main goals: (1) To better understand the various ways in which Geographic Information System (GIS) can be applied in humanitarian settings by revealing how the academic community is utilizing such technology in their research, and (2) to point out strengths and areas that have been overlooked as well as help guide future research in this field.

Every year natural and man-made disasters cause mass population displacement, loss of lives, and human suffering. On a given disaster several international or non-profit organizations will respond depending on the region in need as well as media and donor attention Olsen, Gorm Rye, et al (2003). Because of the extreme unique difficulties found in each disaster zone such as infrastructural damages, uncertain demand and supply, geographical challenges and time pressures, it is imperative that humanitarian organizations have readily available and applicable response methodologies as well as information technologies to increase their relief impact. In

regards to the latter Geographic Information Systems (GIS) has proven to be an indispensable tool in the humanitarian sector.

A study conducted by Kunz and Reiner (2012) can help us better understand the importance of geographic information in humanitarian settings. In their meta-analysis the authors develop a framework, using word frequency, to identify the situational factors which have more presence throughout humanitarian logistics research. As they define it situational factors are “exogenous contextual variables which are present in the disaster affected area and impact the performance of humanitarian logistics.” Their findings indicate that the main situational factors present in humanitarian logistics research include governmental at 23%, Socio-Economic at 19%, Infrastructural at 32%, and environmental at 26%. The latter two should be given a closer look in terms of the importance of geospatial information being that within Environmental situational factors geography and topography were mentioned by researchers the greatest number of times. Infrastructure on the other hand, which includes roads, railways, ports and electricity, all have a spatial component making the use of geospatial techniques indispensable for deciding, for example, where to pre-position points of distribution (PODs) or when planning delivery routes. Because of the importance of geospatial information the UN has established highly skilled departments with their core focus on GIS and geospatial intelligence.

Major geospatial data sources for the humanitarian relief sectors includes UNOSAT (UN Operational Satellite Applications Programme) and Relief Web. UNOSAT coordinates the procurement, processing and analysis of satellite imagery which is then made available to all other UN agencies. It collaborates with other geospatial and space agencies and its end products are used primarily for three main goals: humanitarian and relief coordination, human security and humanitarian law, and territorial planning and monitoring. Relief Web on the other hand was established by the UN OCHA (Office of Coordination or Humanitarian Affairs) and its main role is to assemble an extensive collection of databases for decision making support in humanitarian emergencies. Through its Humanitarian Data Exchange program humanitarian specialist have access to an enormous collection of information including over 1,900 geodata sets. Also, all major UN agencies such as the WHO, FAO, WFP and UNHCR collect geospatial data which helps fulfill each of their particular goals. These maps are also shared with the International community and are made available through their respective websites. For example, the FAO contains an abundant amount of maps regarding land cover, soils, agriculture while the UNHCR (UN High Commissioner for Refugees) keeps maps of displaced populations as well as refugee camps sites worldwide. Readers interested in learning more about geodata sources can visit the UNGIWG's (UN Geographic Information Working Group) website which is a voluntary network of UN GIS and surveying specialist working on common goals such as international data standardization as well as building extensive geodata sets.

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strengths and areas that have been overlooked as well as help guide future research in this field.

Background

The most recent literature review covering different models and technologies that have been employed by researchers in the area of humanitarian emergencies is that by Ozdamar and Ertem (2015). Their study focuses on the area of humanitarian logistics and therefore the majority of the article focuses on network analysis, inventories and transportation models and techniques. The authors also acknowledge GIS as an important tool in humanitarian logistics and briefly describe how different studies have employed various geospatial technologies in humanitarian settings. However, because of the wide scope in different models, methodologies and technologies the authors regret not being able to cover all articles and aspects and therefore dedicate only a short section on geospatial information. Their concluding statements stress the importance of cross collaboration, a major challenge due to the number of different organizations and stakeholders that may be involved, through geocollaborative web networks and open source software. The authors also indicate that despite the wide availability of technologies and models the higher cost of the former and the computational complexities of the latter may create a gap between academics and humanitarian practitioners pointing out the need for mathematical models to be integrated into GI Systems in a user-friendly manner.

This echoes the concern of Cutter (2003) where she stresses that the geographic information community must be fully aware of the challenges that the practitioner community face on the ground. Some of these challenges includes the preference of paper maps over digital maps by some of the practitioners due to lack of formal training in geographic information systems as well as being able to understand complex spatial information. Therefore, she notes that the GI science community should make the application of such technologies as usable and applicable as possible which can only be achieved by taking a bottom up rather than a top down approach which is the route taken by many non-practitioner academics.

Three studies are of particular importance to better help us understand the possible tasks and uses of GIS in humanitarian assistance operations. These include those by Kaiser (2003), Verjee (2005), and Seppanen and Virrantaus (2010). The three studies were conducted from the perspectives and backgrounds of different disciplines therefore creating a broad spectrum of differently defined GIS applications and tasks as well as different terminologies for these. For example, Kaiser's study focuses on humanitarian assistance and epidemiology and describes the different ways in which GIS can enhance traditional epidemiologic methods. The main GIS tasks defined in the study includes: Rapid Assessment, Hazard, vulnerability and risk assessment, survey methods, investigating disease outbreaks, establishing health information systems, integrating data and programmes, and monitoring and evaluation. On the other hand, Verjee's study focuses on the applications of satellite imagery and GPS technologies in humanitarian emergencies providing a rich background as to how these technologies have evolved over time and through non- profit organizations as well as the UN for the use in humanitarian emergencies. Furthermore, the study provides useful lists, links and contact information to different satellite and GPS providers, space agencies and data sources. At the end of the paper the Verjee summarizes the main GIS applications in humanitarian emergencies as follows: Cartography, Humanitarian intelligence, crisis simulation, vulnerability assessment, risk reduction, organizational management, engineering and environmental planning, and media/ communications. Finally, Seppanen's and Virrantaus's study focuses on

the applications of GIS in crisis management. The study illustrates how such applications have been used in a handful of case studies providing a detailed outline of the importance of such applications through different stages of a disaster which includes: mitigation, preparation, response, and recovery. The applications defined in the study includes: presentation of information, probability based risk assessment, impact models, vulnerability and total consequences, and decision making support.

In order to successfully define the scope of this study we must first carefully define what is meant by humanitarian assistance as well as emergency relief. The simplest, yet effective way to begin is by using definitions found in Relief Web's humanitarian glossary which compiles key humanitarian used terms from various UN organizations. Emergency relief is defined as

“the immediate survival assistance to the victims of crisis and violent conflict. Most relief operations are initiated on short notice and have a short implementation period (project objectives are generally completed within a year) (UNCHR).”

Emergency relief is also characterized by the affected community not being able to manage on its own the effects of the disaster therefore requiring outside intervention. These activities can range from administering food and clothing to providing shelter and sanitation needs, usually in compliance with the standards as outline in The Sphere Handbook (Sphere 2018). On the other hand, humanitarian assistance is defined as:

“Aid that seeks to save lives and alleviate suffering of a crisis affected population [...] In addition, the UN seeks to provide humanitarian assistance with full respect for the sovereignty of States. Assistance may be divided into three categories - direct assistance, indirect assistance and infrastructure support - which have diminishing degrees of contact with the affected population. (OCHA).”

The first part of this definition is highly in accordance to that of the IFRCRC (International Federation of Red Cross and Red Crescent Societies), the largest humanitarian organization worldwide, which in addition would include “improving living conditions through health and community care” as well. It is the second component of humanitarian assistance (indirect assistance) which makes identifying appropriate articles more challenging. For example, indirect assistance can be in the form of providing support for disaster management and mitigation activities which includes evacuation plans, environmental monitoring and engineering to developmental aid which may be in the form of financial assistance or by providing “external expertise” as in the case of sustainable development programs. In regards to disaster management and mitigation (potential indirect forms of assistance) there is quite an abundant amount of research incorporating the use of GIS for such tasks. There is no reason why the GIS methodologies and applications from disaster and emergency management cannot be applied in humanitarian settings such as to help increase disaster preparedness or to conduct environmental risk assessments, for example. Therefore, unless other component of humanitarian assistance are clearly found in these studies we will not include emergency management and disaster management articles. This exclusion of literature, which must be done to maintain a direct humanitarian assistance approach, does not compromise the scope of this study. This is because direct humanitarian assistance can include a broad spectrum from short term emergency relief projects to long term/ reconstruction through demining and health care operations which seek to alleviate human suffering as well as improving living conditions.

Defining Geographic Information Systems (GIS) is also not a straightforward task. This is because GIS has evolved over time since the 1950's through different governmental, private and academic sectors. Its users have varied enormously including: natural resource managers, water and sewer engineers, utility companies, as well as urban and transportation planners. Because of this GIS providers have modified their products in order to meet the diverse needs of its end users therefore creating a broad range of spatial analysis software each with its own strengths and weaknesses. We can begin to appreciate that the definition of GIS varies across different industries and depends on the context in which it is being used (Bernhardsen 2002). As Consley (2001) mentions, "many definitions of GIS have been suggested over the years, and none of them have been entirely satisfactory." We could define GIS according to the expected functional operations which includes: map overlay, polygon join, proximity join, buffer creations, spatial query capabilities as well as projection transformations. However, if we were to use such a structured definition we would fail to recognize the various organizations that are involved in the humanitarian sector along with their diverse need to solve distinct spatial problems. For this study we therefore adapt the common ground associated with all Geographic Information Systems, that is, a computerized tool for solving geographic problems.

Methods

For this meta-analysis the unit of analysis are published articles between 1990 to present where the author(s) incorporated the use of geo spatial techniques (GIS) as a support tool in a humanitarian setting. The articles were found using major databases including Academic Search Complete and Web of Science, as well as through backward citations, using the following keyword searches:

- Humanitarian Aid [OR] Assistance [AND] Geographic Information Systems [OR] GIS
- Disaster [OR] Emergency Relief [AND] Geographic Information System [OR] GIS

After identifying appropriate articles (a total of 26) thematic content analysis was conducted by critically reading through all of the articles and identifying the following categories within each of them: Task/Application used in study, Phase of Disaster, Purpose of Study, Context of Operation, Cause of Disaster, and Region of Study. Some of these themes have been used in previous meta-analysis concerning logistics in humanitarian settings while some are new. Task/Application used was developed after critically reading the relevant literature as well as all of the twenty-six identified articles. I propose the following typology summarizing the various geospatial tasks that can be performed in humanitarian settings:

- **Cartography and Humanitarian Intelligence:** Rapid Assessment, Presentation of information, visualization, land use, infrastructure and facility mapping, remote sensing for monitoring and evaluation.
- **Crisis Simulation and Impact Models:** Analyzing what if scenarios and consequences of disaster, incident modeling, forecasting.
- **Risk Assessment:** Identification of "hot spots," combination of vulnerability and hazard assessment to evaluate at risk populations.
- **Vulnerability Assessment:** The integration of socio-economic and environmental data to serve as an early warning alert.
- **Decision making support:** network and location analysis for resource allocation and optimization.

- **Surveying and Communications:** Citizen Participation and Crowd-sourcing, status reporting, program assessment.

Each of these different tasks have a greater importance in one phase of the disaster stage over the others. For example, risk assessment, impact models and vulnerability assessment have greater application in the preparation phase while surveying and communications as well as decision making support are of particular importance in the response phase. Engineering and environmental planning are activities commonly associated with the reconstruction phase of a disaster (a stage in disaster relief). However, it is important to note that such activities can also be found as a form of continuous aid which seeks to improve living conditions in a given region and serves as a form for sustainable development. This leads us to the creation of the following theme; Phase of Disaster which refers to the stage in which the operations conducted are found; preparation, response, or reconstruction. The preparation phase involves activities that are conducted prior to the event such as in the case of prepositioning supply warehouses or predetermining delivery routes. The response phase involves activities conducted immediately after the disaster which may include the distribution of aid or assessing caused damages. Finally, reconstruction refers to those activities conducted to allow the impacted region to be restored to normal living conditions such as through recovery monitoring or identifying where to build new residential areas.

Purpose of study, briefly outlines the goal of the study, information typically found in the abstracts of the articles. Context of operation, introduced by Kovacks and Spens (2007), refers to whether the setting of the study is disaster relief or continuous aid. Disaster relief are activities conducted prior, during or after a natural or man-made catastrophes and are usually short term. Continuous aid on the other hand refers to operations which are long term and can be associated with developmental programs such as those conducted by the FAO, health care programs conducted by the IFRC or even landmine clearings.

Cause of disaster, a category introduced by (Wassenhove 2006), can be either natural as in the case of hurricanes, earthquakes or floods while man-made disasters includes economics crises, war or famine. Previous studies have erroneously described famine as a natural, slow onset disaster. However, we should be aware that such catastrophes are many times human induced through economic, political or environmental actions Young (2012). The final theme identifies the region where the study was conducted and is of special importance to most articles which analyses case studies.

Findings

The following tables illustrate the findings for this study. In regards to different geospatial tasks eight of the twenty-six studies explored cartography and humanitarian intelligence, none conducted risk assessment, three carried out simulation and impact models, four conducted vulnerability assessments, six employed GIS for decision-making support, and four studies used GIS for surveying and communications.

Within cartography and humanitarian intelligence major concerns and objectives were to demonstrate how to successfully integrate various data sources for spatial analysis, how to manage geospatial data in humanitarian settings, and the ethical issues associated with the use of GIS and remote sensing technology.

Cartography and Humanitarian Intelligence	Goal / Purpose	Phase	Context of Operation	Cause of Disaster	Region
Benini, Aldo A., et al (2003)	How to successfully integrate various data sources to better understand humanitarian complexities. Illustrated through impacts of conflict on agriculture.	Rec.	Continuous Aid	Man-Made Landmines	Lebanon
Bhanumurthy, V., et al (2015)	Understanding how to manage geospatial data and data repositories for disaster management.	ATA	ATA	ATA	ATA
Enders, Alexandra, and Zachary Brandt (2007)	Geocoding and intergrating different datasets to better visualize the situation of shelters, housing and transportation for populations with dissabilities.	Prep.	Disaster Relief	Natural. Hurricane.	Louisiana, USA
Karen Payne, Patrick Florance & Stephen Shain (2012)	To better understand the role and classification of geospaital data repositories during humanitarian emergencies.	ATA	Disaster Relief	ATA	ATA
Marx, A., & Goward (2013)	Using remoste sensing technology to assess and monitor potential human rights violations.	Resp.	Continuous Aid	Man-Made. Conflict.	Bosnia, Sudan, Sri Lanka
Mather, C (2000)	Ethical issues of GIS technology in humanitarian demining integrating different knowldeges between developed and developing countries.	Rec.	Continuous Aid	Man-Made. Landmines.	Angola
Sheller, Mimi (2013)	The ethics of GIS & satellite intelligence and the immobility effects of humanitarian intervention.	Rec.	Continuous Aid	Natural. Earthquake.	Port Au Prince, Haiti
Shortland, Anja, et al (2013)	Using remote sensing light sensitivity analysis to measure the impacts of conflict on economic activity.	Rec.	Continuous Aid	Man-Made. Conflict.	Somalia

Risk assessment is a task usually associated with disaster and emergency management and it makes sense that no studies were identified which were predominantly for humanitarian assistance. However, being that vulnerability assessments give input to risk assessment there were many components of risk assessment found in various vulnerability studies (Sherly 2015, Kandeh 2015). In regards to crisis simulation and impact modeling this was the category in which some of the most burdensome methods were found (for example Crooks 2013). Researchers focusing on these tasks must take into account the real needs and constrains of humanitarian personnel on the ground as expressed by Cutter (2003) and Ozdamar and Ertem (2015). If such needs and constraints are not taken into account, it is here where the gap between practitioners and academics will continue to expand.

Crisis Simulation and Impact Models	Goal/ Purpose	Phase	Context of Operation	Cause of Disaster	Region
Bono, Flavio, and Eugenio Gutiérrez (2011)	Spatial network analysis of roads to determine accessibility and blocked areas due to damaged infrastructure.	Rec.	Disaster Relief	Natural. Earthquake.	Port Au Prince, Haiti
Crooks, Andrew T. and Sarah Wise (2013)	Predicting human behavior through agent based modeling after earthquake diminishes mobility.	Rec.	Disaster Relief	Natural. Earthquake.	Port Au Prince, Haiti
Elliott, James R. and Jeremy Pais (2010)	Studying the displacement effects and migration patterns of socially vulnerable populations after a disaster.	Rec.	Continuous Aid	Natural. Hurricane.	Louisiana, USA Miami, USA
Vulnerability Assessment	Goal/ Purpose	Phase	Context of Operation	Cause of Disaster	Region
Kandeh, Joseph and Lalit Kumar (2015)	Assessing social vulnerability ranking of at risk populations to humanitarian crisis using GIS.	ATA	Continuous Aid	Man-Made.	Yemen
Lue, Evan and John P. Wilson (2017)	To better understand the vulnerability of different social population segments in urban areas and the distribution of aid after wild life fires.	Prep.	Disaster Relief	Natural. Wild Fires.	Los Angeles, California- USA
Sherly, Mazhuvanchery Avarachen, et al (2015)	Utilizing social economic data to quantify vulnerability of densely populated urban regions.	Prep.	Disaster Relief	Natural. Various.	Mumbai, India.
Taylor, O., & Slaymaker, O. (2005)	Integration of environmental and socio economic data to identify region susceptibility to disasters.	Rec.	ATA	Man-Made. Conflict.	Cambodia
Decision making support	Goal/ Purpose	Phase	Context of Operation	Cause of Disaster	Region
Ahmadi, Morteza, et al (2015)	Optimizing number and location of local depots as well as forecasting relief demanded after a disaster using network analysis and vehicle routing models.	Prep.	Disaster Relief	Natural. Earthquake.	San Francisco, California- USA
Chen, Zhifen, et al (2013)	Determining shelter locations while considering the changing needs of the population from immediate shelters to permanent housing.	Rec.	Continuous Aid	Natural. Earthquake.	Beijing, China.
Esmaelian, Majid, et al. (2015)	Location optimization of shelters considering urban zones with higher vulnerability.	Prep.	Disaster Relief	Natural. Earthquake.	Tehran, Iran
Horner, Mark W. and Joni A. Downs (2010)	Locations optimization to decrease average distance between relief recipients and distribution centers.	Resp.	Disaster Relief	Natural. Hurricane.	Leon County, FL, USA
Rodríguez-Espíndola, Oscar, et al (2016)	Location optimization of shelters considering flood hazard risks highlighting the importance of combining facilities and environmental factors using GIS.	Resp.	Disaster Relief	Natural. Hurricane.	Iabasco, Mexico. Veracruz, Mexico.
Zhao, Ming and Xiang Liu (2018)	Developing a userfriendly model for location optimization of emergency shelters.	Prep.	Disaster Relief	Natural. Various.	Northern China.
Surveying and Communications	Goal/ Purpose	Phase	Context of Operation	Cause of Disaster	Region
Eklund, L., & Mårtensson, U. (2012)	Quantifying accessibility of vulnerable populations to health care services taking into account geopolitical blockades, checkpoints and road closures incorporating survey data.	Rec.	Continuous Aid	Man-Made. Conflict.	Israel
Kusumo (2016)	Using crowdsourcing data from social media to better plan and determine location of evacuation shelters	Prep.	Disaster Relief	Natural. Flooding	Jakarta, Indonesia.
Porto de Albuquerque, João, et al (2016)	To determine the different tasks that can be performed using crowd sourcing for humanitarian mapping.	ATA	ATA	ATA	ATA
Tunçalp, Özge, et al (2015)	Analysing vulnerable population's access to health care services in post conflict disaster setting by surveying healthcare facilities.	Rec.	Continuous Aid	Man-Made. Conflict	Mali
Williams, Craig and Christine E Dunn	Participatory surveying with local populations to assess the risks and effects of landmines.	Rec.	Continuous Aid	Man-Made. Conflict.	North Western Cambodia.
Prep , Preparation; Resp , Response; Rec , Reconstruction; ATA , Applies To All					

It is interesting to note that all four of the vulnerability assessment studies incorporated the use of socio-economic data highlighting the importance and need for such type of data. In regards to decision-making support, we find that the majority of the studies incorporated GIS for location optimization. As Rodríguez-Espíndola, Oscar, et al (2016) point out, it is imperative that humanitarian agencies use GIS for location analysis being that it is a tool capable of integrating various data sources. For example, flood mapping and facilities layers can be analyzed simultaneously in order to prevent high costly errors such as locating shelters in flood prone regions.



While humanitarian logistics research is more concerned with preparation and response stages of disaster relief, we see that humanitarian geospatial research is a vital tool in the reconstruction phase (47% of all studies) as well as in exploring continuous aid settings (43% of all studies). In regards to cause of disaster 35% of all studies explored man-made disasters while 54% explored natural disasters. Figure 1. can help us visualize what types of disasters are being studied and where. As we can see most humanitarian research caused by natural disasters incorporating GIS is being conducted in the Americas and parts of South East Asia while most Man-Made disasters are being studied in Africa and parts of the Middle East as well which is an unfortunate observation.

Conclusion

This meta-analysis hopes to have revealed the broad range of tasks and challenges that can be accomplished using geographic information systems in humanitarian settings, from quantifying access to health care services by rural populations in Israel to using crowdsourcing data from social media to optimize the location of shelters in Indonesia. This study also hopes to serve as a valuable guide for future research in the field of geospatial information and humanitarian assistance. It is interesting to note that while previous meta-analysis on humanitarian logistics have analyzed over 150 articles (Kovács 2007, Kunz and Reiner, (2012) and while there exists

an abundance of studies incorporating GIS for environmental and disaster management, we see that humanitarian aid research incorporating the use of geographic information systems has relatively been neglected by the academic community. Furthermore, the earliest article found using GIS exclusively in the area of humanitarian aid is that by Mather, C (2000). This shows the relatively recent interest by the academic community which may be attributed to greater computational power and software accessibility in recent decades. As Verjee points out “there still remains a remarkable lack of doctrine in how to properly exploit geographic information during humanitarian emergencies.” Furthermore, no geospatial vulnerability assessment studies were found to have been conducted in Africa which stresses the need for reliable socio-economic data in such region. Multiple studies unfortunately predict natural and man-made disasters are likely to increase over the next 50 years and without greater interest by the academic community this may result in a shortage of properly trained personnel capable of fully utilizing geospatial techniques in humanitarian settings. As Bernhardsen (2002) notes that “we should hope that based on our awareness of GIS’s roots and capabilities, we can be realistic about our potential to foresee (model) and forestall (manage) human affairs on a global basis.”

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