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Urban Disaster Monitoring and Management based on Remote Sensing and GIS Methods

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ABSTRACT Disasters, whether natural or man induced have increased during the last decades in frequency all over the globe threatening a huge population within varied backgrounds. Over the years, remote sensing technologies have been functional in various disasters such as droughts, earthquakes, tsunamis, cyclones, etc. Its large area coverage capacity and observation repeatability makes its application cost effective. This paper tries to give the fundamental contributions and role of geographic information systems and remote sensing in disaster management applications. As an overview, it examines some recent practical application in disaster events. It also tries to look at some measurement characteristics and systems that have been applied to some disaster events within the disaster management framework and technologies. These various techniques and roles of remote sensing and geographic information systems in urban disaster monitoring and controlling, extends to disaster risk management using some sensors and satellites of emerging technologies. This discussion summarises in a single paper some of the many current techniques remote sensing and GIS employ in urban disaster management. Lessons from events can be drawn and implemented in similar scenarios to save lives and property.

Keywords: *Natural disasters; Satellite and Sensors; Disaster Risk Management; Disaster Preparedness; Systems; Urban Disaster sustainability*

INTRODUCTION

A hazard has been defined as a dangerous phenomenon that cause loss to life, damage to property and environment [1]. By this, the implied basis is the phenomenon or activity having occurred.

In this paper, a contextual definition is taken as any source of potential, unpredictable, unanalyzable and dangerous agent force that can cause damage to life, property, or the environment. When this occurrence happens suddenly, is calamitous, leading to loss of property and/or life, it is then classified as a disaster. In other words, when a hazard that is unprepared-for happens, it can be termed as a disaster. A most famous definition is "A serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses which exceed the ability of the affected community or society to cope using its own resources" [2].

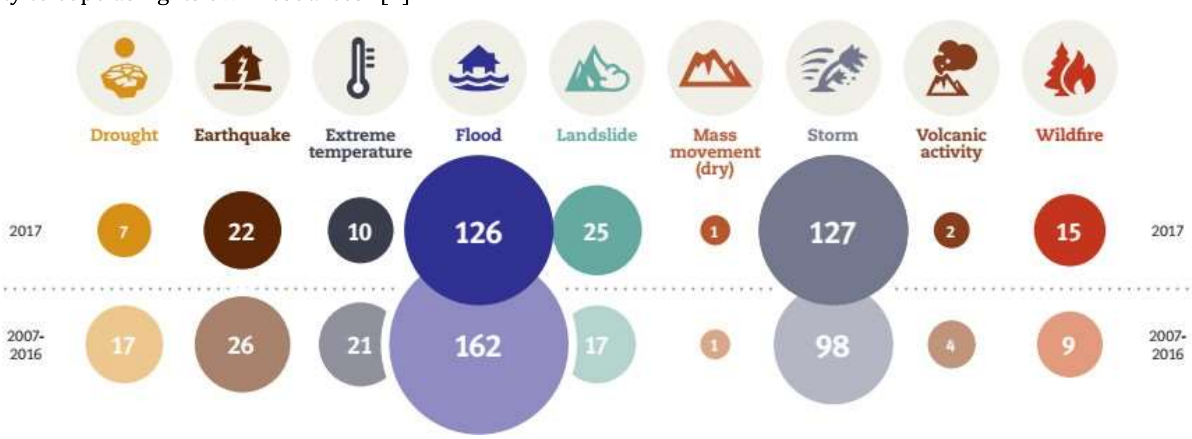

Figure 1. Reported Occurrence by disaster type: 2017 compared to 2007-2016. Source: [3]

Again, [1] elaborated to include a disruption of society causing pervasive economic or environmental, material, human losses which surpass the ability of the affected society to survive with its own resources. As complex as it is, defining a disaster can result in some great frustration, since broadly a disaster in its sense is linked to the vulnerability of the affected to deal with the cause. Natural disasters *mostly* result in significant losses of infrastructure, environmental, and terrible loss of lives [4]. Shown in Figure.1, is the trend of reported cases from the last century, and it is rising.

The economic loss of disasters all over the world runs into billions of US dollars. Between 1998 and 2017 alone, US$ 2,908 billion is reported as the economic loss of disasters. Those that were climate related amounted to US$ 2,245 billion, about 77%. In all, reported weather related losses rose by 151% over the two decades [5]. Due to the high economic cost(loss) of disasters, a lot more researchers are spending valuable time to do studies in the area, all in the quest to find solutions to the varied array of damages, loss and cost from these natural disasters. According to [6], by March 2019 there were over 1,900 related published research works on disasters alone (Figures. 2 - 4). These are multi- facetted. In a study on over 48 countries, it was revealed that nations' ratings can be affected as much as 1 point if there is a 50% insured damages [7].

Using geospatial information, officials can pinpoint hazards and evaluate the risk and consequences of potential emergencies or disasters [8]. Using satellite imagery is cheaper and faster to deal with hazards and disasters [9], in that maps can be produced easily on large scale and for wide areas at different resolutions [8], as opposed to other traditional forms of gathering information. Due to ease of availability, it comes in handy when there is an emergency, like in natural disaster scenarios of earthquakes, forest fires, landslides and flooding. Its consistency makes it important to detect even the slightest change over a period, most efficient and mostly appropriate where it is difficult or impossible to access the disaster site/area.

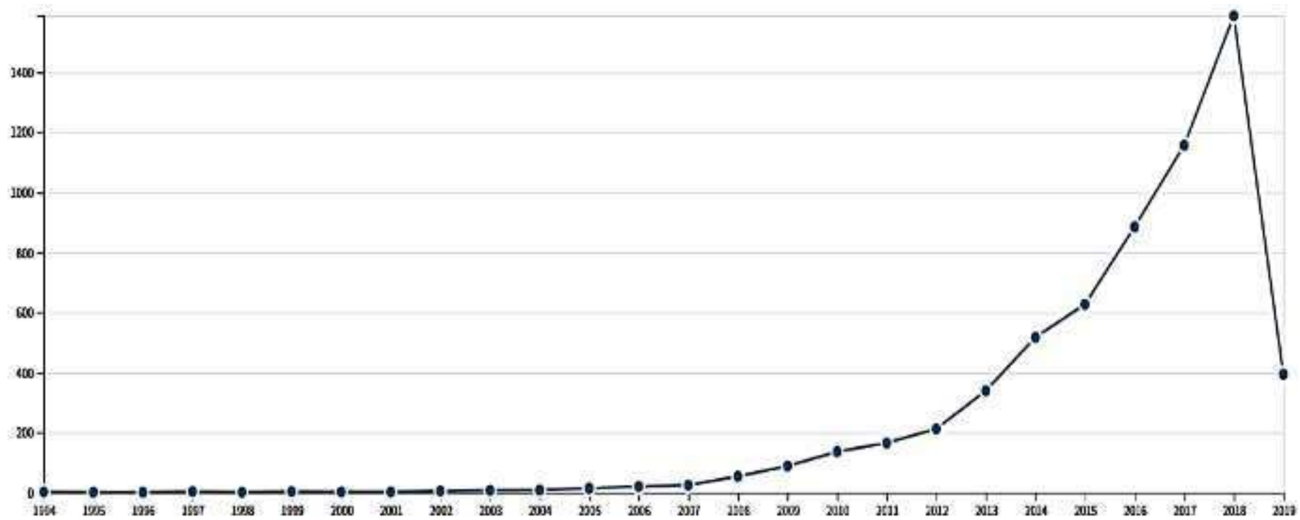

Figure 3. Number of Research Publications Related to Urban Disasters since 1994. Source: [6]

Although the full potential of remote sensing to natural disasters had not been exploited in the early 1990 [11,12], now its application can be found in almost all disaster related issues. It has been applied in landslide and land degradation [13-16], flood related [19-25], earthquakes [28-30], wildfires [31,32], and General Disaster Management [20].

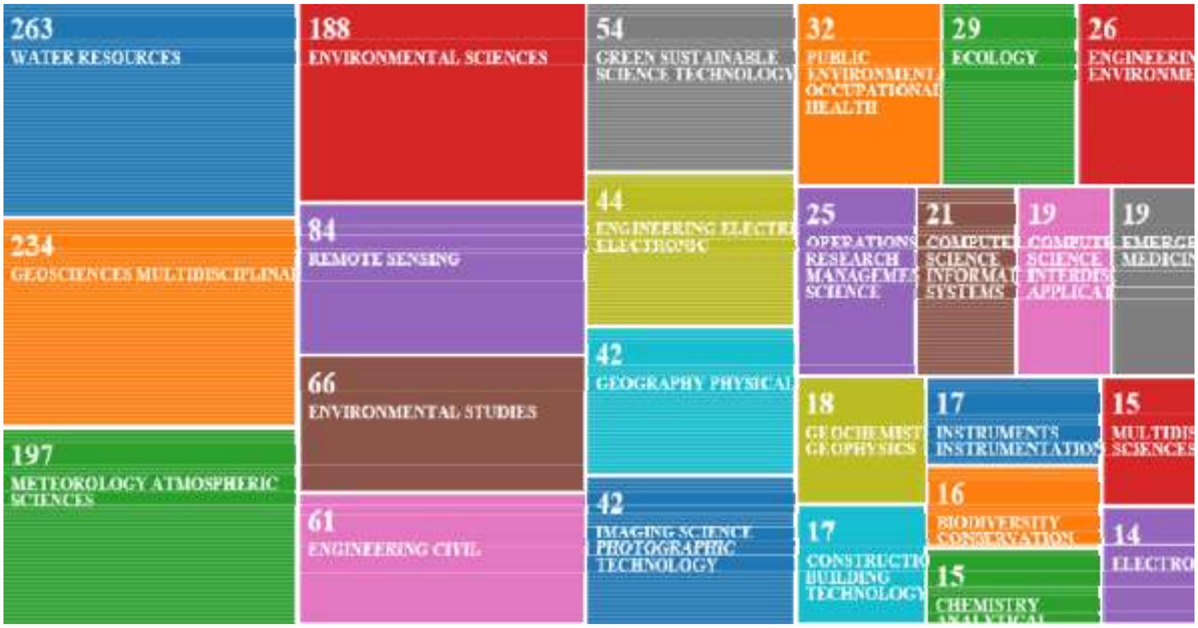

Figure 4. Number of Research Studies in various fields related to Disasters. Source: [6]

1.1 Subsection Types/ Kinds of Disasters

The most extensively accepted forms of disasters are extreme weather related – floods, hurricanes/cyclones, tornadoes, earthquakes, volcanic eruptions, tsunamis avalanches, droughts/famine and blizzards. This list is not exhaustive though. All these are classified by their cause, either natural or man-made. When it comes to natural hazards, there is always the possibility of occurrence in a specific time period at a specific location which has a given intensity [1]. The impacts of disaster can still be seen even after alleviating the instant impact of occurrence. Hence relief activities that are poorly planned always have very dire consequences on the victims [21]. By 2018 the death toll of these disasters had risen to 10,733 with those affected running into millions [3]. Figure 5 is an infographic of deaths by reported disaster types in 2018.

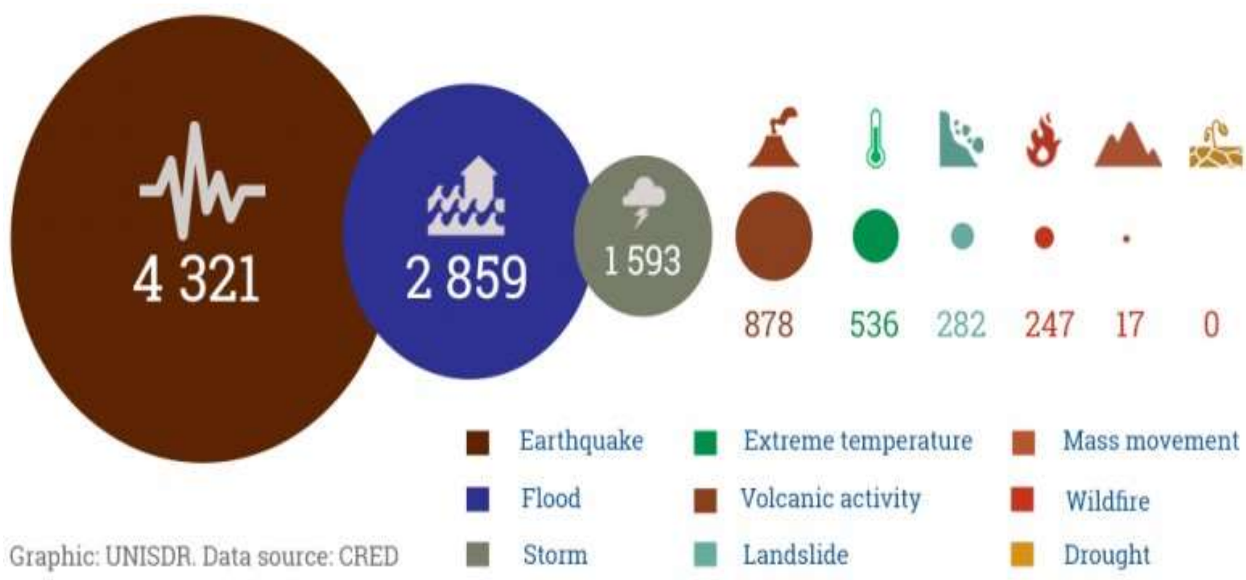

Figure 5. Number of deaths per disaster type 2018 Source: [22]

1.2 Urban Disasters

As complex as the definition of what an 'urban area' is [23], it is easier to use urbanization [24] characteristics to define or explain the concepts of 'urbanism'. Sometimes, the physical expanse can be used [25] in this context to propagate these concepts properly. The area of urban region also presents a unique outer boundary characteristic between it and its environs where there is a drop in rate of human activity flows and movements [26]. In all of these, now, infrastructure and population are two important indicators for describing what an urban area is. Disasters occurring within these settings are mostly classified as 'Urban Disaster' although this definition can be challenging [27]. Impacts are almost always great sometimes due to high population density and inadvertent growths. By 2008, the urban population had begun to overturn the rural population (Figure. 6), which meant the world's population balance tilted to the urban centers. By 2030 this number is expected to balloon to nearly 5 billion (Figure. 7). Coupled with the population concentration, the interplay between technological systems, buildings and people make urban areas particularly vulnerable [28].

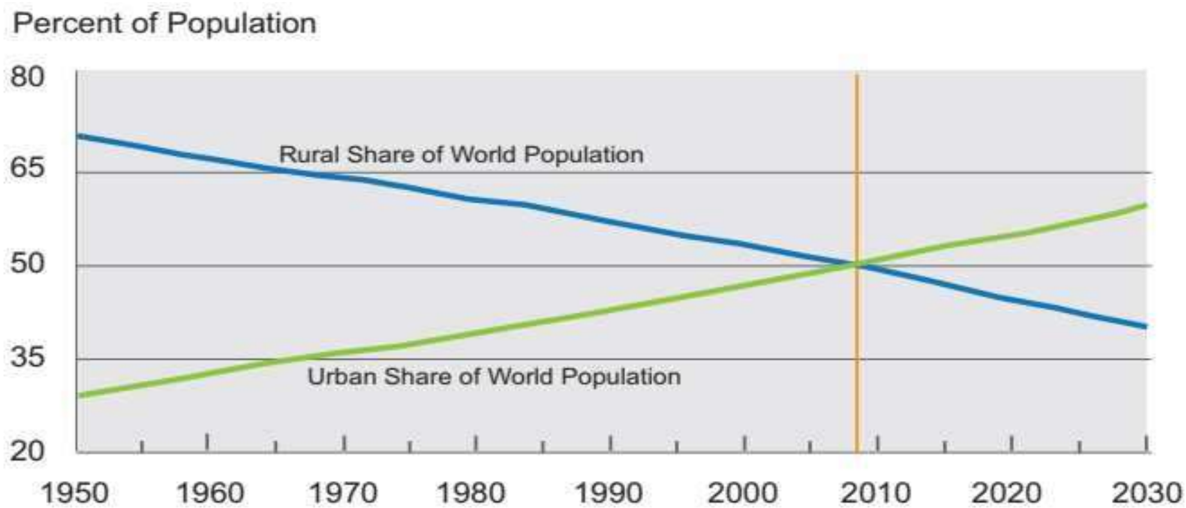

Figure 6. World Rural vs. Urban dwellers. Source: [29]

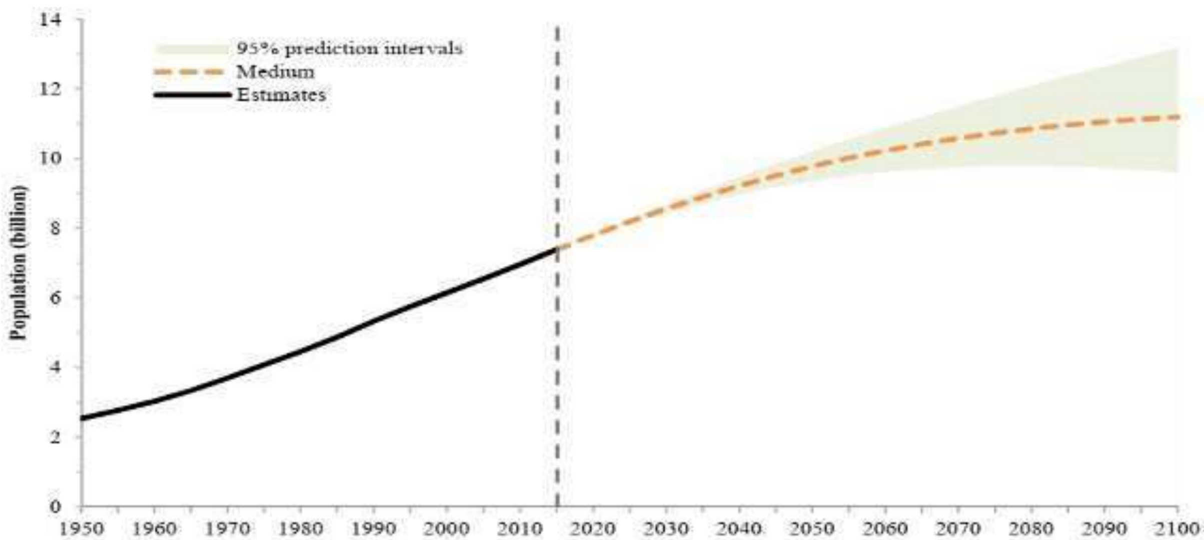

Figure 7. Population of the world: estimates, 1950-2015, and medium-variant projection with 95 per cent prediction intervals, 2015-2100. Source: [30]

2. Methodology

Here, the discussion is intended to examine some of the applications of Geographic Information Systems (GISs) and Remote Sensing (RS) to Urban Disaster (UD). It will also look at some practical application of these techniques to some urban disaster occurrences. Secondary data were collected from journal articles, books, institutional reports, online publications and other relevant documents which were all employed in the discussion process. The information from this studies will provide a great understanding of RS and GIS tools available on different scales to manage high risk areas in disasters [4]. It can mainly help in predicting, monitoring and management of urban disasters (after disaster application).

3. Results Remote Sensing Methods and GIS Techniques

Time-critical information using technology can have great effect on disaster management to aid in the delivery of critical decision during disaster. Traditionally, manual maps are lacking in effectiveness with labour, time used, updating and maintenance. In this regard remote sensing is very effective since maps are prepared, digitized and stored within a GIS environment. Imagery from satellite and aerial photographs, with high resolution in spatial and temporal characteristics, can be used for forest fire detection, flood monitoring, assess and analyse disaster damage situations. Disaster mapping shows danger and impact zones. Digital Elevation Model (DEM) in geo-environmental studies usually provide a base thematic application for production of different maps. These layers can be put in a GIS database for disaster planning, where disaster hit areas can be drawn and the excessive damage to life and infrastructures assessed.

Visual and spatial information are very critical when disaster strikes especially during the initial stage. In context, the application of this technology is better understood when the effects of its practical lack or application is highlighted. A few scenarios have been outlined by [20]. For example, during the 1992 Hurricane Andrew disaster, authorities were unable to deploy resources because it was unable to do a near- real time assessment. Again, damage assessment and recovery of the World Trade Center assault proved the need for remote sensing technologies. Geospatial Information has become a great tool in identifying hazards and even for risk assessment, which values is efficiently exhibited in the utilization of a GIS database or a database that is accessible to a GIS platform.

In a paper by [31], Unmanned Aerial Vehicle (UAV) was used to map the terrain through its stereo vision facility. This has a main advantage over the monocular structure-from-motion, in that, it can reconstruct the terrain from a single synchronization. UAV has been employed in forest fire studies [32], even at real time [33]. The benefits of an emerging technology, Light Detection and Ranging (LiDAR) is making the study of flood related issues very easy with high accuracy. Its 10 cm topographic height data can be exploited to produce the necessary DEM for flood extent prediction, flood risk maps and for hydrological spatial analysis [8]. In recent times the use of visual sensing has been combined with hydrological monitoring cameras to enable the sensing and analysis of local flood events [34]. The advantage here is the provision of spatiotemporal information for use in the automation of remote analysis and monitoring. Interferometric SAR (InSAR) technology has been applied to earthquake studies to detect and assess the extent of damage. Specifically, [35] applied it to detect the damage of the Great Taiwan Earthquake also known as Chi-Chi Earthquake.

3.1 In Predicting

In an urban flood prediction study, [36] combined Landsat and MODIS imagery to do both pre-flooding and post- flooding prediction in a real time. Two data fusion models; Spatial and Temporal Adaptive Reflectance Fusion Model (STARFM) and Enhanced Spatial and Temporal Adaptive Reflectance Fusion Model (ESTARFM), were applied in making the inundation map. In another study, a pre-flood inundation mapping employed quantitative precipitation forecast on Geostationary Meteorological Satellite (GMS) and Advanced Very High Resolution Radiometer (AVHRR) data sets, to generate early warning map [37]. They found the QPF to be accurate with only slight deviation from the actual rainfall values. In a landslide application, a change detection approach was applied to IKINOS images to do an inventories of these occurrences [9], in evaluating the feasibility of replacing satellite imagery for aerial photographs in landslide catalogue.

3.2 In Monitoring

Most monitoring studies usually are based on land-use and land-cover change on the study area over a long period (based on available data). Land use planning studies involving RS and GIS techniques is valuable in many applications. For example, [38] applied it to assess flood hazard using SAR data and GIS. The authors produced hazards map for flood counter-measures. A similar studies was done on Nepal by [39] using land-use and land-cover changes from historical Landsat imagery to map flood hazard. They argued that the frequency and intensity of flooding in Nepal increased due to poorly-planned urbanization and unsuitable land use, hence his study.

3.3 In Managing

Despite the challenges in suitability management due to climate changes [40], scientists and researchers have done remarkable studies in managing disaster. More of an administrative issue, this part of the remote sensing application is the utmost important since it deals with the warning, evacuation and susceptibility [41] facets of disaster impacts on victims. In the United Kingdom (UK), a comprehensive land-use inventory was adopted for landslide management in identifying risk locations [13]. A study on Hoshangabad District on earthquake planning and management in flood prone towns [42], looked at the organizational structure where a scrutiny was made on the existing damage assessment criteria. Disaster prone zones were mapped, and evaluation distinctively done. As shown (Figure. 8a and Figure. 8b), disaster management has a cyclical connectivity between before-disaster stage (preparedness), during-disaster stage (response) and after-disaster stage (recovery). How interwoven these may seem; their sub-division stages help to break down the needed action at each stage.

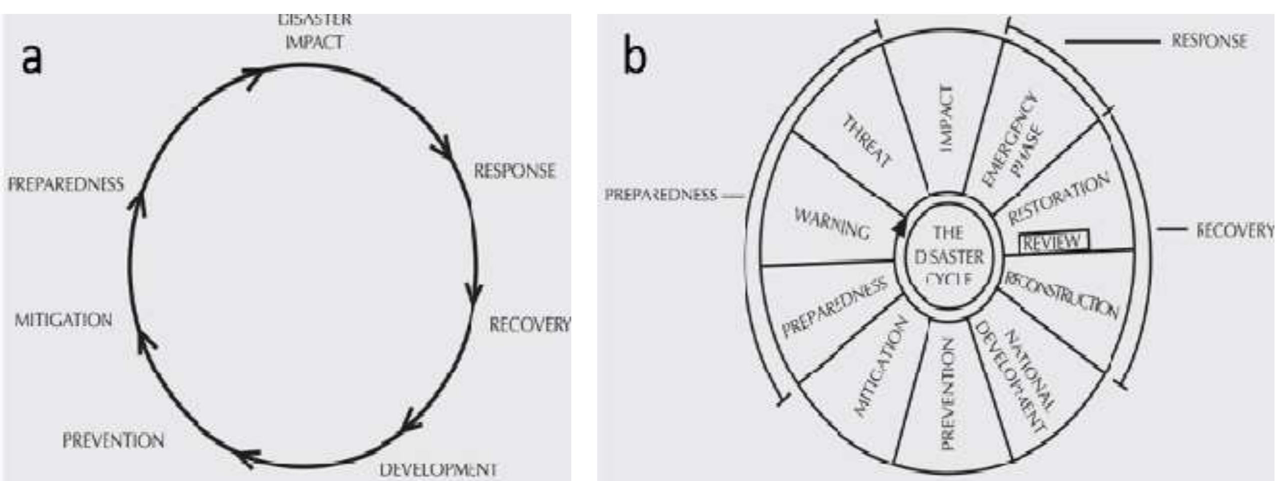

Figure 8. a) Basic Format of the Disaster Management Cycle; b) Alternative Format of the Disaster Management Cycle. Source: [43]

4. Types of Satellite Data Used

Various remote sensors are available, mostly classified as passive and active sensors. Important characteristics such as spectral bands, spatial resolution and coverage as well as temporal resolution, all influence the choice of a sensor or satellite in disaster management applications [44]. High resolution and more expensive sensors, although has the capacity to show refined earth phenomena, are restricted to only small surface area coverage. Hyperion, AVIRIS, IKONOS, and SPOT-5 are examples of such sensors [44]. In applying these, it is important to consider certain factors such as mapping scale, time of image acquisition and the spectral characteristics of the sensors when selecting indicators.

4.1 Satellite sensors

The type of disaster largely determines the kind of satellite imagery or sensors that is effectively applied to the management of the disaster. Table 1 highlights some sensors and their characteristic applications in disaster studies.

Table 1. Some Satellites and Sensors Used in Disaster Management

Disaster Type	Sensor/ Satellite	Spatial Resolution	Applications
Earthquakes	PALSAR, IKONOS 2, InSAR, SPOT, IRS	10m, 30m, 100m; 3.2m; 20m; 2.5-5m; 36m, 72.5m	Hazard mapping, damage assessment, rescue planning routes, rehabilitation sites, etc.
Cyclones	KALPANA-1, radar, INSAT-3A, QuikScat, Meteosat	2km; 10-60m; 1-8km; 25km; 1km	Risk modelling, vulnerability analysis, impact assessment, spatial planning
Floods	AMSR-E, KALPANA I, Tropical Rainfall Monitoring Mission	25km; 2km; 4-5km; 250m	Flood detection, early warning, flood mapping, damage assessment, spatial planning
Landslides	PALSAR, IKONOS 2, IRS, SPOT, InSAR	10m, 30m, 100m; 3.2m; 36m, 72.5m; 2.5-5m; 20m	Rainfall monitoring, risk modelling, DEM models, damage assessment, hazard mapping, slope stability
Volcano	MODIS, Hyperion AVHRR,	250m-1km; 30m; 1.1-4km	Damage assessment, DEM, risk modelling, hazard mapping, emissions monitoring, spatial planning
Drought	FEWS NET, AVHRR, MODIS, SPOT	250m-5km; 1.1-4km; 250m-1km; 2.5-5m	Weather forecasting, vegetation monitoring, land and water management, risk modelling, vulnerability, damage assessment, drought mitigation
Fire	MODIS, SERVIR, AFIS, Sentinel Asia	250m-1km; 30m; 5km; 10-60m	Fire detection and prediction, damage assessment, risk modelling, fuel load monitoring, firefighting efforts,

Adopted from **World Agency of Planetary Monitoring and Earthquake Risk Reduction** (WAPMERR)
Aside the flexibility of Global Navigation and Earth Observation Satellites (EOS) in the applications of disaster alerting, weather forecasting, flood monitoring, vehicle tracking, desertification monitoring, forest fire, oil spill detection and damage assessment of crop and forestry, emerging disaster technologies are on the rise; communication satellites, satellite-based navigation, meteorological and EOS [45]. Now, current trends indicate a global approach to monitoring and setting up early warning systems. For instance, the Global Disaster Alert and Coordination System (GDACS), a collaboration between United Nations and European Commission, allows for information harmonization and exchange to improve and manage worldwide alerts in real time [46].

5. Remote Sensing Disaster Management

Over 100 disaster management models exists from Causative models, Logical models, Integrated models, Combinatorial models, etc., [47]. Integrated and logical models deal with pre-disaster phase, learning stage, response stage, rehabilitation or reconstruction stage, preparation and resilience, monitoring and assessment, vulnerability modelling and damage assessment [49-52]. Causative models as applied by [50] are concerned mostly with precautionary measures and action plan development which has been comprehensively dealt with in [51]. The combinational models usually integrate the above mentioned models. Risk reduction and management are the central focus of such models [52]. A list of disaster management models has been discussed by [47].

5.1 Preparedness Assessment

The main focus here is the geospatial technology in strengthening disaster management mechanisms [8]. As espoused by [53], it involves the overall level of mitigation and response activities along with their timely implementation. In a community based approach, [54] argues out the strengthening the coping and adaptive abilities within the smaller communities where the disaster impacts are great [55]. It is possible to incorporate GIS and Remote Sensing in organizing paramedics, medical support and logistics for rescue. Precision of results is very critical as any error in mapping fatality zones can lead to more deaths and damage. A higher accuracy in urban flooding mapping was achieved by [56] using a generalised regression neural network-based super-resolution algorithm, both quantitatively and visually. That study adds to efforts at prevention and disaster management. The linkage between mitigation measures and risk preparedness has been considered in context to actual events by [57] on China typhoon event, in the Philippines by [58] and on residents' awareness in Japan typhoon [59].

5.2 Emerging Technologies and Actions

Globally, collaboration between research establishments and governments ensures disaster risk mitigation, preparedness, response, relief, recovery and reconstruction, are significantly improved [45]. These partnerships are leading to the emergence of systems of systems architecture of an integrated web-based service that combines under one umbrella, critical disaster information systems [46]. GDACS is made of a Web-based alert notification, emergency managers and emergency operation centres capable of an information exchange between the disaster systems. It was successfully applied to the 2009 pacific Typhoons, 2008 Wenchuan earthquake, [46]. Other example of application is the cyclone Aila which hit Bangladesh in 2009. Satellite was able to give very early warning.

Another argument lies with minimizing the losses of both life and property by improving the preparedness systems and

information technologies in the various operational stagesup to visualizing geospatial data [60]. The successes achieved by the Joint Board Geospatial Information Societies (JBGIS) and the United Nations Office of Outer Space Affairs (OOSA) as well as the United Nations Space-based information for Disaster Management and Emergency Response (UN-SPIDER), give attestation to the benefit in applying geoinformation to disaster managing [60]. Using example from Istanbul [61] argued that crisis preparedness plan is highly augmented by the use of remotely sensed data in the GIS environment, where quick and reliable data can be acquired by employing photogrammetry, remote sensing, and spatial information science.

In this context, coupled with increasing weather related disasters, the narrative has been the usage of free data and free software components like the Humanitarian OpenStreetMap Team to collect added data for the affected area [62]. This approach and suggestion can be utilized in the meantime by developing countries with no Spatial Infrastructure. The three level risk management stages include Crisis Preparedness Plan, Early Warning System, and Rescue and Management Action [61], which strong case is made for an inventory of all structures and their risk potential, thus a good database is the most significant criteria for any success in the management of disasters.

A typical example of improved disaster risk management and the importance of collaborative approach is argued outin [63], in which the events of Nepal where non implementation of preparedness measures raised the levelof death tolls, contrast the lower situations of Japan, California and Chile, where these methods had been implemented. In a comprehensive review by some top guns in sustainable cities and disaster management [64], various disaster events on the various continents were analysed within the framework of the well-being of disaster management and risk reduction systems, technologies and implementation gaps that helped to reduce the impacts on one hand, and in some jurisdictions, their lack escalated the impacts of these disasters.

6. Conclusions

Remote sensing and GIS provide satellite data and aerial photos that is used for a database of information for disaster. This allow for hazard maps from terrain properties in space and time. Satellite images offer a synoptic view over very large coverage at varied scales and these are used for early disaster detection. This information is available at recurrently short interval. This enable the monitoring capacity of remote sensing and GIS technologies. The speed with which these platforms provide information, makes satellite a unique advantageous tool for planning, hazard zoning, warning systems, relief phase, impact assessment and rehabilitation stage. Global collaboration systems are even a better approach at providing timely information alert to countries, to reduce disaster impacts. Preparedness measures implemented to the maximum capacity will go a long at dealing with impacts. The use of free data and software has been argued to help countries with Spatial Data Infrastructure deficit. It is inevitable for hazards to occur, however the use of RS and GIS technologies can play an important role in reducing the impacts and the development of methods in mitigation and preparedness.

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