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Application of Remote Sensing and Geographical Information Systems in Flood Management: A Review

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Abstract: Floods are one of the most widely distributed hazards around the world and their management is an important issue of concern among all the stakeholders. The aim of this review is to synthesize the state of art literature in the application of Geographical Information Systems (GIS) and Remote Sensing (RS) techniques in all the flood management stages (pre-flood, during flood and post-flood stages). Flood types and common concepts in flood management are precisely explained. Case studies of flood management using GIS and RS are summarized. Current challenges in using GIS and RS techniques for flood management are also given. One lesson we learn from this review is that flood management is very diverse and it requires multidisciplinary involvement. It can also be deduced that RS techniques offer cheaper and faster options of accessing spatial data about the flood event even in the physically inaccessible areas. GIS techniques on the other hand facilitate hydrological models in data collection, analysis, querying and presentation of information in a more simplified format. The present review is expected to contribute to an improved understanding of the potential applications of RS and GIS techniques in flood management, especially among scientists in the developing countries where the use of these techniques particularly in flood management has generally been limited.

Keywords: Floods, GIS, hazards, remote sensing, spatial data

INTRODUCTION

Floods stand out to be the most frequent and devastating natural disaster around the world (Berz *et al.*, 2001; ISDR, 2004; Sanyal and Lu, 2004), affecting an average of 99 million people per year between 2000 and 2008 (WHO, 2010). According to Jonkman (2005), floods alone killed 100,000 persons and affected 1.4 billion people in the last decade of the 20th century. The frequency and the intensity of floods in recent years (EM-DAT, 2006) have raised a lot of questions as to whether it is linked to anthropogenic activities. Several studies (Milly *et al.*, 2002; Bronstert, 2003; Christensen and Christensen, 2003) indicate that land use changes could be behind the recent frequent and erratic floods. While other studies (IPCC, 2001; WHO, 2010) link the flood problem with climate variability and climate change.

Flood problem has been reported almost everywhere in the world with much more pronounced effects in the developing countries (Alcantara-Ayala, 2002; ISDR, 2004) due to their low incomes, poor housing facilities, inadequate warning systems and preparedness generally grouped by Alcantara-Ayala (2002) as social, economic, political and cultural vulnerabilities. Floods are associated with primary effects such as loss of lives and property, damage to infrastructures, eco-systems, cultural values, roads and bridges (Jonkman, 2005), secondary effects such as

outbreak of diseases as well as tertiary effects like loss of soil fertility, famine and poverty.

Like any other natural hazard, floods are difficult to control, but its impacts can be minimized and several attempts have been put in place to this regard. Advancements in computer knowledge, modelling, Remote Sensing (RS) and Geographical Information Systems (GIS) have particularly been handy in flood management. Through modelling coupled with RS and GIS use, floods can be predicted and the flood vulnerable as well as flood risk areas can be mapped out. This information is not only important to the policy makers but also to the public especially in the affected areas, in terms of providing early warnings, evacuation exercises and general preparedness. Post flood analyses can also be done using RS and GIS techniques and in this way an idea in terms of economic losses, infrastructural damages and costs of reconstruction can be computed. This partly explains why floods of the same magnitude cause more losses and damages in developing countries compared to developed countries who generally have well developed monitoring and early warning systems, strong infrastructures and buildings as well as elite population that makes sensitization and evacuation exercises rather easy.

Generally, flood disaster management involves four stages of prediction, preparation, prevention and mitigation and damage assessment (Konadu and Fosu, 2009). RS and GIS techniques have been reported to be

handy in all these stages. With the flood problem expected to escalate due to increasing climate variability and change (Berz *et al.*, 2001; IPCC, 2001; Milly *et al.*, 2002; Kundzewicz *et al.*, 2010; WHO, 2010) and increased land use change (Milly *et al.*, 2002), the ability to provide fast and accurate flood information is/will be critical in order to minimize flood associated damages. This review aims at exploring various ways in which RS and GIS techniques have been successfully utilized in flood management. The present review is expected to contribute to an improved understanding of the potential applications of RS and GIS techniques in flood management, especially among scientists in the developing countries where the use of these techniques particularly in flood management has generally been limited.

The review is presented in 4 sections; section 1 is introduction, section two gives an overview of flood types and common concepts in flood management, section 3 provides the application of RS and GIS in flood management and current challenges in using RS and GIS for flood management. The last section presents conclusions and recommendations.

FLOODING

Flooding has been defined in several ways, but generally to mean temporary covering of land by water. For example, Kron (2002) defines flooding as a temporary covering of land by water as a result of surface waters escaping from their normal confines or as a result of heavy precipitation. Most definitions found in literature also define flood as a temporary covering by water of land not normally covered by water.

Types of floods: Generally, classification of floods can be done by establishing the main difference between flood types. This is done by considering the size of the affected area and the duration of the triggering precipitation event. These two elements are then useful in defining the spatial and temporal scale of flood events consequently leading to two main classes of extensive long lasting floods and local sudden floods (Bronstert, 2003). Floods have also been classified into three main types namely; river flood, flash flood and storm surge (Perry, 2000; Berz *et al.*, 2001; Kron, 2002; Jonkman, 2005). Perry (2000) further categorizes floods as ice-jam floods, dam-and levee-failure floods debris, landslide and mudflow floods but emphasizes that these types are rather less common.

In his study on global perspectives on loss of human life caused by floods, Jonkman (2005) reports that the damaging impact of flood to a larger extent is determined by the flood physical characteristics such as depth of the water, flow velocity and the rate of rising of the waters all of which depend on the flood type.

Knowledge of flood type is therefore important for proper planning; flood monitoring, management and development of flood early warning systems as well as assessment of flood damage (Huang *et al.*, 2008). Jonkman (2005) though further describes the classification of floods as a hard task given the complex inter-related nature of processes that cause flooding. It is however worth noting that most studies have generally classified floods according to where they occur as well as the speed within which a given flood occurs. This implies that there can be as many flood types as possible depending on the study. In this review the most common flood types reported in literature are briefly described and include the following;

Coastal floods: have been defined as floods that occur along the coasts of the seas and big lakes. This type of floods is caused by wind storms such as cyclones and low atmospheric pressure that eventually result to the set-up of water levels on the coast (Berz *et al.*, 2001; Jonkman, 2005). It is mentioned that when this set-up of water levels coincides with astronomical high tide at the coast, coastal floods can lead to high water levels and thus flooding of the coastal area (Jonkman, 2005).

Flash floods: are defined by their fast speed occurrence usually after a heavy and high intensity localized rainfall. This in turn leads to a sudden and quick raise of water levels causing a threat to lives and property of the inhabitants (Berz *et al.*, 2001; Jonkman, 2005; Younis and Thielen, 2008). Other factors that strongly contribute to flash flooding include steep slopes, impervious ground surfaces and low permeability soils (Younis and Thielen, 2008). According to Younis and Thielen (2008) and Jonkman (2005), the sudden occurrence of flash floods leaves extremely short time for prediction and warning. Furthermore the high rising rate and flow velocity of flash floods also make them more dangerous to human lives than river floods (Younis and Thielen, 2008). This is line with findings by Jonkman (2005), which indicated that flash floods caused the most deaths when compared to other flood types.

River floods: refer to floods caused by flooding of the river outside its regular boundaries. They can also be associated by a breach of dikes or dams next to the river. According to Jonkman (2005), river floods can be caused by various sources including high precipitation levels, melting snow and blockage of the flow. Unlike flash floods, river floods can be predicted in some period in advance (Jonkman, 2005).

Other types of floods include drainage problems: caused by high precipitation levels that cannot be handled by regular drainage systems. This type of flood poses a limited threat to life due to limited water levels

and causes mainly economic damage. Tsunamis are defined as a series of large waves generated by sudden displacement of seawater usually caused by earthquake, volcanic eruption or submarine landslide (Jonkman, 2005). Tsunamis are further reported to be capable of propagation over large distances as well as causing a destructive surge on reaching land. Last but not least is the tidal wave/bore, according to Jonkman (2005), this type flood is caused by the abrupt rise of tidal water usually as a result of atmospheric activities that move faster inland from the mouth of an estuary or from the coast.

Common concepts in flood management:

Flood hazard: Flood hazard is defined as the probability of the occurrence of a potentially damaging flood event of a certain magnitude in a given area within a specific period of time (Crichton, 2002; Kron, 2005). Dang *et al.* (2010) have identified several factors that contribute to the damaging potential of flood hazards. They report that these factors depend on indicators such as flood depth, duration, velocity, impulse (product of water level and velocity) and the rate of the rise of water levels, warning time and the frequency of occurrence. Among these, flood depth is one of most important parameters used in the determination of flood risk indices. The concept of flood hazard is therefore very important in flood management especially in the determination of flood risk.

Flood vulnerability: Vulnerability is certainly one of the most important concepts that have widely been studied in hazard risk management. With reference to flood hazard management, Adelekan (2011) suggests that sound assessment of community vulnerability to floods is required. Flood vulnerability has been defined in several ways in several studies (Alcantara-Ayala, 2002; Pelling, 2003; ISDR, 2004; Barroca *et al.*, 2006), but generally used to refer to conditions that can be physical, social, economic and environmental, that make a given population more susceptible to the impact of flood hazard.

Furthermore, Weichselgartner (2001) and Adelekan (2011) suggest that vulnerability should be studied in three distinct categories of vulnerability indicators; susceptibility, exposure and coping indicators. Susceptibility indicators are a measure of the sensitivity of subject being confronted by the flood hazard (Adelekan, 2011). According to Adelekan (2011) building types, people's awareness and preparedness before the flood and their ability to cope up after the flood event can be used as indicators of susceptibility. Weichselgartner (2001) considers proximity of the area to rivers, elevation of an area as well as frequency of floods in a given area as exposure indicators, while Messner and Meyer (2006) combine

the latter's definition and flood characteristics such as inundation depth, duration and flood velocity to indicate exposure. In addition, Jonkman and Kelman (2005) suggest water depth rise rate, wave characteristics and water temperature should be included in the computation of flood hazard action. Coping indicators on the other hand are said to depend on the social response and tempered responses (Adelekan, 2011). They include general information on age, gender, level of education, poverty, proportion of vulnerable population and institutional development (Weichselgartner, 2001; Adelekan, 2011). As will be shown in the subsequent part of this review, information on flood vulnerability and flood hazard is of paramount importance in determining the flood risk of any given area.

Flood risk: Risk is generally described as the uncertain product of a hazard and its potential loss (Crichton, 2002; Kron, 2005). Flood risk has been defined as a degree of the overall adverse effects of flooding. It incorporates the concepts of threat to life and limb, the difficulty and danger of evacuating people and their possessions during a flood, the potential of damage to the structure and contents of buildings, social interruption, loss of production and damage to public property (Dang *et al.*, 2010). Like other studies (Karim *et al.*, 2005; Kron, 2005; Apel *et al.*, 2009), Dang *et al.* (2010) define flood risk as a product of flood hazard and flood vulnerability, equation (1); where flood vulnerability includes exposure:

$$\text{Flood Risk} = \text{Flood hazard} \times \text{Flood vulnerability} \quad (1)$$

Essentially this definition shows a direct influence that flood hazard as well as the level of flood vulnerability have on flood risk, the higher the values of these two, the higher will be the level of flood risk. In line with this, Dang *et al.* (2010) suggest that flood risk assessment requires interdisciplinary approaches and studies. They specifically suggest that the potential flood risk can be reduced by decreasing the level of vulnerability, reducing the exposure value and by reducing the hazard.

Flood damage: Flood damage is widely accepted as the main indicator for the impact of damaging floods (Pielke and Downton 2000; Munich and Topics, 2005). Dutta *et al.* (2003) have classified flood related damages as either tangible or intangible. Tangible damages are further divided into direct damages such as agricultural and environmental damages caused by direct contact with flood and indirect tangible damages such as business interruption, impact of floods on regional or national economy. Intangible damages on the other hand include health and psychological losses. It is worth noting that both types can be expressed in

monetary terms, for example Huang *et al.* (2008) computed flood damages in monetary terms having classified property loss due to floods as a direct tangible damage and income loss calculated as the difference in income between the year preceding the flood and the year of the flood, as an indirect tangible damage. On the other hand an increase in medical cost for households in the flood year compared to the preceding year was calculated and categorized as intangible damage due to flood.

APPLICATION OF RS AND GIS IN FLOOD MANAGEMENT

GIS has been defined in different ways, perhaps the most commonly used definition is that provided by Burrough (1986) generally known as the tool box definition. He defined a GIS as a powerful set of tools that enables collection, storage, retrieval, analysis and presentation of geographically referenced information. Remote sensing on the other hand is generally defined as the science of acquiring information about the earth's surface without actually being in physical contact with it. The transfer of information is done using electromagnetic radiation with the aid of sensors. RS has been reported to have played a part in the development of GIS, both as a source of technology and as a source of data. Together with RS and modelling, GIS provide a wide range of applications in agriculture, geology, natural disaster management, hydrology, weather monitoring, business and service planning, government, logistics and transportation and environmental management. In this review however, emphasis is put on the role and applications of these techniques in flood management. Flood management stages considered in this review include prediction, preparation (flood hazard, vulnerability and flood risk mapping), prevention and mitigation and flood damage assessment.

Flood simulation/prediction: Information on predicted flood extent is required by the government, the public and emergency department in order to facilitate early preparations and planning well in advance before the actual flood event. Early preparations and planning will in turn result into effective and efficient response thus minimizing and or mitigating the after flood effects.

There has been wide spread development or updating and use of hydrological models with a flood prediction component. These models are in most cases either loosely or tightly coupled with GIS and remotely sensed data (Chormanski *et al.*, 2008). Examples of such models include; WetSpa (Wang *et al.*, 1996; De Smedt *et al.*, 2000), HYDROTEL (Fortin *et al.*, 2001), LISFLOOD (De Roo *et al.*, 2000), TOPMODEL (Quinn *et al.*, 1991) and SWAT (Arnold *et al.*, 1998).

Most of these models require different types of data input such as land cover, land use, river discharge rate, rainfall amount, surface roughness, Digital Elevation Models (DEM) and size of drainage basin among others. In this case RS techniques can be used to obtain spatial and temporal information needed for parameterization of the distributed hydrological models (Chormanski *et al.*, 2008). In addition, Dams *et al.* (2009) have demonstrated the potential of RS derived impervious surface cover maps to improve hydrological models parameterization specifically for their applications in urban catchments. GIS tools on the other hand provide storage, analytical and data presentation capabilities. Integrating GIS with hydrological models (Fig. 1) according to De Roo *et al.* (2000) provides an ideal environment for modelling processes in a landscape.

Townsend and Walsh (1998) is one example of many studies that have used RS and GIS in predicting floods. The objective of this study was to compare the flood detection abilities of RS data as well as GIS based models. For RS data, Synthetic Aperture Radar (SAR) images were derived from multispectral satellites and then analyzed using Normalized Difference Vegetation Index (NDVI) to derive possible flood inundation. On the other hand DEMs were used to generate GIS models representing potential wetness and potential flood inundations. Their findings indicated that both SAR images and GIS models obtained comparable results of possible flood inundation.

In their study of watershed modelling and flood prediction, Konadu and Fosu (2009) used a vector based GIS and DEM in order to delineate watershed boundaries and predict areas of possible inundation during a flood event in the city of Accra. In this study digital contours obtained from the topographic map of the study area were utilized for DEM generation. The DEM generated provided the terrain representation and information in terms of the direction in which water that enters into an area will flow. Through the use of GIS, raster analyses were performed to generate data on flow direction, flow accumulation, stream definition, stream segmentation and watershed delineation. These data were then useful in developing a vector representation of catchments and drainage lines. Flood extent was then simulated based on the derived drainage lines, their depth and capacity to hold rainfall run-off. The flood level contours derived for the selected flood water levels of 0.5, 1, 1.5 or 2 meters were used to indicate areas that could face possible inundation in the event of any flood.

Several other studies (De Roo *et al.*, 2000; De Smedt *et al.*, 2002; Usul and Turan, 2006; Rahman, 2006; Batelaan *et al.*, 2007; Chormanski *et al.*, 2008; Stancalie *et al.*, 2009; Kabir *et al.*, 2011) have also demonstrated the potential of different GIS based

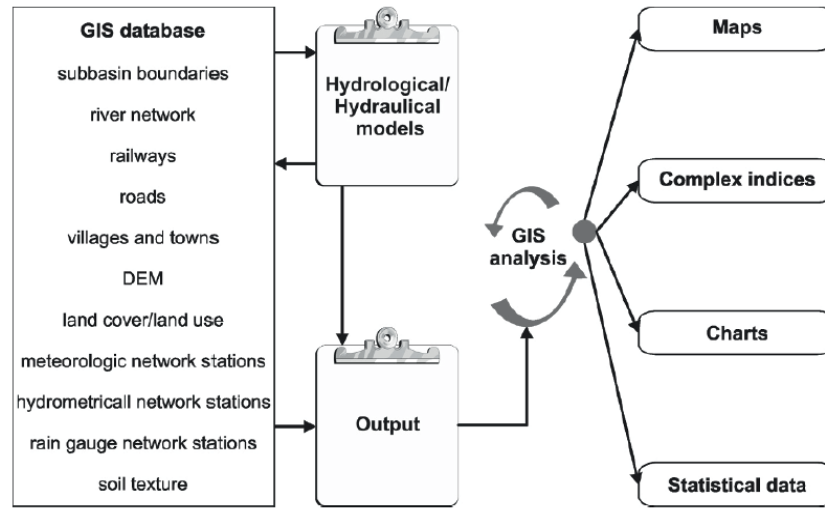


Fig. 1: Integration of hydrologic model outputs and GIS info-layers for preparing flood-risk maps (Source: Stancalie *et al.*, 2009)

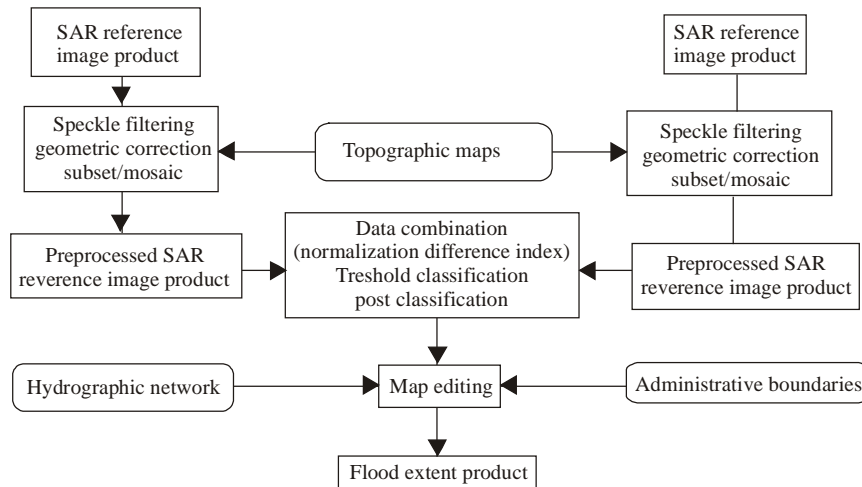


Fig. 2: Flowchart showing the generation of flood-extent maps from Satellite Radar (SAR) images (Stancalie *et al.*, 2009)

hydrological models to simulate/ predict flood. The general idea is that RS and GIS provide spatial and temporal data input required by the distributed hydrological models in order to simulate runoffs and thus floods. RS data in some studies have also been utilized to calibrate and improve on the performance of distributed hydrological models. RS also provides an option of accessing information from otherwise physically inaccessible areas. GIS tools have been imbedded in the hydrological models to facilitate in data analysis, querying and presentation of information in a more simplified way, thus they form critical part of the distributed hydrological models used for flood prediction. Figure 1 and 2 provide a summary of how GIS and RS respectively can be used in flood management.

Flood hazard, vulnerability and flood risk mapping:

One of the key stages in flood management is identification of areas with potential flood risk (Sanyal

and Lu, 2004). Flood risk as mentioned earlier is the product of flood hazard and flood vulnerability. Mapping of flood risk areas is not only important for the location of these areas but also for government, Nongovernmental Organizations (NGO’s) and other planners to get an idea of where priority should be given when allocating resources. Evacuation exercises, insurance companies as well as relief providers also require knowledge of spatial extent of inundated areas (Brivio *et al.*, 2002). This could be information about roads that may or may not be passable, worst affected areas and areas suitable for camping during flood periods.

RS and GIS have yet proved resourceful in this stage of flood management. For example Konadu and Fosu (2009) having predicted areas of potential flood risk, were able to utilize the overlaying function of a GIS to combine land cover maps with the flood-predicted zones. The resultant maps provided

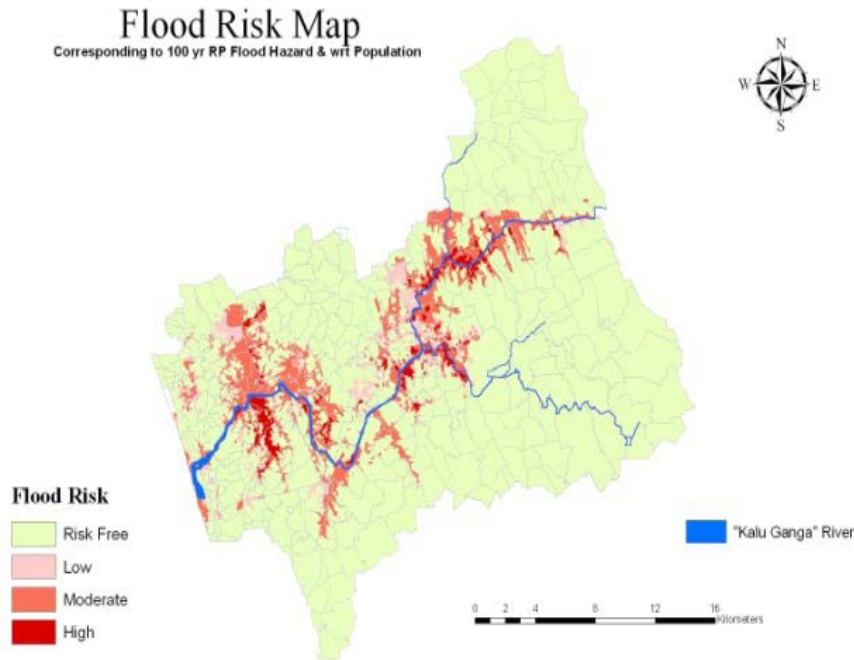


Fig. 3: Flood risk map for 100 year period obtained by overlaying flood vulnerability and hazard maps with the polygon map of Kalu Ganga-Sri Lanka (Samarasinghe *et al.*, 2010)

simplified information on the flood hazard (depth, velocity, direction of flow), elements at risk, their exposure and vulnerability. In addition, flood hazard, vulnerability and risk maps were drawn showing areas at low or high flood risk.

A study by Samarasinghea *et al.* (2010) is also a typical example in which RS and GIS techniques have successfully been used in flood risk analysis and mapping. In this Study, RS satellite imageries acquired during a dry season and also during flooding were analyzed to derive flood extent. Their results indicated that flood extent derived from RS data were comparable with those obtained when one of the flood inundation models, Hydrologic Engineering Centres River Analysis System (HEC-RAS model) was used and based on this, they were able to validate their model.

The study also made use of GIS data and functions for flood simulation and flood risk mapping. They were able to obtain the flood risk map by map multiplication in ArcGIS environment of flood hazard and flood vulnerability maps. By overlaying vulnerability and flood hazard values with the polygon map of the area, Samarasinghea *et al.* (2010) were able to map out zones with low, moderate and high flood risk (Fig. 3).

Usul and Turan (2006) have also used GIS in their study in order to map out flooded areas (Fig. 4). Apart from its usefulness in flood hazard mapping, Usul and Turan (2006) report that using GIS tools have added advantages as it enables determination of basin characteristics, easy manipulation of conditions of river

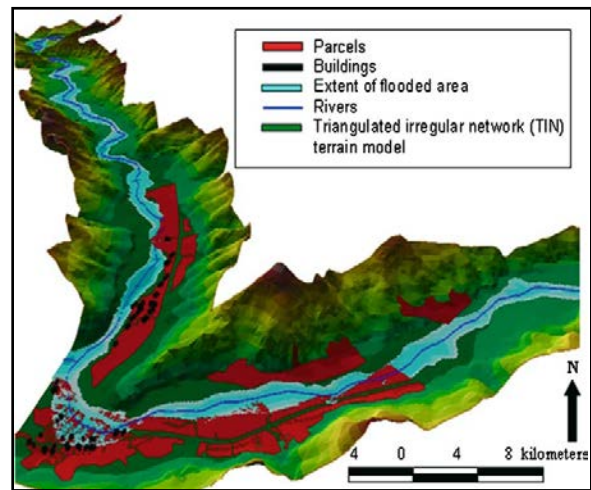


Fig. 4: Map showing flooded areas on Ulus Basin determined from the 100-year flood simulation using GIS techniques (Source: Usul and Turan, 2006)

components to suit any river size as well as enabling the end-user to have a bigger and more complete picture of what is likely to happen in a watershed during and after a flood. In India, Sanyal and Lu (2005) have used Landsat Enhanced Thematic Mapper Plus (ETM⁺) and ERS SAR imageries to classify non flooded areas and flood depth within flooded zones. Many other studies (Islam and Sado, 2000; Brivio *et al.*, 2002; Hardmeyer and Spencer, 2007; Singh and Sharma, 2009; Stancalie *et al.*, 2009) have also utilized RS and GIS techniques in identifying and mapping flood risk zones.

Flood prevention and mitigation: Through their use in flood prediction and flood risk mapping, RS and GIS have been resourceful in flood prevention and mitigation. GIS and modeling approaches in particular have been used in investigating the possible effects of land use changes in flood generation. In a number of studies (Liu *et al.*, 2005; Chormanski *et al.*, 2008) land use scenarios have been hypothesized and possible impacts of these scenarios in the generation of runoffs and consequently flooding have been investigated. This information can be useful in developing policy guidelines and recommendations for urban planning, land use planning as well as settlements and types of buildings. In this way, flood impacts can be prevented or even mitigated.

Liu *et al.* (2005) for example were able to assess the impacts of land use changes on runoff generation in the Steinsel sub-basin, Alzette, Grand-Duchy of Luxembourg, using GIS and the Water and Energy Transfer between Soil, Plants and Atmosphere (WetSpa) model. Among the data used in this study included 52 months of observed hourly rainfall as well as DEM and soil data which were available in GIS format. In addition, land use data were obtained from remotely sensed images. In order to assess the hydrologic effects of land use changes on floods, three land use scenarios of urbanisation, deforestation and afforestation were hypothesized. Results from the model simulation indicated urbanisation land use to be associated with large negative impacts in terms of increasing peak discharge, flood volume and time to the peak. Deforestation as well was reported to be associated with negative impacts while afforestation land use gave moderate positive impacts in terms flood generation prevention.

Hardmeyer and Spencer (2007) were able to use GIS to create a map showing areas where flood would occur and the frequency with which these floods would occur in an Urban Watershed in Rhode Island. They report that the GIS map created was useful to mayors and other town planners in seeing potential flood areas and the possible damages. This in turn would enable them to identify priority areas thus enhancing flood mitigation planning and communication of the information to the public and other stakeholders.

Other studies (Irimescu *et al.*, 2009; Jeyaseelan, 2003) have also shown that RS data can easily help in prevention, through mapping of hazardous areas, land cover, drainage lines as well as precise modelling. In addition RS techniques have been helpful in monitoring flood extent and damage even during the event.

Flood damage assessment: Knowledge of damage inflicted by flood is required by the authorities and Insurance companies in order to effect compensation as well as to have an estimate of the cost of reconstruction.

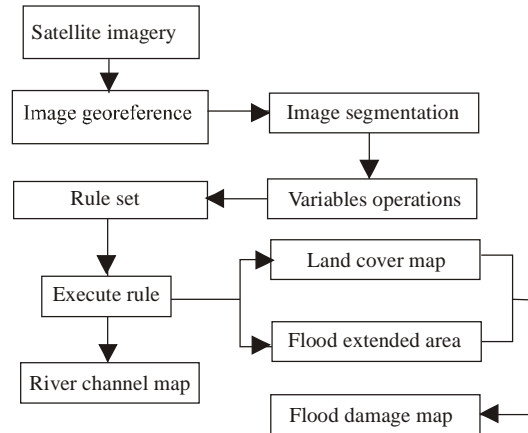


Fig. 5: Flow chart showing steps on how RS data can be processed for use in flood damage assessment (Source: Uddin and Shrestha, 2011)

GIS has a function of overlaying layers and through this function, layers on inundated areas can be over laid with land use maps, land cover layers, infrastructure layers among others. RS in this case is a very valuable tool to obtain images before, during and after flooding (Townsend and Walsh, 1998). These images are there after processed and analyzed in order to obtain information of the land cover, buildings, roads, schools and other infrastructures of the area under normal hydrological conditions (before flooding), inundated areas and flood extent (during flooding) and flood effects, deposits and debris (after flooding). When the comparison of these images together with pre-flood data is carried out, the extent of flood damage can be estimated (Fig. 5).

In addition, Dutta *et al.* (2003) have introduced a mathematical model for estimating losses due to floods. The model is an integration of physically based hydrological distributed model and distributed flood loss estimation model. In their case study in Japan, Dutta *et al.* (2003) have shown that this model requires spatial and temporal data input, especially given the fact that it includes physically based hydrological distributed model. This implies that RS and GIS techniques are handy in providing data required by the model. For example, they used SPOT and LANDSAT satellite data in order to derive detailed land cover information as well as in the estimation of urban floor area. When the mathematical model was applied in a river basin in Japan, results indicate that the model results were comparable with the observed damages (Fig. 6). The model was also shown to perform better in estimating urban flood damage compared to rural flood damage.

A study by Islam and Sado (2000) is also an example in which RS and GIS techniques have been used to map out flood damaged zones. Mohit and Akther (1998) have also used GIS to delineate flood

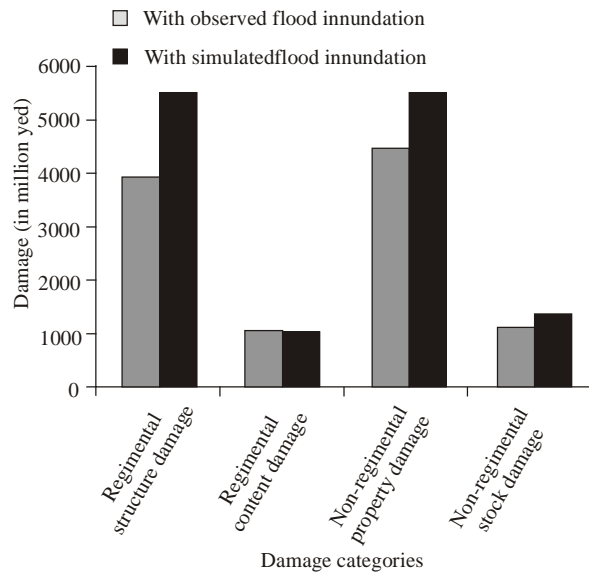


Fig. 6: Simulated flood damage using a mathematical model (Source: Dutta *et al.*, 2003)

damaged zones of Dhaka city; Sanyal and Lu (2004) have applied RS for flood damage assessment in the monsoon in Asia while Yi *et al.* (2010) in a study carried out in Anyang Stream Basin in Korea have been able to provide GIS-based distributed technique for assessing economic and engineering loss caused by flood damage.

Challenges in using RS and GIS for flood management: In spite of the great potential that RS and GIS offer in flood management, their use has been limited to some extent. Presence of cloud cover during the flooding periods for example has been reported as the major challenge in the use of optical remote sensing in flood management (Sanyal and Lu, 2005). According to Sanyal and Lu (2005) using SAR is a better option since radar pulse has a higher penetration power to overcome the problem of cloud cover, however its use especially in developing countries has been constrained by its high prices as well as limited coverage. Other challenges to the use of RS include limited availability of imageries in time and space, seasonal variations, technical limitations and above all the problem of low temporal resolution.

With reference to the problem of temporal resolution, most radar images are taken some time before and also after the flood and in most cases the flood peak may not be captured. In other words, there is a timely delay between the actual time the flood occurs and the time images are taken. According to Schumann *et al.* (2007), the current radar satellites have a long revisit time that can be up to 35 days. They add that acquiring a SAR image at the actual flood time is rather a fortunate event.

In order to demonstrate the challenge to the use of microwave RS data due to temporal resolution, a study by Brivio *et al.* (2002) is used as an example in this review. In their study, Brivio *et al.* (2002) processed two ERS-1 SAR images one captured one month before the flood event and the other captured three days after the flood event. After performing visual interpretation and different thresholding techniques they were able to obtain the flood map. They report that the flood map obtained showed only 20% of the actual flooded land and this was attributed to the time delay between the flood peak and the satellite overpass. Brivio *et al.* (2002) however in the same study demonstrated the potential of integrating RS with digital topographic data from GIS to overcome temporal resolution problem. Their findings indicated that an integral of these two techniques yielded 96.7% accuracy when compared with the actual flooded area. Even then Sanyal and Lu (2004) have still reported some weaknesses associated with this approach.

Last but not least, Carrara *et al.* (1999) have outlined a number of challenges to the use of GIS technology in the field of natural disasters. Among other challenges they have pointed out include high cost of digitization and raw data collection, the intrinsic complexity of predictive models, lack of appropriate raw data, inadequacy of hardware technology to handle large spatial data sets and the difficulty in GIS to manage historical data necessary for some natural hazard assessments.

CONCLUSION AND RECOMMENDATIONS

Conclusion: From the preceding three sections of this review, quite a number of conclusions can be made. The first one is that flood hazard is the most widely distributed and devastating disaster, more so in this era of climate change. Secondly, knowledge of flood types is critical in flood prediction and flood damage assessment and here it is worth noting that although flash floods have not been very common compared to other types like river floods, they have caused more deaths and property damage than many other flood types. Flood management is a three phase procedure that includes pre-flood, during flood and post-flood activities. These three phases can further be subdivided into flood prediction, flood prevention and mitigation, flood risk identification and mapping and flood damage assessment. The lesson we learn from here is that flood management is very diverse and it requires multidisciplinary involvement. As an example flood prediction, mapping and damage assessment require disciplines of hydrology, soil science and geography. Flood prevention, mitigation and flood damage assessment require efforts from government, insurance companies, professionals and above all the general public.

However all these different stake holders need to start from somewhere, they need data and information in order to answer questions like where will the hazard occur? When is the flood likely to occur? What extent will it be? Who will be affected among other questions? Fortunately, the preceding discussion in this review has explored how advancements in RS and GIS techniques coupled with computer modelling have been handy in answering most of these questions. It can be deduced that application of these techniques are critical in all the various stages of flood management that include prediction, prevention, mitigation, flood risk identification and flood damage assessment. Specifically RS techniques offer cheaper and faster options of accessing spatial data about the flood event even in the physically inaccessible areas. GIS techniques on the other hand facilitate hydrological models in data collection, analysis, querying and presentation of information in a more simplified format.

This review also provides an over view of the limitations to the use of these techniques. Key among these is the limited availability as well as high cost of high resolution imageries especially among the developing countries. This can also explain why there has been a generally limited application of these techniques for flood management in developing countries. This is also reflected in this review as most of the studies cited here come from the developed countries. Other limitations include seasonal variations and temporal resolution for RS techniques while high cost of digitization and raw data collection, the intrinsic complexity of predictive models and lack of appropriate raw data remain a challenge to the use of GIS. Never the less some studies have already obtained promising results on how to solve most of these constraints and with time we can be rest assured that applications of these techniques in flood management will strike higher limits.

Recommendations: The major challenge remains on how developing countries can get more involved on the use of RS and GIS techniques for improved flood management. Save for the already mentioned challenges, most developing countries still have their own problems of poverty, poor governance, lack of technical capacity and out dated data base such as land use maps, soil maps among others. One would therefore recommend for a holistic approach involving governments, institutions, professionals and the general public to uplift the use of these techniques that have proven to provide fast and accurate information required to mitigate and minimize the damaging impacts of floods.

To begin with these different stakeholders should work together and utilize RS and GIS techniques to derive flood hazard and vulnerability maps for their urban and rural catchments. This will already be a great

step towards reducing flood risk and its impacts, as already mentioned in section 2 of this review that reducing flood vulnerability is a critical step towards reducing flood risk.

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