DISASTER MANAGEMENT

FLOOD RISK ANALYSIS AND MANAGEMENT: A REVIEW

GEOM200023 Application of GIS, the University of Melbourne

26/04/2017

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WORD COUNT: 2130

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ABSTRACT

Floods are among the most significant natural hazards around the world and proper management practices are vital in minimising their impact. The aim of this review is to provide a synthesis of current literature on the topic of flood management and the integration of Geographic Information Systems (GIS) in managing such events.

The paper explores flood hazards, the history of GIS in flood management and its applications in different stages of flood management. Flood risks are generally modelled in GIS in two ways: flood reach estimation (static), and flood routing (time-stepped). Non GIS techniques embedded into the program that contributes to collecting data for flood modelling and mitigation are remote sensing data including satellite imagery, RS, LiDAR and LADS. These resources provide integrated results to flood mapping and management. However, certain limitations exist, especially in the availability of data as well as the lack of hydraulic modelling experience within management practices.

ABBREVIATIONS

Abbreviation	**Meaning**
ARI	Average recurrence interval
DEM	Digital elevation model
DTM	Digital terrain model
GIS	Geographic information system
GPS	Global positioning system
LADS	Laser airborne depth sounder
LiDAR	Light Detection and Ranging
MODIS	Moderate imaging spectral radiometer
RS	Remote sensing

INTRODUCTION

Floods are one of the most frequent and catastrophic hazards in the world. In fact, in Australia, they are known to be the country's costliest natural disaster (Bureau of Transport Economics, 2001). Floods are a natural phenomenon and they play a significant part in the hydrological cycle. Climatological factors are usually the leading cause of floods (Green et al., 2000). However, other factors as identified by Ward, R. (1978) such as the nature of the terrain (geology, soil types, vegetation cover), stream network characteristics (storages capacity, channel length) and channel characteristics (roughness and shape) determines the extent and effect of floods.

Flood hazard

Knowing that floods occur naturally and are vital to the ecosystem (Ward, R., 1978), floods could at times escalate into environmental hazards. This is when floods threaten the livelihood of human beings. Thus, there is a distinct delineation when floods are categorised as hazards. As highlighted by Green (2000), the extent of flooding could be further exacerbated by human-induced interventions which include urban growth, change in land cover, deforestation and the modified structure of watercourse. In management practice, the concept of **'flood vulnerability'** is rather adapted to depict an anthropocentric understanding of floods, in order to realize the risk and accordingly predict and manage the consequences (Opolot, 2013).

Flood risk management

Similar to any other natural disaster, flood risk management involves four stages—prediction, preparation, prevention and mitigation. With a short response time, a reliable and timely flood warning system capable of predicting future flood events is necessary (Kourgialas & Karatzas, 2011; Konadu & Fosu, 2009). Post-flood measures that focus on identifying flooding-prone areas and evaluating the damages made is also crucial for future planning and re-establishment.

Due to the unpredictability and extensive scale of flooding, challenges still remain in assessing and managing floods. However, with the aid of Geographic Information Systems

(GIS), flood management practises have been greatly improved. As such, this report aims to explore the various applications of GIS used in each indicative flood management stage. A range of case studies has also been used to analyse the effectiveness of GIS in the event of actual flooding occurrences.

GEOGRAPHIC INFORMATION SYSTEM IN MANAGING FLOOD HAZARD

It has been widely recognized among management authorities that estimation of flood inundation is a major task in managing flood hazard (Bates & De Roo, 2000). With the multi-dimensional and spatial nature of such events, Geographic Information System (GIS), as a result, has been frequently utilized as the primary tool for flood risk analysis and preparation of maps (Ozkan & Tarhan, 2016). The platform functions as:

i. *an information database* which provides a systematic data storage
ii. *an analytical tool* allowing to specify mathematical relationship of data elements
iii. *a means of visual communication* of spatial information for management and decision support (Kourgialas & Karatzas, 2011).

GIS in modelling flood risks

Flood reach estimation

A common practice in mapping that estimates the extent of flooding areas involves 'multi-criteria analysis' (Kourgialas & Karatzas, 2011). This involves the assessment of various aspects that contributes to the flood. Henceforth, creating a map that display areas that are susceptible to flooding. As proposed by Carver (1991), several procedures could be adopted to evaluate the flood vulnerability of a water body and they include Weighted Linear Combination (WLC) analysis and concordance-discordance analysis. While the latter is infeasible to compute, WLC proves to be very forward in GIS.

Two studies by Kourgialas & Karatzas (2011) and Ozkan & Tarhan (2016) have applied the WLC methodology in predicting areas of high flood vulnerability to great success. The first study, for example, takes into consideration six variables that contribute to the flood vulnerability, namely elevation (m), flow accumulation (pixel), rainfall intensity (MFI[1]), slope (degree), geology (type) and land use (type). They are then ranked within each category and also against each other to find their weighted contribution to the hazard. The final hazard result is calculated using Weighted Linear Combination formula performed within GIS (1)

$$S = \sum \ w_i x_i \tag{1}$$

Six thematic maps, along with final flood-hazard map are produced to illustrate the findings.

Flood routing model

Another method of flood modelling is flood routing. Contrary to the previous model, it is often used at a segment scale to simulate time-based flood inundation (Weinmann & Laurenson, 1979). These simulation model ranges in complexity from 1D representation (showing rivers as series of cross-section, such as HEC-RAS model[2]) to fully three-dimensional simulation with high computational data handling.

Bates & Roo (2000), for example, presents a simple raster-based model named LISFLOOD-FP combining one-dimensional hydraulic data with DEM to predict inundation extent. Sample results from the models are shown in **Figure 1.** However, it is readily identified in the study that certain limit of such models is the pre-made assumption in hydraulic behaviour in order to simplify the model which might result in inaccurate prediction of the flooding event.

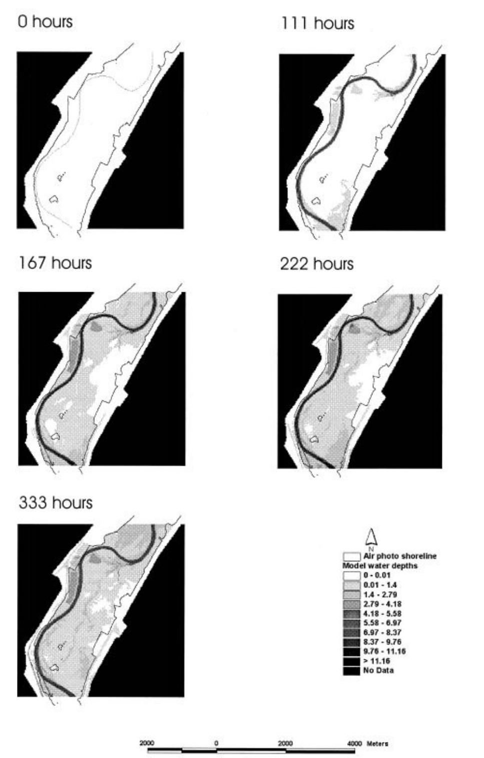

Figure 1: Results from time-step model to predict inundation (Bates & Roo, 2000)

[1] Modified Fournier Index (Morgan, 2005) that takes the sum of average monthly rainfall intensity at a station.

[2] Stands for Hydrological Engineer Centre - River Analysis System. A 1D flood analysis model capable of giving water surface profiles with time-step data.

Merwade (2008) looks into another model that uses a DEM or DTM within arcGIS to create a 3D river terrain model to accurately simulate flood stages. Elevations (z-axis) of DEM are stored as a 'PolylineZ', cross sections can be mapped in a 2D array of points, with each point corresponding to a s, n coordinate. The difference between x, y and s, n coordinates is shown in **Figure 2**. Following from the collection of cross sectional points, profile points are gathered along the direction of flow. Each profile point is labelled as s, n, z coordinate, and all points are joined, to create a line that depicts a flow of a river (**Figure 3**). While complex equations are used to collect and arrange the data and profile points, the final result of the arrangement of these points is similar to figure 1 below (Merwade, 2008).

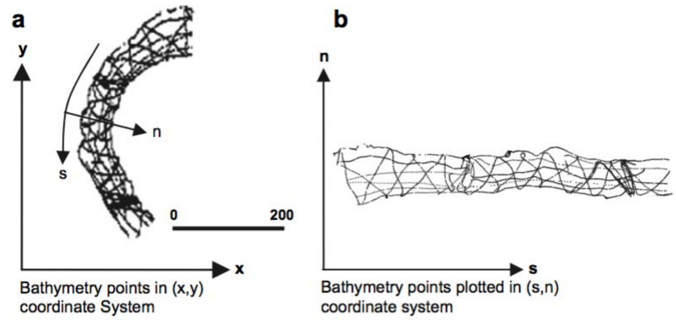

Figure 2: Mapping of a river using both x, y and s, n coordinate systems (Merwade, 2008)

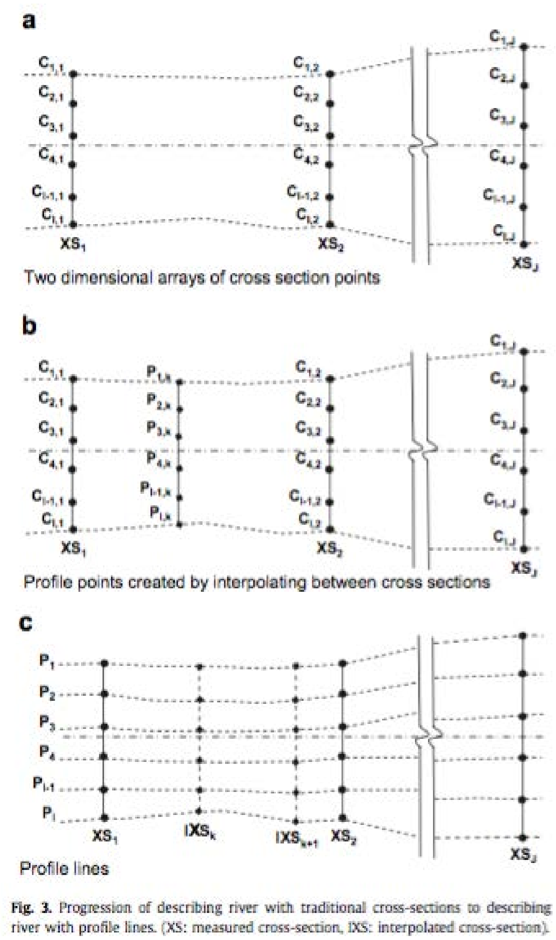

Figure 3: Steps to creating a terrain using data points (Merwade, 2008)

Data from LiDAR and aerial imagery can be added, to create a clearer and more visual model on GIS, as seen in **Figure 4 & 5**, where an integrated terrain has been added into the LiDAR model. This model is utilized mostly to predict the floodway and help to mitigate and reduce the likelihood of floods. A limitation to this model is that if the data is not gathered concurrently, some features may not align due to a change in the landscapes geomorphology.

Some models require smoothing in ArcGIS, due to uneven points, through creating 'buffer polygons' to specified extents in GIS. The level of smoothing in a sample model is shown in **Figure 4**.

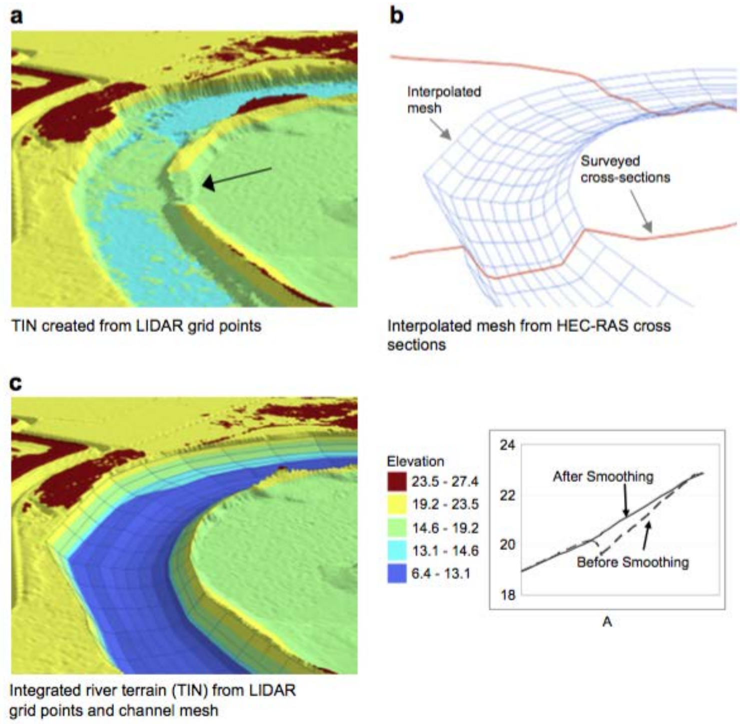

Figure 4: Terrain created in ArcGIS using LiDAR and flood route modelling (Merwade, 2008)

GIS in monitoring and mitigating flood events

Flood monitoring and damage assessment

Flood monitoring utilises hydrodynamic models such as those presented above, that combines data on precipitation, DEMs, soil types, land uses, baseflow, etc. to track the precipitation and monitor inundation (Jeyaseelan, 2003).

During and immediately after a flood has occurred, assessment of flood damage is often required by authorities in order to identify affected areas, estimate rebuilding costs and implement future mitigation measures (Opolot, 2013). GIS and remote sensing is used in these situations to map flood extents and real time monitoring through satellite, airborne and direct survey to assess and analyse damage to buildings and infrastructure.

Damage can be assessed and predicted through previous models, weather maps in GIS from infrared satellite images, or low altitude satellite orbits. While the amount of rainfall can be predicted using these techniques, with the aid of previous models, it is possible to have an indication of the affects the flood will cause. The estimated damage a flood causes from observing previous models can be estimated using flood/ storm frequency models and observing the ARI (Finkl, Benedet & Andrews, 2004). It is essential that information be accurate and timely, in order to address emergency situations (for example, dealing with diversion of flood water, evacuation, rescue, resettlement, water pollution, health hazards, and handling the interruption of utilities etc.).

GIS in flood risk mitigation

Hydrodynamic flood models play a significant role in mitigating the risk of natural hazards. Through providing time series inundation, emergency services can be given onset data of the event, to better aid in management. Hence, offering easier ways to observe the event, and plan evacuation routes, locations for emergency shelters, better infrastructure, and other plans for the land usage (Kundzewicz & Takeuchi, 1999). As demonstrated from a case study in Cairns in 2004, using GIS makes it easier to reduce the volume of all data, as everything is collated into one integrated model (Zerger & Wealands, 2004). This makes it much easier for a disaster manager to assess the data and answer complicated risk questions.

External sources used alongside GIS in monitoring floods

Impacts of flood could be further examined via other spatial approaches that complements GIS. While determining the flood water levels, velocity and flow, it is possible to monitor the flood prone areas, using DTM and observing the areas with lower elevations and more catchments (V.Anselmo, 1996). Hydrological-hydraulic modelling is a classic approach to aid in visualising this trend (Geoscience Australia; V.Anselmo 1996). Hydrographic survey maps created on GIS display contours of sea and land, and through using the created maps, the depth of floodwaters across the region can be visualised post flooding. This data can be obtained through RS, LiDAR or LADS (Finkl, Benedet & Andrews, 2004).

The purpose of LiDAR is to create a terrain through capturing the elevations of the region (Q.Chen, 2007). This model can be imported into GIS and further analysed. LADS is similar to LiDAR however, is used to gather elevations in water. The result gathered from LADS is placed into ArcMap using 'digital image enhancements' from 'pattern recognition, and shape detection', to create a vector dataset with layers (V.Anselmo, 1996). The DTM created from either LiDAR or LADS is shown with each geomorphological area clearly standing out (**Figure 5**).

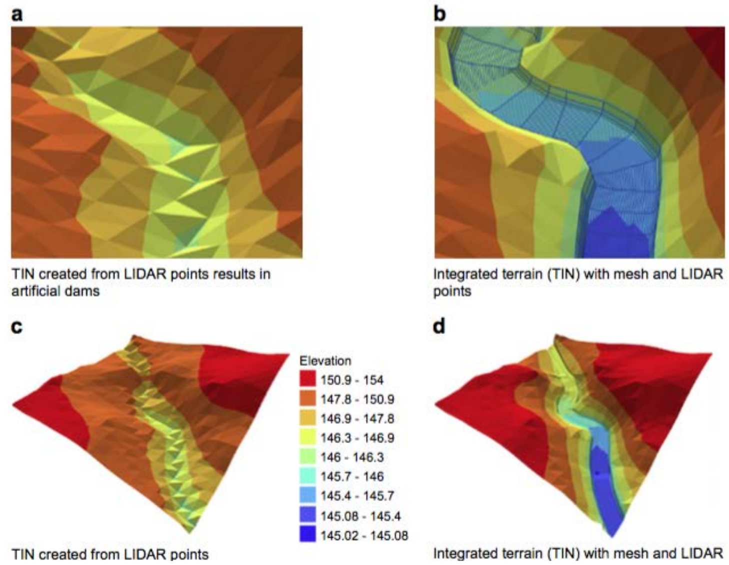

Figure 5: Terrain created in ArcGIS using LiDAR (Merwade, 2008)

MODIS data collected from NASA's TERRA and AQUA satellite images is another RS technique that is used to visualise areas affected by flood, through using various spectral bands, to display different features (Haq, 2012). These images can be collated with topographic maps, to show the locations of rivers, lakes and other land covered areas (**Figure 6**). Along with data from the bureau of statistics, the population density can be overlaid in Arcmap, to better aid in managing the flood.

Using the above techniques of remote sensing, LiDAR and LADS, it is possible to reduce the level of risk of a flood using GIS. Since the amount of rainfall and floodwaters reaching the area is known, using the DTM data in GIS, the geomorphic units that can hold more water is visualised. The floodwater levels

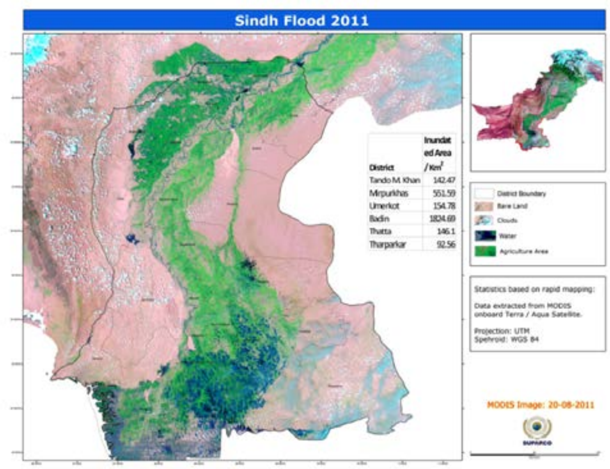

Figure 4a (a) MODIS image showing the inundated area on Aug 20, 2011.

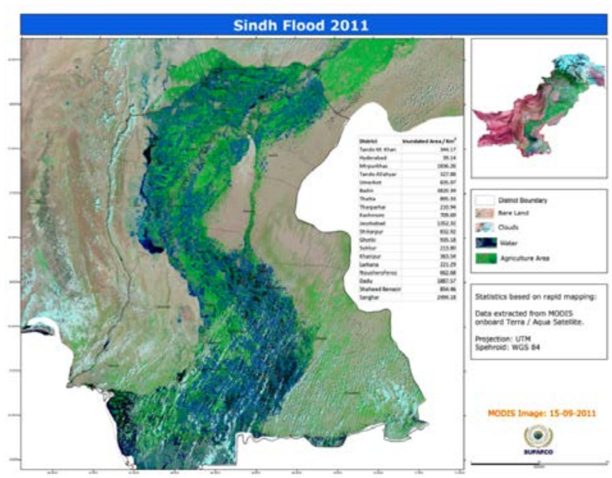

Figure 4d (d) MODIS image showing the inundated area on Sept 15, 2011.

Figure 6: Modis images from 20/08/2011 to 15/09/2011 displaying the flood inundated areas in Sindh province, India (Haq, 2012).

can be predicted, for effective management strategies to be put in place. While taking the elevation, land use/ land cover area, population distribution and soil types into consideration, the terrain can be managed during floods, as suitable locations for infrastructure can be found (Ramlal, 2008).

DISCUSSION

The use of GIS and remote sensing in flood management has proved to be extremely valuable, with its use growing in nations all around the world as highlighted by several case studies. There is still however much room for improvement, particularly in developing nations which have been limited by its high cost and lack of coverage (Opolot, 2013). This is because GIS is often constrained by issues inherent in these developing nations such as poverty, poor governance, lack of resources and outdated or inadequate data. Several other limitations existed in current application of GIS in flood management are also outlined below.

Limitation in modelling flood risk

Remote sensing technique, an integral part of GIS, usually involves acquiring satellite imagery that is often captured at a certain time interval. Hence, there might be a significant **time delay** as when images are taken compared to peak flood event, resulting in inaccurate measurement of flood extent (Opolot, 2013). For example, Brivio et al. (2002) model reported to only predict 20% of the flooded areas of a historic flood event due to three-day delay between captured images and flood peak. However, the study demonstrated that with the integration of DEM model along with satellite images, the predictability reaches more than 90% accuracy.

Lastly, the importance of **spatial resolution** in both the satellite imagery and DEM model is emphasized in some reviewed papers. As desired resolution is not always available especially for rural areas, relying on low spatial resolution in a raster-based model might lead to high variance in flood predictability (Horritt & Bates, 2001).

Limitation in managing flood risk

Data acquisition and handling as well as inadequacy in hydraulic modelling experience present some of the most challenging aspects in flood management practices (Bates & Roo, 2000; Opolot, 2013). The lack of publicly available data such as high-resolution DEM leads to the limited use of advanced simulation model. Knowledge of hydraulic modelling, in addition, is deemed to be still limited in non-expert users who are often in charge of hazard assessment.

CONCLUSION

GIS has played an increasingly important role in all the different stages of flood management, acting as a key tool in the mitigation of floods. GIS is usually used in conjunction with remote sensing and computer modelling to predict and display when and where floods will occur, the extent of flood damage and assessing the damage from floods. GIS however requires large amounts of data, which may not always be available, as well as technical knowledge in order to be used to its full potential./.

REFERENCES

Bates, P. D., & De Roo, A. P. J. (2000). A simple raster-based model for flood inundation simulation. *Journal of hydrology*, *236*(1), 54-77.

Brivio, P. A., Colombo, R., Maggi, M., & Tomasoni, R. (2002). Integration of remote sensing data and GIS for accurate mapping of flooded areas. *International Journal of Remote Sensing*, *23*(3), 429-441.

Bureau of Transport Economics (2001). *Economic Costs of Natural Disasters in Australia*. Report 103, Bureau of Transport Economics, Canberra.

Carver, S. J. (1991). Integrating multi-criteria evaluation with geographical information systems. *International Journal of Geographical Information System*, *5*(3), 321-339.

Chen.Q. (2007). Airborne Lidar data and processing and information extraction. *Photogrammetric engineering & remote sensing* (2007) 109-112

Finkl, C. W., Benedet, L., & Andrews, J. L. (2004). Laser Airborne Depth Sounder (LADS): A new bathymetric survey technique in the service of coastal engineering, environmental studies, and coastal zone management. In *Proceedings of the 17th annual national conference on beach preservation technology* (pp. 11-13).

Geoscience Australia. Retrieved 25/04/2017 from http://www.ga.gov.au/scientific-topics/hazards/flood/australian-flood-risk-and-information-portal/share-flood-study-data/data-entry/data-entry-guidelines/analysis/hydraulic-modelling

Green, C. H., Parker, D. J., & Tunstall, S. M. (2000). Assessment of flood control and management options. *WCD Thematic reviews. World Commission on Dams Secretariat, South Africa*.

Haq.M et al. (2012). Techniques of remote sensing and GIS for flood monitoring and damage assessment: A case study of Sindh province, Pakistan. *The Egyptian journal of remote sensing and space sciences*. Vol 15, 135-141.

Horritt, M. S., & Bates, P. D. (2001). Effects of spatial resolution on a raster based model of flood flow. *Journal of Hydrology*, *253*(1), 239-249.

Jeyaseelan, A. T. (2003). Droughts & floods assessment and monitoring using remote sensing and GIS. In *Satellite remote sensing and GIS applications in agricultural meteorology* (Vol. 291). Dehra Dun, India. Geneva, Switz: World Meteorol. Org.

Konadu, D. D., & Fosu, C. (2009). Digital elevation models and GIS for watershed modelling and flood prediction–A case study of Accra Ghana. In *Appropriate Technologies for Environmental Protection in the Developing World* (pp. 325-332). Springer Netherlands.

Kourgialas, N. N., & Karatzas, G. P. (2011). Flood management and a GIS modelling method to assess flood-hazard areas—a case study. *Hydrological Sciences Journal–Journal des Sciences Hydrologiques*, *56*(2), 212-225.

Merwade.V et al. (2008) GIS techniques for creating river terrain models for hydrodynamic modelling and flood inundation modelling. *Environmental modelling & software*, vol 23, 1300-1311.

Morgan, R. P. C. (1988). Soil erosion and conservation. *Soil Science*, *145*(6), 461.

Ozkan, S. P., & Tarhan, C. (2016). Detection of Flood Hazard in Urban Areas Using GIS: Izmir Case. *Procedia Technology*, *22*, 373-381.

Opolot, E. (2013). Application of remote sensing and geographical information systems in flood management: a review. *Research Journal of Applied Sciences Engineering and Technology*, *6*(10), 1884-1894.

Rahman, A. & Goonetilleke, A. (2001). Effects of non-linearity in storage-discharge relationships on design flood estimates. Proceedings of the Conference: MODSIM 2001, International Congress on Modelling and Simulation, 113-117.

Ramlal.B & Baban S.M.J (2008). Developing a GIS based integrated approach to flood management in Trinidad, West Indies. *Journal of environmental management*, vol 88. 1131-1140.

V.Anselmo et al. (1996). Flood risk assessment using an integrated hydrological and hydraulic modelling approach: a case study. *Journal of Hydrology* 533-554.

Ward, R. 1978. Floods: A Geographical Perspective, London: MacMillan.

Weinmann, P. E., & Laurenson, E. M. (1979). Approximate flood routing methods: a review. *Journal of the Hydraulics Division*, *105*(12), 1521-1536.

Kundzewicz, Z. W., & Takeuchi, K. (1999). Flood protection and management: quo vadimus?. *Hydrological Sciences Journal*, *44*(3), 417-432.

Zerger, A., & Wealands, S. (2004). Beyond modelling: linking models with GIS for flood risk management. *Natural Hazards*, *33*(2), 191-208.