A GIS TO REDUCE FLOOD IMPACT ON ROAD TRANSPORTATION SYSTEMS

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ABSTRACT

Flooding is considered to be one of the most catastrophic forms of natural disaster. The adverse effect of flooding is recognised when it disrupts the road transportation system of a country since it is considered as a country's socio-economic lifeline. The level of interactions between various measurable flood dimensions and transportation networks determines the potential impact of a flood. By determining interaction probabilities, the flood impact can be modelled, visualised, quantified and evaluated by developing a sophisticated GIS. Besides this, the ways for the reduction of flood impact on the road transportation systems can be demonstrated using the GIS. The paper presents the development of such a system within the framework of an advanced Software Development Life Cycle (SDLC). Finally, the application of the GIS has been demonstrated taking a case study area into account. This enables an understanding of the applicability of the system in analysing, visualising and reducing the addressed problem from various perspectives. In future, the system could be used to assess the flood impact on various objects apart from route networks in an interactive and user-friendly way and therefore can be used as a spatial decision support tool.

1. Introduction

Road transportation is considered as an integral part of a nation's infrastructure and often termed as its '*socio-economic life line*' since it is used to promote social and economic activities more than any other form of transportation (Solway, 1999 & Bruton, 1995). A road transportation system comprises facilities and activities domains.

The facilities domain consists of the physical components of the system, which is fixed in space and constitutes the network of links and nodes of the transportation system. This is often termed as 'the route network'. The flow of traffic (the movement of vehicles on a route network to facilitate the transportation of goods and passengers to their desired destination) within this route network mainly constitutes the activities domain of the transportation system (Bruton, 1995).

From the above, it can be seen that a *spatial relationship* exists between the two domains, which is related through the spatial arrangement of the route network (Maguire, 1999). Therefore, when a route network is closed, it eventually affects the activities domain. This implies that the quality and capacity of the transportation system are dependent upon all of the system components combined together.

Floods can be one of the most catastrophic natural events in that they can severely damage any transportation system. When a segment of a route network is closed by floodwater, the various flood impacts can be observed on the characteristics of *traffic flow*, including the disruption of communication, traffic congestion, increased traffic volume, decreased speed limit and increased travel time. For this reason, any effect on the route network can be seen as a potential threat to the various characteristics of traffic flow.

This threat is variable and depends on the intensity/scale of interaction between various dimensions of flooding (including areal and depth) and the route network (Davies and Hossain, 2000). Therefore, when a flood poses a threat to various segments of a route network, the components of the road transportation system are exposed to the potential impact of flooding due to the existing spatial interrelationship between them. In addition to that, when one part of the route network is affected, it can potentially affect traffic flow in many other parts to a greater or lesser extent.

Consequently, it is necessary to devise a solution to the problem of flooding by developing an Information System (IS) with the capacity to visualise the interaction between flood dimensions and route network. This, in turn, could enable an understanding of the flood impact on an object because impact of flooding can be termed as the probability of interaction between flood dimensions and real world object (Hossain and Davies, 2002). Further, the system should be capable of identifying, classifying and evaluating the various levels of flood impact on the route network and displaying them in both two and three-dimensional ways. This could provide a scope to analyse and visualise the physical impact of a flood on a route network in a qualitative way. Since the flow of traffic (activities domain) is dependent upon the availability of a route network, the system could be used to visualise the flood impact on characteristics (traffic volume, travel time, speed) of traffic flow, in both qualitative and quantitative ways. The above could facilitate to support decision-making processes to reduce flood impact on the road transportation systems.

Therefore, the paper presents the development of such a system within the framework of an advanced software life cycle. Since both the flood and road transportation have strong spatial existence, GIS technology, which allows displaying and manipulation of all forms of spatial data (Coppock, 1995), has been considered as the appropriate environment to build the system. The initial findings of the research, obtained from the application of the system, are also presented. The findings could facilitate an understanding of the applicability of the system as a tool to analyse and visualise the impact of flooding on the road transportation from various perspectives.

Bangladesh has been chosen as the principal study area for this research, as it is prone to frequent and debilitating floods, often followed by loss of life and heavy economic damage (Hossain and Davies, 2002). The route network system of the country undergoes frequent disruption each year, causing great suffering to the population. The prototype GIS-based system will form the basis for future investigation into emergency planning and impact assessment of the Bangladesh flood problem with particular reference to road transportation system. Clearly, such a system will also be highly relevant in any area of the world subject to flooding.

2. Flood Impact on Bangladesh Road Transportation

The route networks of Bangladesh undergo frequent disruption every year, which causes much suffering. The effect of flooding on even a small part of the route network in Bangladesh can cause flood impacts on a much greater part of the route network (Hossain, 2000). This is followed by substantial changes in the characteristics of traffic flow on the entire network, including increase in travel time, reduction of speed limits and decrease in traffic volume.

In the worst-case scenarios, some areas of the country can be completely cut off from other parts because of the closure of a road by flooding. In such cases, there is often an absence of alternative routes available to reach the people in flooded areas so the community of that area becomes virtually isolated.

3. The System

The GIS-based system, presented in this paper, has been developed by considering the different phases of the Software Development Lifecycle.

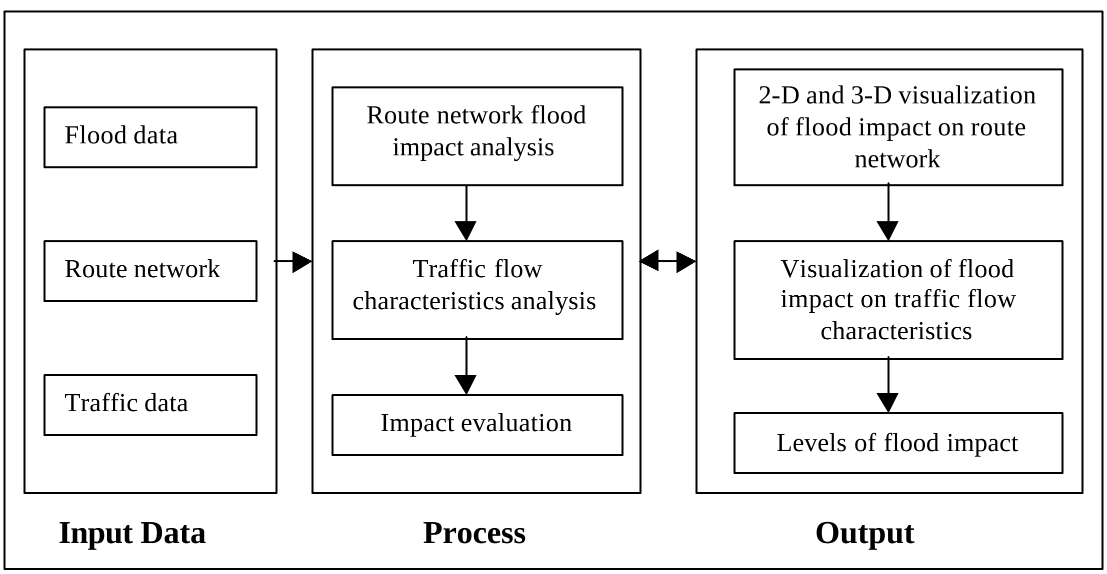


Figure 1. Outline System Architecture

Figure 1 illustrates the essential system architecture for the system following as it does a consideration of the data, processes/functions and output from the system.

The system utilises average flood depth map based on historical data in GRID format, with the details of the route network in the format of an ARC/VIEW shapefile (digitised from 1:250,000 scale map) and the traffic characteristics data in Microsoft Access (mdf). All data is co-ordinated and held in standard ARC/View data repositories as discrete entities. ARC/View has been chosen as the main implementation environment for this work as it provides all the necessary facilities required and will run in the initial target environment of the Bangladeshi Government.

4. System Applications

The application of the system in visualising the flood impact on the route network in both two and three-dimensional ways, considering a higher-level administrative unit of Bangladesh, named *Sylhet*, is presented in this section.

4.1 2-D Visualisation of Flood Impact

Figure 2 illustrates the impact of flooding for a 20-year return period of flood, while Figure 3 illustrates it considering 50-year return period of flood. It can be seen that the impact of flooding on the various links of the route network is not the same for the two different kinds of flood.

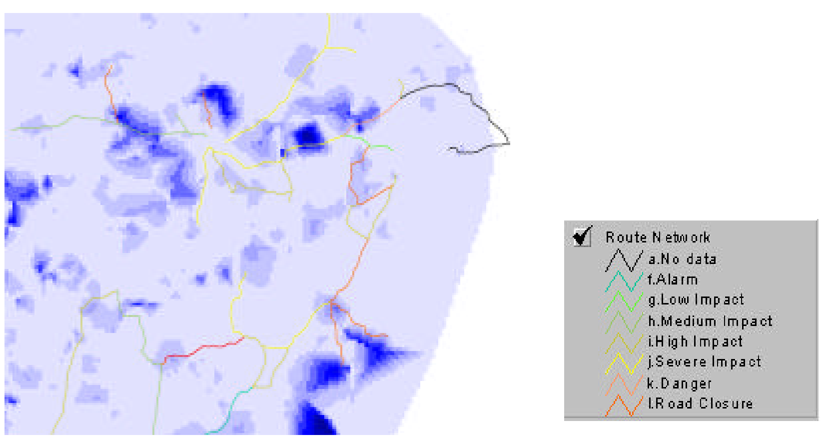


Figure 2. 20 Years' Flood Impact on Route Network

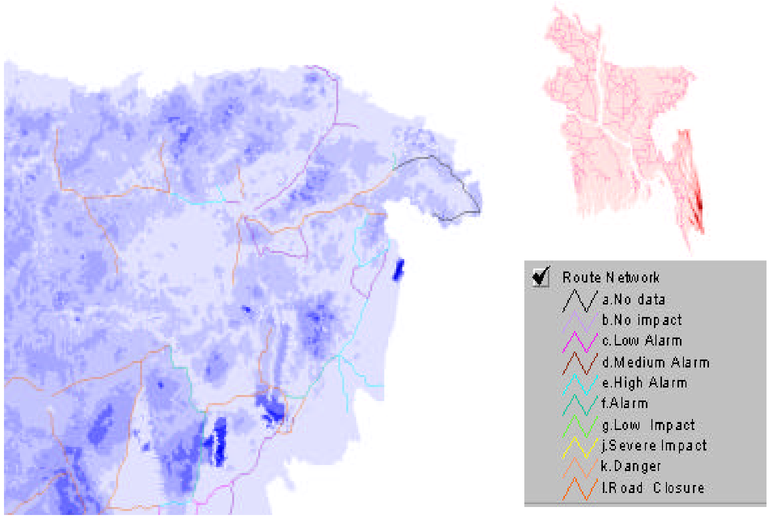


Figure 3. 50 Years' Flood Impact on Route Network

This can be better understood from the interpretation of Figures 4 and 5. Figure 4 illustrates that the route links 1,2 and 3 are completely closed because of a 50-year period. On the other hand, Figure 5 illustrates that the 20-year flood can produce less flood impact on the two links (1,2), while it produces the highest impact on the third link (3).

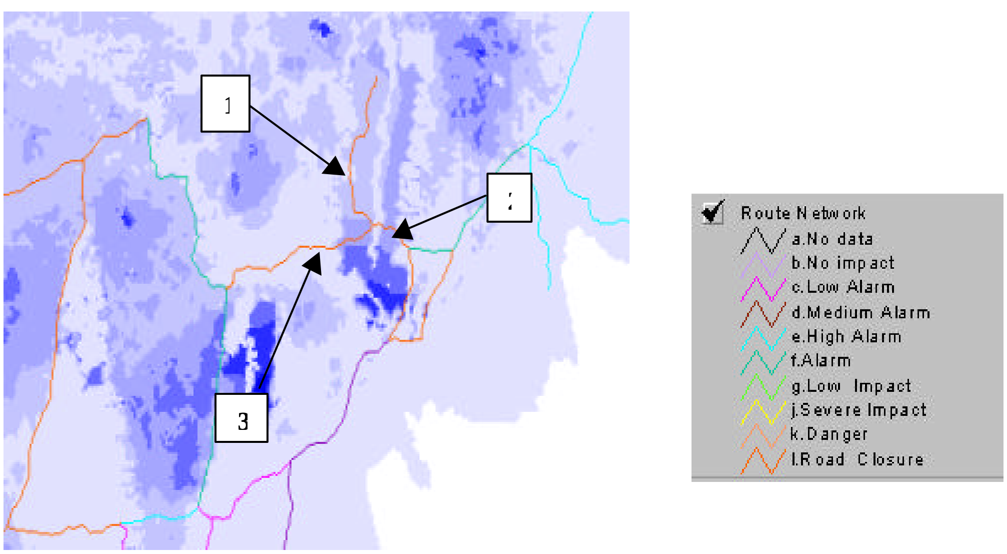


Figure 4. 50 Years' Flood Impact on Route Network (Selected larger view)

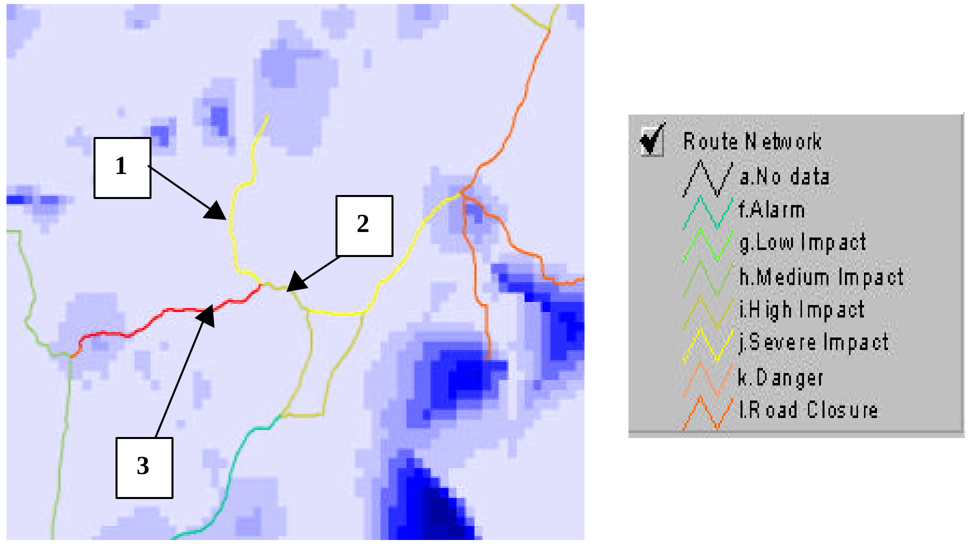


Figure 5. 20 Years' Flood Impact on Route Network (selected larger view)

In this way, different scenarios of flood impact on the same route links for different kinds of flood can be visualised using the system. Hence, by looking at different scenarios of flooding the system can be used to analyse (identify, classify and evaluate) and to visualise (two-dimensional way as illustrated in graphics part of Figures 5 to 7) the flood impact on a route network in a qualitative way.

4.2 3-D Visualisation of Flood Impact

Figures 2 to 5 visualise the impact of flooding on the route network in a two-dimensional way, which covers only the areal dimension of a flood. Therefore, by considering both the areal and depth dimensions of a flood, a visualisation of the flood impact on a route network in a three-dimensional way is necessary.

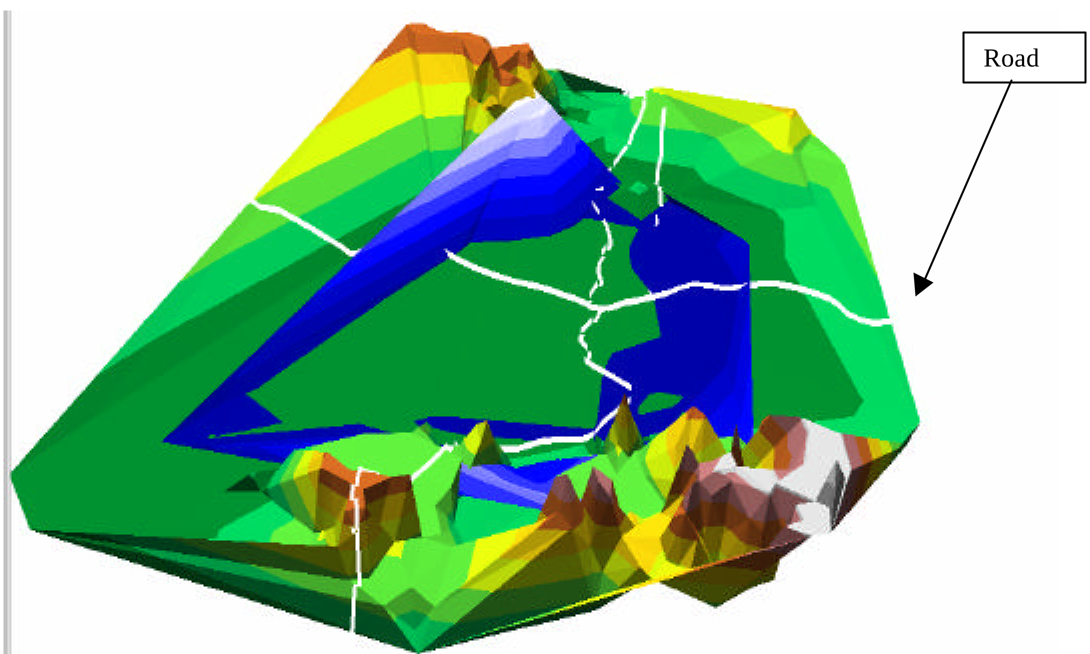


Figure 6. 3-D Visualisation of Flood Impact on Route Network

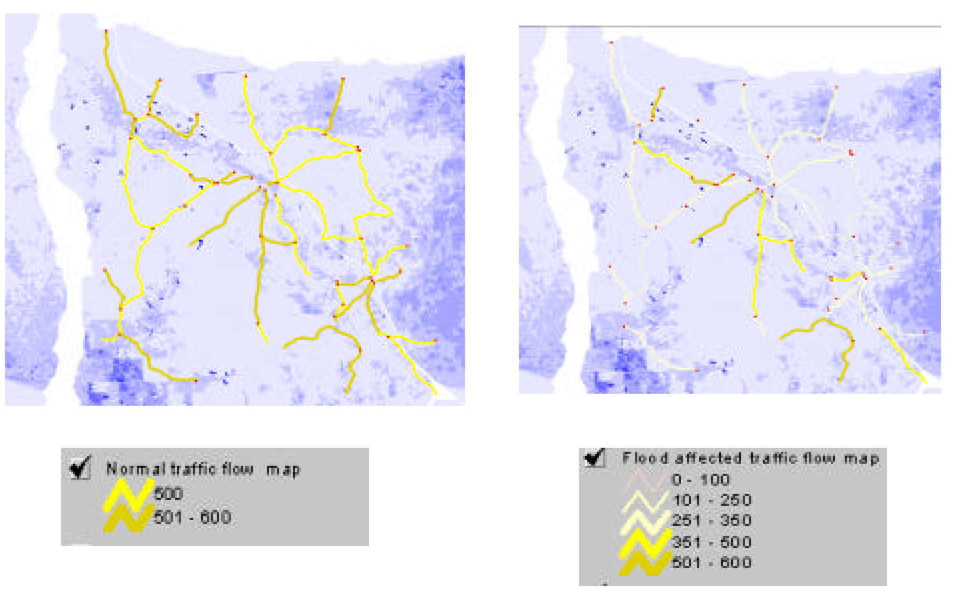
Figure 6 illustrates the impact of flooding on the route network in a three-dimensional way, which enables the identification of the portions of the route network that are under water or not in a clear way. A 2-D visualisation or analysis of the flood impact on the route network cannot achieve this.

4.3 Visualisation of Flood Impact on Traffic Characteristics

Considering the national level route network of a region of Bangladesh (*central Bangladesh)*, the system has been used to analyse and visualise the impact of flooding on the various characteristics of traffic flow.

4.3.1. Flood Impact on Traffic Volume

Figure 7 (a) illustrates the normal traffic volume on the route network of the study area, under flood-free conditions. On the other hand, Figure 7 (b) illustrates the changed traffic volume on the route network under flooding condition, because of its physical contact with the floodwater. Figure 7(b), shows that the traffic volume on some of the links of the route network has been tremendously reduced; in many case it



(a) Normal Traffic Flow (b) Flood Affected Traffic Flow

Figure 7. Flood Impact on Traffic Flow (Changing Scenario)

is in the range of 0-100 (vehicles/hour). This in turn could disrupt the movement of commuters and thus bringing suffering to the people of the study area. Hence, the system can allow analysis and visualisation of the flood impact on the traffic volume as well as on other characteristics of traffic flow including *speed restriction, travel time* and *traffic service level.*

5. Discussion and Conclusion

An extensive literature review (Hossain, 2002) indicates that there is an absence of a GIS-based system to assess the impact of flooding on road transportation. However, a number of other systems (Shibata, 1997; Isil, 1996) currently exist related to the assessment of the impact on road transportation for other disasters such as earthquake and man-induced hazards. These systems are limited to the visualisation of the impact in a two-dimensional way, which covers only areal dimension. Therefore, a clear identification of the portions of the route network, which are affected or not is difficult to perceive. On the other hand, the system, presented in this paper, provided a means to identify distinctly the portions of the route network that are under water or not (Figure 6), as it does consider a three-dimensional visualisation. This, in turn, enables a visualisation of the interaction between the flood and the route network and therefore the ***presented problem***.

Further, referenced systems, do not include the procedures to analysis (classification and evaluation) the impact on a route network in a qualitative way. Therefore, it is difficult to identify the route networks or their associated traffic flow, most or least vulnerable to the impact of a disaster. Studies of similar systems (Damen and Westen, 1999; Ochi et al., 1991) to assess flood impact on other objects apart from the road transportation also show that they inherit the drawbacks of the referenced systems mentioned above.

On the other hand, the system, presented in this paper, can effectively classify the levels of flood impact on the route network (Figures 2 through 6) and this enables an evaluation of the impact in a qualitative way. Besides this, the system can successfully visualise the flood impact on the characteristics of traffic flow as the consequences of the inundation of the route networks (Figure 7). The above could support engineers and planners of a country in their decision-making processes to ensure the movement of traffic from one place to another during the flood period. Hence, the system has the potential to be used as a decision support tool to reduce the flood impact on road transportation.

References

Bruton, M.J.(1995) *Introduction to Transportation Planning* (3rd Ed.), Hutchinson, London, 1995, ISBN 0-09-1580412.

Coppock, J.T. (1995), "GIS and Natural Hazards: An Overview from a GIS Perspective". In Carrara, A. and Guzzetti, F. (eds), *Geographical Information Systems in Assessing Natural Hazards*, Kluwer Academic Publishers, Netherlands, pp. 21-34.

Damen, M.C.J., and **Western, C.J. V.** (1999). *Model of Cyclone Hazard in Bangladesh*, International Institute of Aerospace Survey and Earth Sciences (ITC), Netherlands. http://www.itc.nl/dev/applic/app03.htm,

Davies, C.G., and Hossain, M.S. (2000) "Flood Risk Assessment of National Transportation Networks", *Proceedings, 20th ESRI International User Conference*, ESRI, California, July 2000, CD-ROM.

Hossain, M.S., and **Davies, C.G. (2002),** An Information System to Analyse and Visualise Flood, *Proceedings, 5th International Conference on Computer and Information Technology (ICCIT)*, December 2002, Dhaka, Bangladesh, ISBN 984-43-0450-6.

Hossain, M.S. (2002). *A Method to Reduce Flood Impact on Road Transportation Systems*, PhD Thesis, Department of Computation, University of Manchester Institute of Science and Technology (UMIST), U.K.Unpublished

Hossain, M.S. (2000). *An Investigation into the Provision of a GIS to Assess Risks Associated with Flood Disasters on Road transportation*, MPhil Thesis, Department of Computation, University of Manchester Institute of Science and Technology (UMIST), U.K.Unpublished

Isil, B. N. (1996), *Risk Assessment for Highway Transportation System,* DAI, 1996, vol.57-08B page 5198, 358 pages. http://www.proaxis.com/ greenem/

Davies, C.G., and Hossain, M.S., (2001), "A System for the Simulation and Prediction of Floods". In Kidner, D.B. and Higgs (eds.), *GIS Research in the UK, Proceedings of the GIS Research UK 9th Annual Conference GISRUK 2001*, University of Glamorgan, Wales, UK, ISBN 1-840540-26-5, pp.490-494.

Maguire, D.J. "GIS customisation", in P.A. Longley, M.F. Goodchild, D.J. Maguire and D.W. Rhind Maguire, D.J and Rhind, D. W. (eds), *Geographic Information System: Principles and Technical Issues*, (2nd Ed.), Jhon Wiley & Sons Inc., New York, 1999, Vol.1, pp. 359 – 369, ISBN: 0471-33132-5,

Ochi, S., Rahman, M.N., and **Kakiuchi, H.** (1991), "A Study on Flood Risk Evaluation in Bangladesh Using Remote Sensing and GIS", *Journal of the Japan Society of Photogrammetry and Remote Sensing*, Vol. 30, No. 6, pp. 34-38.

Shibata. F. (1997), "Road Maintenance System Providing an Integrated Picture of Damaged Highways at Disaster Time", *Proceedings, 17th ESRI International User Conference*, ESRI, California, 1997. http://www.esri.com/library/userconf/proc97/

Solway, L. "Socio-Economic Perspective of Developing Country Megacities Vulnerable to Flood and Landslide Hazards". In Casale, R. and Margottini, C. (eds), *Floods and Landslides: Integrated Risk Assessment*, Springer-Verlag, Berlin, 1999, pp. 245-260.

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