Chapter 2
Geo-hazards Science and Management

2.1 Introduction

My association with Geo-sciences came about from being raised in the oil rich city of Kirkuk and being surrounded by oil and gas production and wanting to 'belong' to this world. I managed to gain entry in 1977 and successfully obtain an undergraduate degree in Geology from the University of Baghdad during 1979. It was then; I thought I had found a suitable home for my academic interests. This was followed by an M.Sc. in geophysics and a position with an oil exploration company. My Geo-sciences background was helpful with establishing a profile in the discipline through obtaining research projects and conducting consultancy activities as well as involvement in supervising student projects, in the UK, Malaysia, the Caribbean and Australia.

My research in Geo-sciences based issues has evolved as a response to my active involvement with international research groups and societies, relocations and the need for developing solutions for and managing geo-science based challenges such as floods and landslides in these new countries and locations, I called home for a number of years. For example, when I moved to the Caribbean during September 2000, it was evident that floods and landslides occur frequently and tend to dominate all aspects of life on the Small Island States (Fig. 2.1). Hence, within a year of moving to the region, established a research focus on managing these issues. My approach was founded on developing prediction approaches and progressed based on advancing the *deductive* and *pro-active approaches* for managing the dominant geo-hazards of floods and landslides. In Australia, coastal erosion represents a serious problem; hence, I initiated investigations into coastal erosion with Darwin City Council in North Australia. The sections below will provide details of my research in geo-hazards science and management worldwide.

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Fig. 2.1 Floods and landslides in the Caribbean region

2.2 Geo-hazards Science and Management in Iraq

I started my research in geo-hazards science and management through my M.Sc. degree in 1981–1983, with studies of induced seismicity using Geo-sciences and Environmental Geophysics to examine the possible impacts of a water column and volume in the Hemren Dam Lake on the seismicity of the surrounding area (Fig. 2.2)

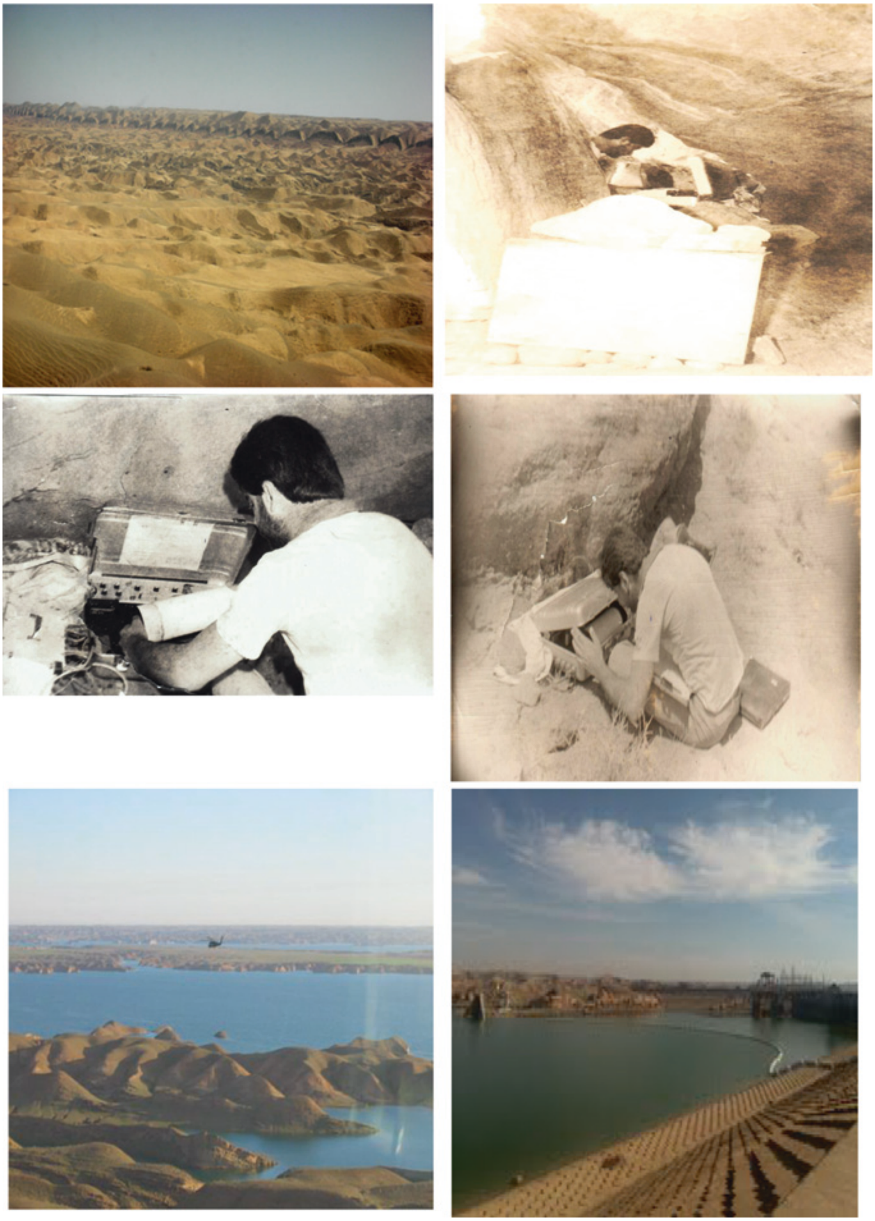

Fig. 2.2 M.Sc. field work and the research site at hemren dam area during 1983

My thesis is entitled "*Microearthquake Monitoring of Hemren Dam Area, Iraqí*". The project involved continuous recording of seismicity for 4.5 months, analysing those records, modelling and data analysis. Historical seismicity was also examined. I concluded that the background seismicity in the area was related to tectonic forces and geological formations. Furthermore, the recorded induced seismicity was associated with the level and residence time of water in the reservoir. Consequently, recommendations were made for operating the reservoir safely and contributed to establishing the seismic code of the area. I completed and passed all the taught modules with an overall First Class mark during 1983.

This research was published a paper in the *Second Iraqi Hydrological Conference,* on the Seismological Engineering considerations for the Hemrin Dam Area (Alsinawi and Baban 1984); I also collaborated with Professor Sahil Alsinawi (my M.Sc. supervisor) and compiled a comprehensive inventory for Historical Seismicity of the Arab Region. This work was published in the *proceedings of the Symposium on Historical Seismograms and Earthquakes of the World* (Alsinawi et al. 1985). The analysis part of my M.Sc. thesis, which dealt with the seismicity of the Hemrin Area, was published in the proceedings of *the 27th International Geological Congress* (Alsinawi and Baban 1986), and was revised and published as my first publication in a referred journal paper in the *Journal of Geological Society of Iraq* (Alsinawi and Baban 1986). My M.Sc. thesis also produced 4 conference abstracts for conferences in the *Union of Soviet Socialist Republics* (USSR) and Japan (Baban and Alsinawi 1984a, b, 1985).

During October 1985, I was offered and accepted the post of a *Geophysicist and Party Manager Assistant* by the Exploration Division in the Iraqi National Oil Company. Here my duties included supervising all scientific aspects from planning to production and quality control as well as performing all Geophysical duties in the seismological party. I was also responsible for managing and motivating a team of 150 staff working under severe conditions.

All through this period, I developed an interest in communicating science to the public through writing for popular science magazines with wide circulations in the Middle East, these included articles in *Uloom (Science) Journal* with topics ranging from the *Causes for the formation, development and distributions of deserts on the planet earth* (Baban 1985a) to *Large sea creatures committing suicide or being misguided by the magnetic field* (Alsinawi and Baban 1986) as well as *Space imagery unveils similarities between Earths and Mars deserts*. I also developed articles for several National Newspapers in Iraq including articles on *Glaciers and the awaited ice age* (Baban 1985a), and articles on the possibility of predicting earth quakes including an article entitled, *Can animal's strange behaviour prior to an earthquake be used as a prediction tool*? (Baban 1985b). These activities paid reasonably well and formed an unexpected and welcomed source of income.

2.3 Geo-hazards Science and Management in the UK

My geo-sciences background and knowledge was helpful for obtaining two posts immediately after completing my Ph.D. from the School of Environmental Sciences, University of East Anglia. First, I was employed as a *Research Associate* dealing with coastal zone management scenarios (Fig. 2.3). Here, I was

Fig. 2.3 Coastal erosion in east Anglia UK

responsible for categorising and mapping urban patterns in the coastal areas of East Anglia and estimated natural and defended rates of erosion and contributed to calculations of resulting economic losses. In addition, I examined possible scenarios (Abandon to nature, Stand firm and nourish and Set back and rebuild) for each coastal sector and recommended the most cost effective scenario within a certain time span. My second post was a *Senior Research Associate* analysing the solid geology and relief information for selected parts of the UK. Here, I analysed, modified and established new solid geology sub-groups within the defined groups. Furthermore, I formulated the datasets and established a database for the solid geology and relief information.

At Coventry University, my interests in Geo-sciences were strengthened through postgraduate research, funded research and consultancy activities. Through a successful Ph.D. student (in association with Dearing), I was involved with measuring and mapping magnetic susceptibility of topsoil's in England; and using soil magnetism to identify and map environmental pollution. This research produced a publication in *Geophysics Journal International* (Dearing et al. 1996) and a publication in the journal of *Physics and Chemistry of the Earth* (Hay et al. 1997) and a conference presentation (Fig. 2.4). Through another successful Ph.D.

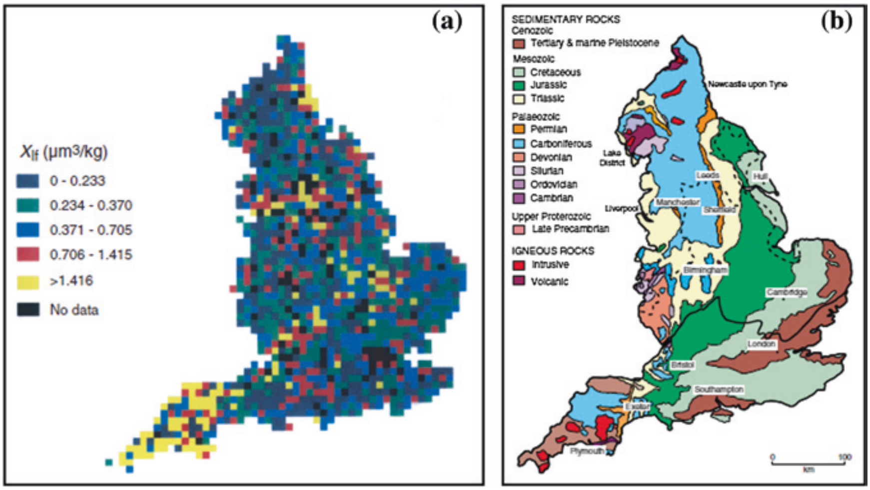

Fig. 2.4 Magnetic suitability values for english topsoils (**a**) and major cities, geological and glacial limits in England (**b**) (Dearing et. al. 1996)

student (in association with Ian Foster), we examined the spatial variability of soil nitrates in arable and pasture landscapes, nitrate leaching and the development of Geographical Information System to model this process. The thesis aimed to support the implementation of Nitrate action programmes. Some of the outcomes dealing with the development processes for setting up a GIS for mapping nitrate vulnerability was published in the proceedings of the *National Hydrological Society/Midlands Research Meeting* (Wade et al. 1993) whilst issues dealing with the spatial variability of soil nitrates in arable and pasture landscapes and the implications for the development of Geographical Information System models of nitrate leaching was published in the Soil *Use and Management* journal (Wade et al. 1996).

2.4 Geo-hazards Science and Management in Malaysia

During 1996, in a conference, I met some colleagues from Malaysia, it was then I was made aware that soil erosion is a critical problem due to large scale land clearance operations driven by rapid development on Langkawi Island (Fig. 2.5). Hence, I suggested that Land degradation has always been associated with the failure to identify areas that are prone to soil erosion. I proposed and they agreed that having a soil erosion map would be useful in the decision-making context to avoid land acquisition in the erosion risk areas or alternatively to recommend soil conservation measures to reduce soil loss if developments were to continue. A few months later, I started to supervise a Malaysia Ph.D. student working on these issues in Lagkawi Island, Malaysia. Whilst conducting fieldwork on Langkawi Island during

Fig. 2.5 Land clearance and deforestation in Malaysia due to the development process as well as growth of oil palm estates

1997, meeting local scientists and recalling previous discussions, I am become involved. An additional factor for increasing deforestation and land clearance on a large scale is the growth of oil palm estates as most of the world's oil palm trees are grown in Malaysia. A report published in 2007 by the United Nations Environment Programme (UNEP) acknowledges that oil palm plantations are now the leading cause of rainforest destruction in these two countries (Fig. 2.5). I learned that land surveying using conventional methods is expensive and time consuming. In contrast, mapping soil erosion using the integration of remote sensing and GIS could identify areas that are at potential risk of extensive soil erosion and provide information on the estimated value of soil loss at various locations. In addition, it can provide answers to spatial queries; for instance, whether the erosion is associated with specific factors such as the loss of continuous vegetation cover. Our review showed that the Universal Soil Loss Equation (USLE), developed by Wischmeier and Smith (1978), has been used within a Geographical Information System (GIS) framework to calculate the total erosion loss. Furthermore, the spatially distributed parameters involved in the equation such as topography and land use, could

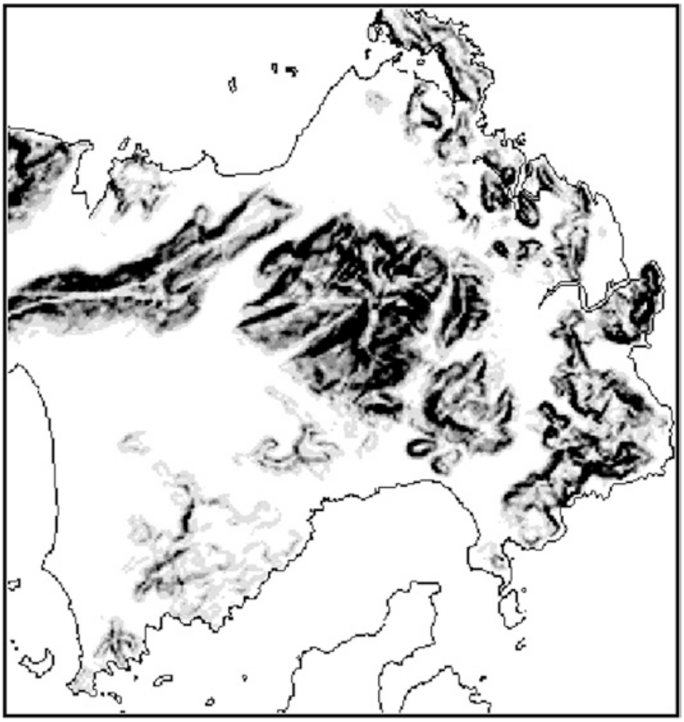

Fig. 2.6 High erosion risk areas (Wan-Yusof and Baban 1999)

be generated by remote sensing techniques (Moore and Wilson 1992). These can then be converted into raster layers to input into a GIS to be analysed and, to produce a soil erosion risk map. I noted that in Malaysia, several soil erosion studies have been conducted using this approach. These include the soil erosion study of the Bakun Dam project (Samad and Abdul Patah 1997) and soil erosion risk assessment for genting highlands (Jusoff and Chew 1998).

My research, through the Ph.D. project, developed a soil erosion risk map for Langkawi Island, using the Universal Soil Loss Equation (USLE), remote sensing and GIS. Spatially modeling soil erosion in the GIS required generating representative raster layers based on secondary data for the following parameters in the equation; rainfall erosivity, slope length/gradient, soil erodibility and conservation practices. Landsat images were utilised to produce a land use/cover map of the Island. This map was then, used to generate the conservation practice factor in the USLE equation. Upon comparison, the produced erosion map showed significant similarities with an erosion risk map of the Island produced by conventional means in 1986. The majority of high erosion risk areas were confined to the highlands (Fig. 2.6). This erosion risk map was a valuable resource for planners to minimise soil erosion problems caused by future and ongoing development projects on the Island. This process can be repeated in the future using updated

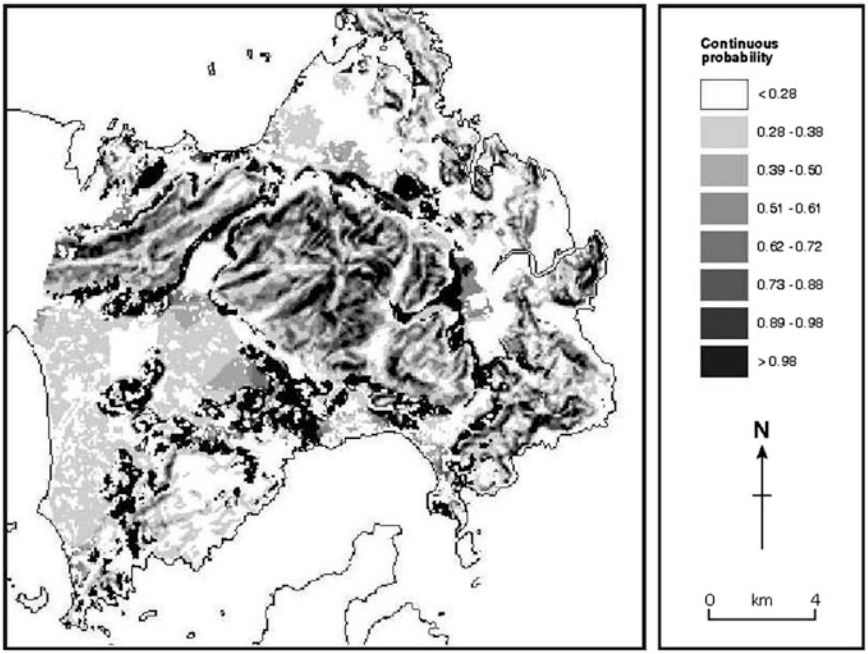

Fig. 2.7 Probability of soil erosion assuming a 10 % risk (Baban and Wan-Yusof 2001)

remotely sensed data to monitor and manage all related issues. This work was presented and published in proceedings of the 20th *Asian Conference in Remote Sensing* (Wan-Yusof and Baban 1999).

Our approach and the GIS in this context was the norm then, however, it occurred to me that this approach is based on two assumptions; firstly, the datasets are free of errors and secondly, the decision rule does not add any error to the final outcome. However, it is evident that all geographically based datasets contain incorrectness. Furthermore, there are uncertainties associated with the decision rule originating from the way in which criteria are coupled to reach a decision. This realization has encouraged me to move towards less rigid decisions, where; given the uncertainties in the data and in the decision rule, it is possible to convert the rigid results of traditional GIS decisions into malleable probabilistic outcomes which present the outcomes in terms of the likelihood of soil erosion in specific geographic locations. This approach has introduced the concept of acceptable and unacceptable risk into the decision makers considerations. Hence, I developed an approach to produce soil erosion probability maps under various case scenarios, by accounting for uncertainties in the data and in the decision rule, using the Universal Soil Loss Equation (USLE), remote sensing and GIS. The outcomes were two continuous probability soil erosion maps indicated that accounting for the uncertainties has in general decreased the probable soil erosion risk. Assuming a 10 % risk (Fig. 2.7), this impact has increased by 12, 11.8 and 5.7 % for high, medium and low soil erosion risk areas on the Island respectively. This research has added a valuable tool for decision makers based on the binary approach to risk management, i.e. acceptable and not acceptable risk, it was recognized by the scientific community and published in the *Hydrology Sciences Journal* (Baban and Wan-Yusof 2001).

2.5 Geo-hazards Science and Management in the Caribbean

When I arrived in Trinidad and Tobago, which is a partially hilly and mountains tropical environment, during September 2000, I noted a large number of landslides on the hillsides, was told about the flooding problem in the region and how these events tend to dominate all aspects of life when they occur. Having lived in England I thought we *have landsides* and *floods too, but life goes on…* I had a very real awakening during November (and every November for the next 7 years), the rainfall was copious and relentless, the landslides started to block some of the main road networks and the floods were ravaging residential areas and farms. This was different from anything I had previously experienced, it had a direct impact on daily life and was touching everyone on the Island, my neighborhood was flooded, outside my office on the Campus was flooded then pubic service was disrupted, the price of vegetables doubled over night and so on. It was very personal. Evidently, due to land space and economic limitations, the effects of landslides and floods had a significant impact upon the livelihood and the economies of small mountainous tropical islands such as Trinidad and Tobago. This is mainly due to the existing favorable physical conditions, as it became clear after several field visits, for landslides and their triggers, lack of effective management coupled with the increasing demands of development, tourism and population growth.

I was called upon by the community and the University, to help develop some solutions and options to manage Geo-hazards on the Island and naturally, I was keen. However, it became clear that the absence of a recording system for landslides and floods was hindering the investigation of landslide susceptibility in many Caribbean Island States. This in turn has had a negative influence in the formation of proper National Planning Policies and Property Insurance Systems. In the worst cases scenarios, developments are permitted on slopes liable to failure without adequate slope stabilization.

2.5.1 Landslides

During this period, I learned that landslides in the Caribbean can occur as a result of a number of determining and triggering factors (Fig. 2.8). Therefore, landslide susceptibility analysis will invariably require the identification and

Fig. 2.8 Landslides in Trinidad and Tobago, West Indies

quantification of these factors (Varnes 1984; DeGraff et al. 1989). In practice, any single or combination of technique(s) may be employed for landslide hazard analysis and there is generally no accepted single method that can be applied to all situations and environments. The selection of an appropriate landslide hazard modeling approach is therefore dependent upon the management scale, site-specific conditions and data availability (Carrara et al. 1997). In this context, the Geographical Information Systems (GIS) is a promising instrument in the analysis of landslides and floods through its ability to handle large data sets, providing an efficient medium for analysis and display of results, with a powerful series of tools that allow the collection, retrieval, manipulation and display of spatially referenced data representing the real world. Furthermore, GIS allows the integration of quantitative and qualitative data through their spatial distribution to yield spatial relationships that may not be evident otherwise. My research, within a year, developed a focus founded on the need for developing prediction approaches and progressed based on advancing a deductive approach for studying landslides founded on the concept that *conditions at known landslide sites within an area are reliable indicators of where future slope failures might occur.* More specifically; Landslides in the future will most likely occur under geomorphic, geologic, and topographic conditions that have produced past and present landslides. Underlying conditions and processes which cause landslides are understood; and relative importance of conditions and processes contributing to landslide occurrence can be determined and each assigned some measure reflecting its contribution.

My research developed and implemented GIS assisted methods for landslide susceptibility analysis for tropical mountainous environments using a varied weighted method. This was based on the concept that hazard assessments are estimations of an area's susceptibility to landslides based on key factors, such as topography, geology and land use/cover. Furthermore, that each factor is capable of being mapped and the number of conditions present in an area can then be factored together to represent the degree of potential hazard present. This research was published in *the Asian Journal of Geoinformatics (*Fig. 2.9) (Baban and Sant 2004). The concept was also tested and implemented for the Island of Tobago using geo-environmental indicators and was published as a chapter is a book dealing with managing Geo-hazards in the region (Baban and Sant 2008). Furthermore GIS and multi-criteria evaluation techniques were used to map landslide susceptibility in Tobago and the outcomes were published in the *Caribbean Journal of Earth Sciences* (Fig. 2.10).

I was also involved with developing a GIS based approach for locating and mapping critical slopes in mountainous tropical environments, examining Tobago as a case study, using factors (geology, slope, aspect, soil, rainfall and land use) that positively influence landslide occurrence. The outcomes were published in the West *Indian Journal of Engineering* (Baban and Sant 2006). Finally, I developed a number of geomorphological indicators for recognizing unstable slopes in Trinidad and Tobago and proposed preliminary management options. This work was published as chapter in a book dealing with geo-hazards management in the Caribbean region (Fig. 2.11) (Baban and Ritter 2008) and the possible applications to hillside developments was published in the *Journal of Sustainable Development* (Baban et al. 2008).

My research team also developed and published some general concepts for mapping landslides using geo-environmental indicators and to proactively managing geo-hazards (Baban 2009a, 2011). Finally, as non landslide specialists often tend to identify areas prone to landslides and endangering the public, our team

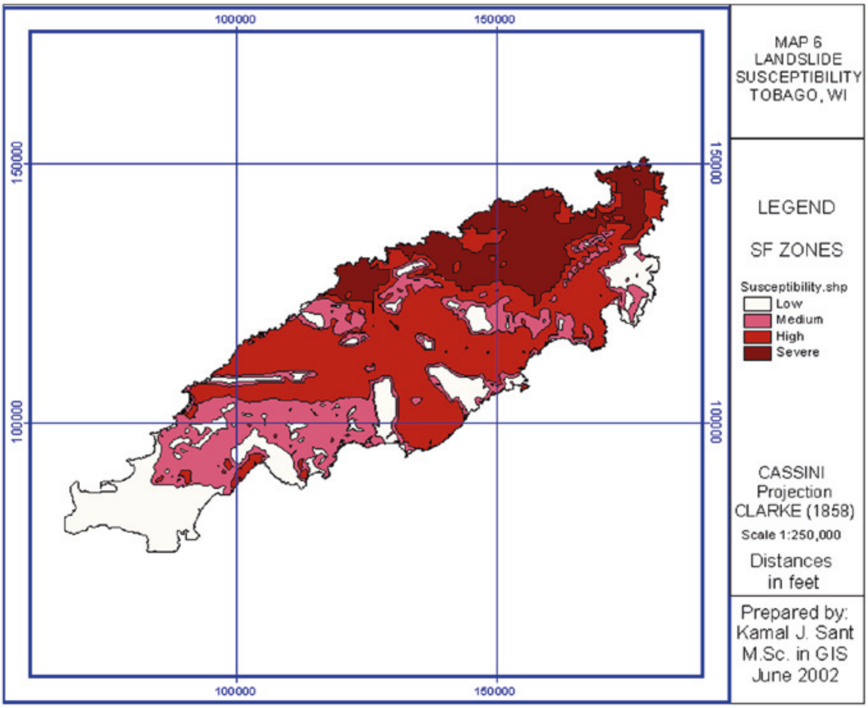

Fig. 2.9 Tobago landslide susceptibility map (Baban and Sant 2004)

developed a rapid field based assessment for non specialists (Baban 2009b), this has proven to be a simple practical tool for identifying potential areas prone to landslides and it is currently being used this purpose.

2.5.2 *Floods*

In Trinidad and Tobago flooding is a major problem occurring frequently and causing injury to persons, damage to infrastructure, economic losses and general destruction (Fig. 2.12). Flooding is seen as an increasing problem due to the combined and interlinked associations amongst population growth, development, economy and deforestation. As population increases, the need for cleared land to locate basic amenities such as electricity, pipe-borne water and roads increases. As a consequence, squatting for both housing and farming have increased, especially on hillsides, which means removing the trees and other vegetation. In fact, the Land Settlement Agency of Trinidad and Tobago now estimates the number of squatter households to be about 25,000 (Forestry Report 2001).

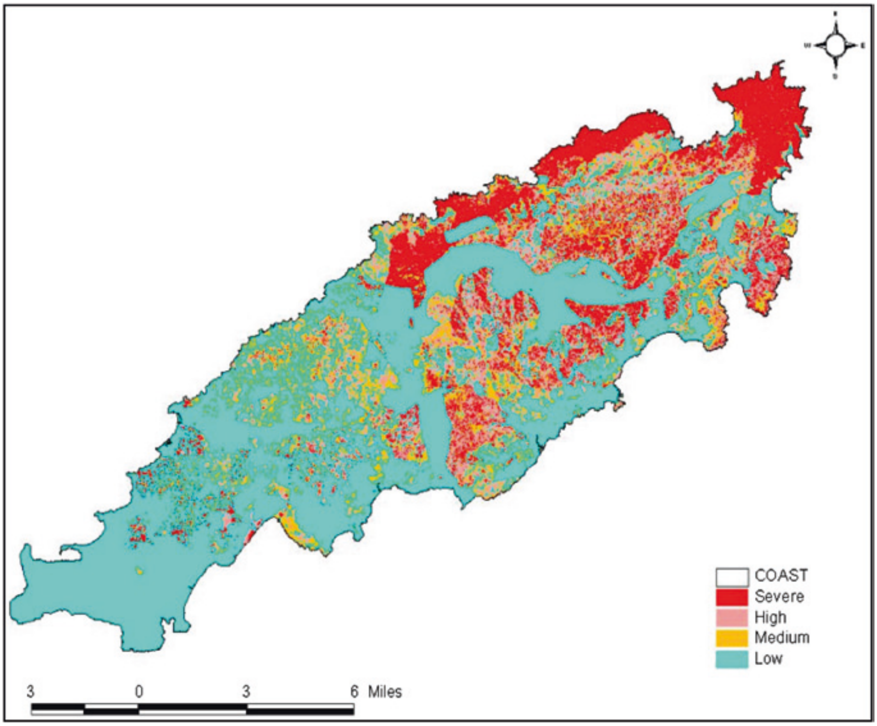

Fig. 2.10 Developed landslide susceptibility distribution map for Tobago (Baban and Sant 2005)

According to Menne et al. (2000), the main causes of flooding include:

- Climatic Effects: these involve the combined effects of weather systems (Cold and Warm fronts) wind speed, humidity and pressure.
- Topographic Effects: the presence of highlands can cause convectional rainfall.
- Anthropogenic: slash and burn, no soil conservation measures, blocked watercourses due to dumped and discarded litter, etc.

The orderly development of land, in feasible areas, is of utmost importance in managing all natural resources. The dramatic increase in population has led to an increased demand for land for housing, agricultural use and industrial sites. In the real world situation survival of the fittest leads to the grabbing of "prime land" by the financially able in society leaving others to fend for themselves. Those who cannot afford housing develop haphazard, illegal squatting settlements and farmers whose income does not allow them to purchase rich lands on the plains, turn to the mountain slopes for their survival. These approaches lack any real short or long term planning and their chaotic nature can lead to deforestation and soil loss, which in turn can cause flooding.

The Environmental Management Authority (EMA) of Trinidad and Tobago in their Environmental Impact Assessment Report (1992) sited the destruction

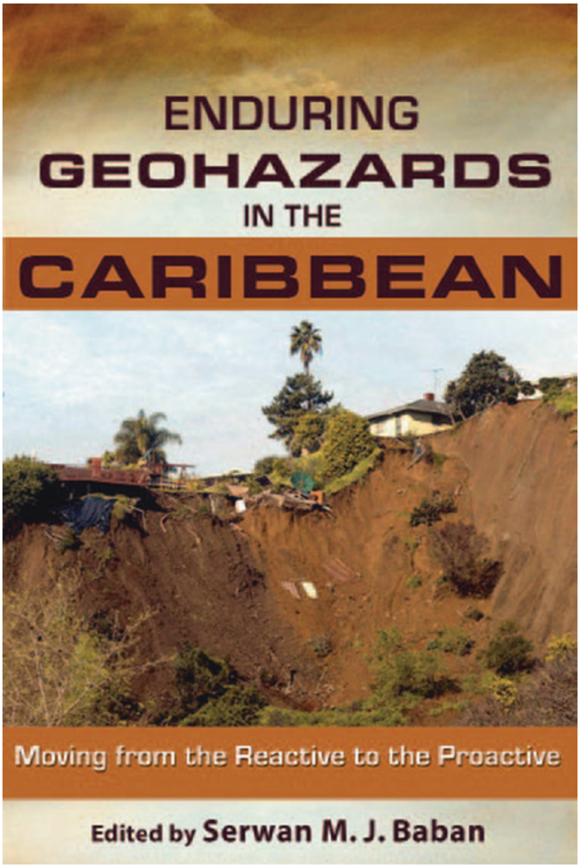

Fig. 2.11 Enduring geo-hazards in the Caribbean book

of watersheds as a major environmental problem. The destruction of watersheds result in loss of habitat for a wide variety of plants and animals and secondary effects include landslides and flooding, which causes damage to infrastructure, loss of property and possible loss of life. I have developed a view that to effectively deal with this problem, there must be an understanding of the intricate relationships existing between the eco-system and socio-economic activities in river basins.

GIS analysis is developed to examine spatial and temporal patterns and to find associations between various geographical factors. Since flooding is a spatial phenomenon and is a consequence of a number of factors (including soil type, vegetation cover and type, rainfall intensity, rainfall frequency, etc.) the GIS will allow the user to handle, manage and analyse the spatial data sets to determine which factors have which effect and to foresee the resulting consequences. One of the strongest assets of a GIS is the ability to carryout temporal analysis, which is essential for flood prediction. By storing data on previous floods, soil types and river channel size. It is possible to create a model of peak flow, discharge and

Fig. 2.12 Floods in Trinidad and Tobago, West Indies

runoff to determine what the consequences would be for a rainfall incident of a particular intensity and frequency. In terms of the impacts of land use/cover on flooding, GIS can not only be used to map change but also be used to identify trends, both visually and statistically, between land use changes and flooded areas. The use of a GIS allows further spatial analysis of the data derived from remotely sensed images and analysis of the impact of land cover change on regional sustainable development. The development of a flood risk assessment map is essential for planners and decisions makers in timing steps during pre-disaster preparation and post-disaster activities for the assessment of damages and losses due to flooding. Additionally, for developing countries where there is insufficient long-term datasets GIS can still be implemented with some level of success. Flooding cannot be completely avoided, but damages from severe flooding can be reduced if an effective flood prevention scheme is implemented.

My first research project dealt with the St. Joseph flood during November 2001 as indicated before. I found out that within the St. Joseph watershed, development in the agricultural sector and an increased need for housing for a growing population has lead to removal of the natural vegetation which has been replaced with pitched roads, concreted yards, galvanized roofs and bare soils. Not only has the earths' natural barrier been stripped, but the development in both sectors has been haphazard so that controlled rainfall runoff is difficult, if not impossible. Using field based data and GIS; I examined, through an M.Sc. project, the factors that may have played a part in flooding in the St. Joseph Watershed on the 5th November, 2001; including rainfall, deforestation, development/housing and squatting. As a result a Flood Risk Assessment Map (FRAM) for the St. Joseph Watershed was developed. Data collection and development included traversing,

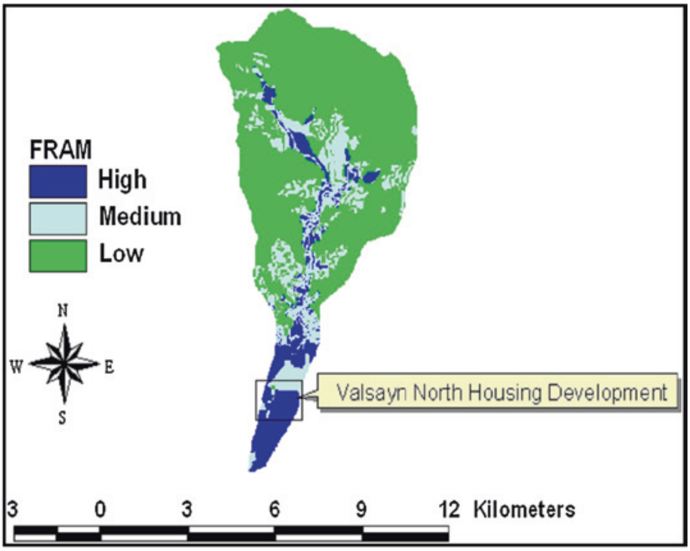

Fig. 2.13 The flood risk assessment map (FRAM)

collecting cross-sectional data for the river, developing information layers for road, soil, and vegetation. Additionally a Flood Depth and Extent Map for the Valsayn North Housing Development was developed and linked to population and losses due to the flood event of November 5th utilizing questionnaire, field survey data and photos (Fig. 2.13). A comparison between the latter and the developed FRAM indicated that the FRAM although basic has managed to predict areas susceptible to flood risk correctly. This study showed the power of GIS as a tool for developing both a FRAM, as well as flood depth and extent maps within a localized area (Valsayn Housing Development) and at a watershed scale, however it is important to note that the use of rainfall and climatic data and the analysis of these are essential in the overall development of any GIS output map. The development of a Flood Risk Assessment Map is indeed essential to allow the identification of possible risk factors and their location as well as the impact of each risk factor. Additionally the FRAM will give authorities greater foresight to areas that may be at risk so that preventative measures (physical earthworks or enforcing legislature) can be undertaken. These measures will not only aid in flood reduction but also, and probably more importantly the reduction in loss of infrastructure and life. This paper was published was presented in an international conference and published as a chapter in *IAHS Publication* (Baban et al. 2006). This concept was expanded to include flood sensitivity mapping and was published as chapter in a book dealing with geo-hazards management in the Caribbean region (Baban and Kantasingh 2008).

My second project dealt with Flooding in the Caparo River Basin which is considered to be a major problem in Trinidad. In the last few years especially; there have been many severe flooding events which have led to significant damage to livestock, agricultural produce, homes and businesses. I formed a view that there is therefore an urgent need to introduce mitigation measures to ensure that these areas are protected so that erosion and flooding is minimized. The first step in achieving this is to identify the nature and extent of vulnerability of the areas under consideration. Next, determine the most appropriate mitigation measures that should be used to address the problem. Finally, these measures must be implemented and maintained. Clearly there is a need for developing flood mitigation and management strategies to manage flooding in the areas most affected. This research utilised GIS to map the extent of the flooding, estimate soil loss due to erosion and estimate sediment loading in the rivers in the Caparo River Basin. In addition, the project required the development of a watershed management plan and a flood control plan. The results indicated that flooding was caused by several factors including clear cutting of vegetative cover, especially in areas of steep slopes that lead to sediment filled rivers, narrow waterways, poor agricultural practice, and uncontrolled development in floodplains. Hence, problems stem from the inappropriate use of lands that are vulnerable to erosion, quick water runoff and slope failure. Poor land use practices include slash and burn agriculture, quarrying, illegal logging, forest fires, and illegal settlements. These have lead to the soil becoming more exposed and therefore more susceptible to being washed away during periods of heavy rainfall and subsequent runoff. Consequently, heavy sedimentation occurs in the river channels causing these channels to be reduced in size. This ultimately leads to flooding (Fig. 2.14). In addition, the lack of vegetative cover leads to much shorter lag times between rainfall and the water reaching the waterways causing the already reduced channels to overflow leading to massive floods. Inappropriate land use is further exacerbated by several problems including the absence of relevant information on the level of vulnerability of different areas to damage due to these usages, the lack of political will to address the problems and the lack of adequate resources for the relevant authorities to enforce the laws of the country. For this study, GIS was successfully used in determining the extent of the problem including the identification of areas that needed conservation, the extent of soil loss and flooding at different sections of the watershed. The analysis provided by GIS made it possible to expedite the development of mitigation strategies that are most likely to address the anticipated changes in the river basin. Flooding in the Caparo River Basin may be mitigated if the recommendations provided are implemented in its entirety since the proposed strategies comprise of many interdependent components. Piecemeal implementation will not provide the appropriate results. This research was published in the leading journal in the filed, the *Journal of Environmental Management* (Ramlal and Baban 2008).

My third project dealt with developing and implementing a 'flood prone areas' concept. I was motivated by the facts that flood-prone—area maps can be used for flood hazard identification, regulation of future development, helping communities to understand where flood-prone areas are located, establishing flood insurance premium rates, and identifying areas having unique, natural and beneficial functions. Clearly, the actual impact of flood events depends mainly on the physical characteristics and the conditions of hydrological catchments. For example, if the

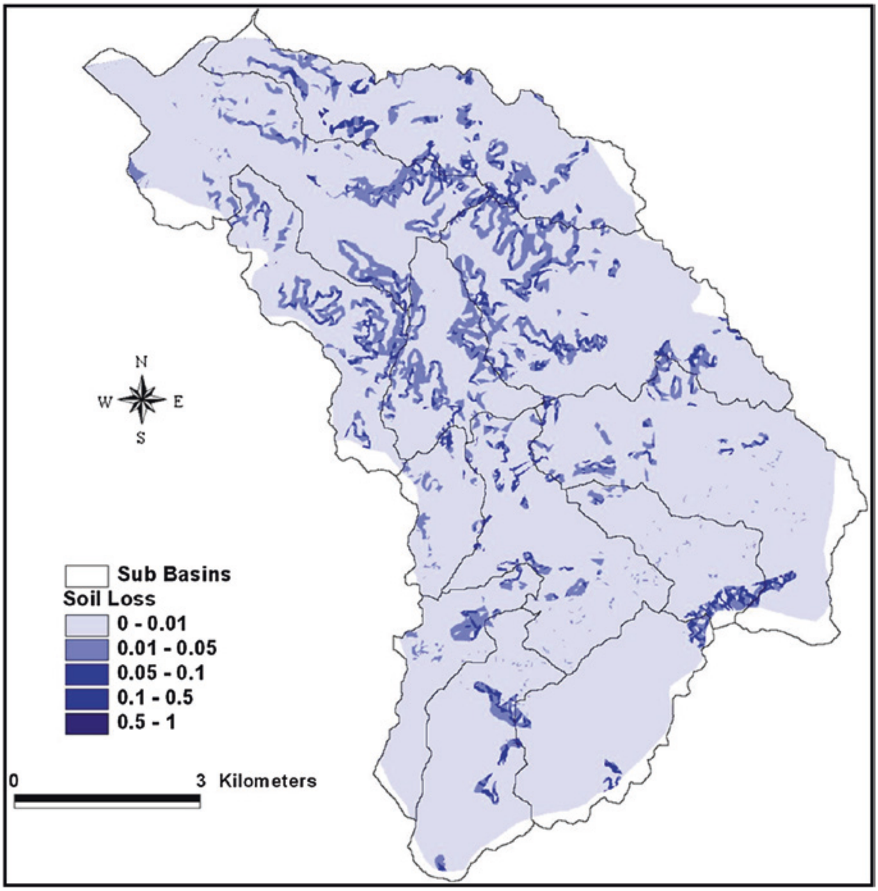

Fig. 2.14 Soil loss estimation for the Caparo river basin sub-catchments (cubic meters/sqkm). It should be noted that the blank areas on the boundaries of the map represent data gaps (Ramlal and Baban 2008)

topography of the catchment is steep, the velocity of the floodwater will be great, thus causing destructive damages, though the inundation areas would be limited and the duration short. However, if the topography of the catchment is gentle, the flood will be extensive and will last for a long period. Furthermore, if the vegetation cover and distribution within a catchment is poor, and the geology is fragile, the flood will carry and contain large amounts of debris and will be more destructive. Since humans historically have established settlements in river valleys, floods have created hazards for human communities for centuries. In turn, human activities involving environmental degradation, deforestation and inappropriate land use, often encourage flooding. Riverine flood waters often carry a considerable amount of sand, silt and debris that can block channels and dams, intensifying flooding upstream. It is evident that most of the extensive flood-prone areas are located along the coastal plains and riverine areas, which tend to coincide with densely populated and highly built-up areas.

Literature (Cooke and Doornkamp 1974; Smith 1991) indicates that the following are the most vulnerable landscape settings for floods:

1. Flat and low lying or areas with gentle slopes with poor drainage, in their natural state. These settings will suffer the most frequent flooding.
2. Low-lying coasts, deltas and estuarine areas are often exposed to a combined threat of floods from rivers and high tides.
3. Small catchment basin, basins characterized by a combination of steep topography, little vegetation and heavily developed urban settings.
4. Areas below unsafe or inadequate dams.
5. Low-lying inland shorelines.
6. Catchments with rivers functioning with reduced carrying capacity and flow constraints due to vegetation, tidal influences or infrastructure such as bridges and culverts.
7. Watersheds with short longitudinal axes. The time of arrival of a flood wave is generally shorter than for equivalent watersheds having longer longitudinal axes.
8. Watersheds characterized by high runoff, if the surrounding land has a high runoff potential, due to development of impervious soils.
9. Alluvial fans, which tend to have a history of flooding and often provide attractive development sites due to their commanding views and good local drainage.

However, mapping of flood-prone areas requires considerable collection of historical data, accurate digital elevation data, discharge data and a number of cross-sections located throughout the watershed. In the context, GIS provides a broad range of tools for determining areas affected by floods for predicting areas likely to be flooded due to high discharge of rivers. GIS can also be used to create interactive map overlays, which can illustrate which area of a community may be in danger of flooding, thus, coordinating mitigation efforts before an event and recovery after the event. Furthermore, the ability of GIS to develop three-dimensional topographical mapping and terrain modeling in the form of digital elevation models (DEM) is particularly useful for flood analysis and estimation (Jones et al. 1998).

This research aimed to identify flood-prone areas in Trinidad using a variety of sources, including available flood maps, topographic maps, aerial photos, DEM, newspaper articles, and historical data. Based on available data, 106 flood events were identified in Trinidad from 1986 to 2006 (Fig. 2.15). These events were analysed, related to geographical locations, and the areas that were repeatedly flooded during this 20-year period, were identified and mapped. The geophysical terrain characteristics such as slope, elevation, geology and rainfall for these susceptible areas for flooding were derived. These terrain characteristics were then used to identify potential flood-prone areas and to generate a map identifying these areas in Trinidad (Fig. 2.16). The developed methodology is simple and easy to implement. The outcome map is useful for hazard identification, the regulation of future development, and for the establishment of flood insurance premium rates.

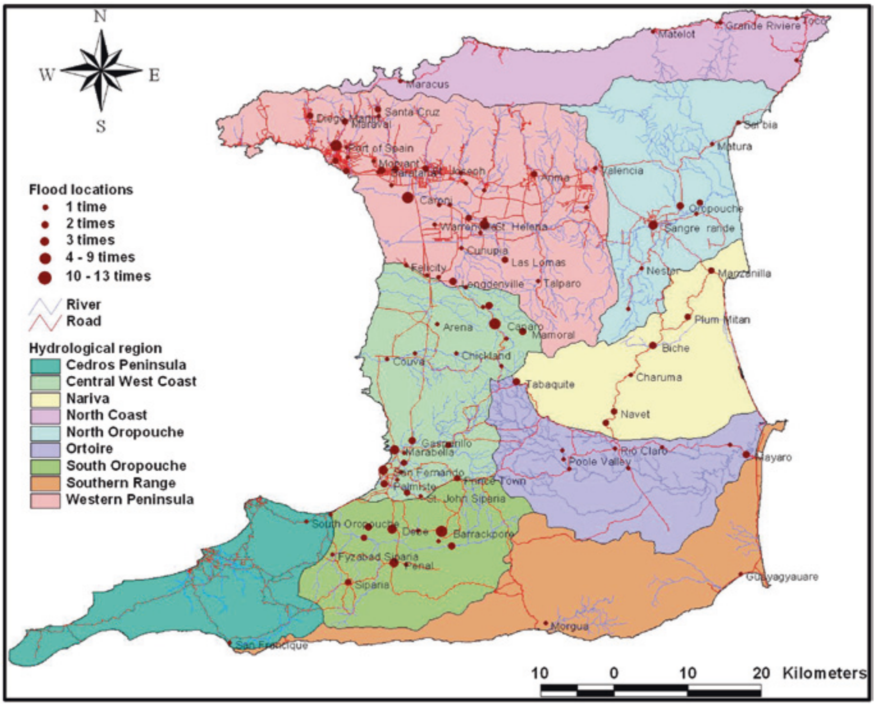

Fig. 2.15 Flood prone areas based on 106 events from 1986–2006 (Baban and Cannisus 2008)

This study shows a simple and cost effective methodology, which uses geographic information systems (GIS) for creating flood-prone maps from the available data on a national scale. It is acknowledged that accuracy of the key information, past records of flooding, and their geophysical characteristics, depends upon the scale that represents them. It is anticipated that the flood-prone map developed in this study will be employed for a range of uses, which may include insurance guidance, flood risk assessments, public awareness of various flood-risk zones, generation of flood-warning schemes, emergency evacuation planning, strategic road network planning, protection of key utility assets, water resources management and land-use planning. Another use of an understanding of the effects of inundation over time will be to help in the construction or reconstruction of infrastructure. If a detailed analysis shows specific flood duration patterns, then structures can be built in a way that mitigates impacts from future storms. The inundation history, conditions and duration, can also be used to make appropriate future planning scenarios. Due to lack of cloud-free satellite images and detailed DEM, we could not access the large-scale flood event and duration maps for critical flood events. Detailed study requires a large amount of local topographical and/or detailed data such as LIDAR and weather independent SAR data. This option is likely to be resource intensive to produce national-level maps. However, in some locations, it may be justified. Other than that, further research is required into

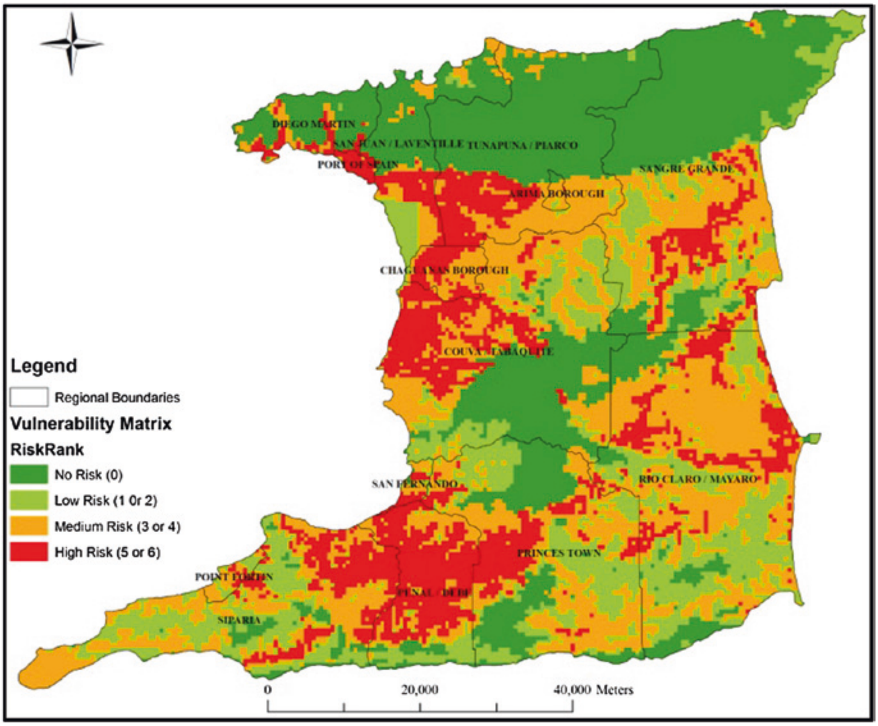

Fig. 2.16 Flood risk map of Trinidad (Baban and Cannisus 2008)

mapping pluvial flooding at the scales necessary for flood risk mapping purposes. This research was published as a chapter in a book dealing with geo-hazards management in the Caribbean region (Baban 1999).

The fourth project examined in more depth, the approach of identifying flood prone areas and focused on linking this idea to development utilising the concept of 'carrying capacity' at the watershed level. Clearly, there are advantages of using the watershed as a unit, in mountainous areas as this is not only a unit in the water regime, but is useful as an indicator for allocation of space for agriculture or human settlements. Even though Carrying Capacity has been used as early as 1838 in the context of logistic population growth (which evolved in the Verhulst–Pearl Logistic Equation), the concept of carrying capacity was first developed by Errington in 1934 (Monte-Luna et al. 2004). Although this concept is vastly used, it is still vague and difficult to define, while some believe that the carrying capacity concept should be avoided all together. Applying this to natural disaster management, development in watersheds is inevitable and without proper management and monitoring practices of the resulting physical changes taking place, these developments may result in the watershed reaching its tipping point and lead to Geo-hazards such as floods.

The aim of this research was to identify the carrying capacity of watersheds in Trinidad which indicates the amount of changes a watershed can tolerate before its susceptibility to natural hazards increases. In doing this the following are the objectives:

- Identify the Watersheds affected by Floods, develop a Flood Prone Map and extract watersheds affected and not affected by floods.
- Identify possible contributing factors. Reclassify the Soil, Land use and Geology maps in terms of their contribution to runoff or infiltration rate.
- Examine and quantify the differences between the geology, soil, slope, area, Land use/cover and elevation of the watersheds affected and those not affected.
- Develop the limits which can be tolerated and used as the carrying capacity for the watershed.

For the purpose of this research, carrying capacity has been defined in the context of watershed management and attempts to highlight the tolerable levels of development and changes that can take place within these watersheds before predefined thresholds for the triggers of the geo-hazard, flood, are reduced. As focus is on the tolerable levels of changes before thresholds are lowered, the only interrelated dimension considered is the intensity/duration threshold for floods. This was predefined and applies as a constant to each watershed. It was found that the watersheds of larger area and less steep slopes were more prone to floods. Further examinations revealed that Slope, Elevation and Land use/cover were sufficient to be indicators for Carrying Capacity (Fig. 2.17). This approach is simple and easy to implement. The outcome map is useful for hazard identification, regulating future development, helping communities to understand where flood prone areas are located, establishing flood insurance premium rates, and identifying areas having unique, natural and beneficial functions. This research was published as a conference proceeding in the *Second International Conference on Geoinformatics Technology for Natural Disaster Management and Rehabilitation* (Baban and Aliasgar 2008). Later, it was published in a more comprehensive form in the *International Journal of Geoinformatics* (Baban and Aliasgar 2009). I was also involved in developing early warning systems for managing floods and landslides in the Caribbean based on rainfall intensity, aspects of this work was published as a chapter in book dealing with geo-hazards management in the Caribbean (Baban and Aliasgar 2008).

Another project, I was involved with dealt with developing a Proactive Approach to Geo-hazards Management in Trinidad and Tobago. Over a the period of some 7 years of living and working in the Caribbean, it became clear to me that the current management of floods and landslides is reactive since the major effort is focused on cleaning up operations, post event. Mitigation works are designed to repair infrastructure after the event has occurred. Clearly, there is an urgent need for objective decision-making, and for moving geo-hazards management from being reactive to proactive. However, the lack of an effective and reliable information base makes this transformation difficult. For example, at present there is an absence of a national data depository for hazard events, in which event

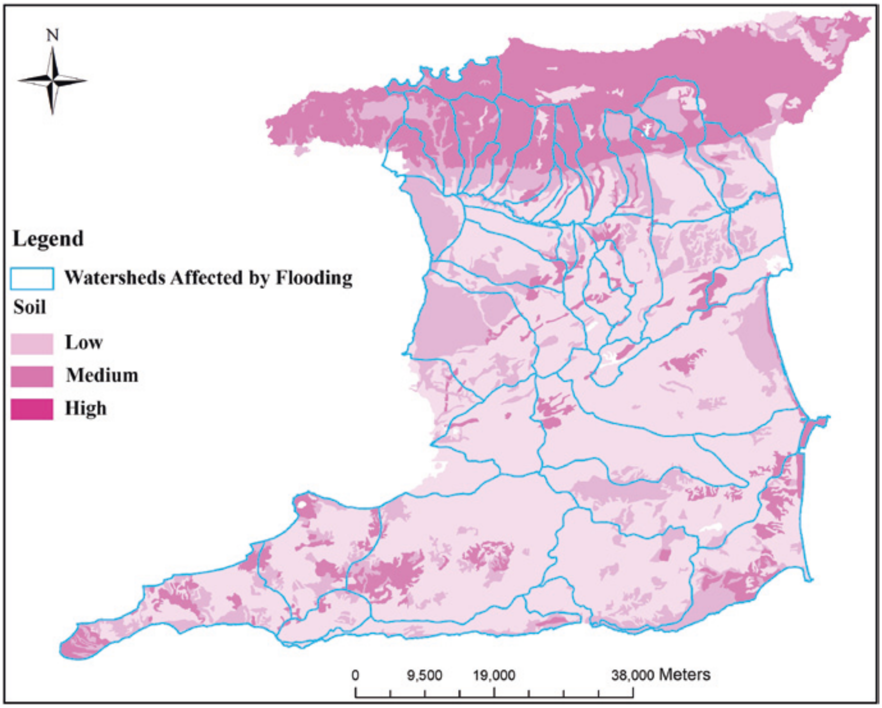

Fig. 2.17 Carrying capacity floods showing the impact of soils (Baban and Aliasgar 2008)

occurrences can be recorded and quantified for post analysis. Furthermore, several governmental agencies seem to be responsible for geo-hazard management. These agencies are neither capable of handling geo-hazards on their own nor do they have effective coordination among themselves. The states in the Caribbean have a number of common characteristics, which make them vulnerable to geo-hazards. These include geography, climate/weather conditions; limited physical size; finite natural resources; dependence on agriculture and tourism; and high population densities concentrated in vulnerable areas, including hillsides and flood plains. In addition, the region is experiencing rapid economic development combined with a fast rate of urbanization, population growth and questionable agricultural practices. Typically, these factors lead to floods, landslides, deforestation, soil erosion and extinction of an unknown number of animal and plant species. Clearly, there is a need to determine strategies to cope with the uncertainties of the effects of geo-hazards on natural resources, the environment, and goods and services. This process will require an understanding of the links between geo-hazards and societal well-being, and the promotion of effective interventions.

Reliable information is one of the most important strategic factors influencing decision-making and development. Nevertheless, there are clear indications that the information poverty obstacle can be overcome by using reputable technologies that facilitate management decisions, such as Geoinformatics, which encompass remote sensing, GIS and global positioning systems (GPS). Geoinformatics contains the necessary tools to collect, handle and analyse the necessary data sets, as well as to expand our knowledge of the processes involved at the appropriate scales. Geoinformatics can provide a means for the unconstrained analysis of conditions that influence landslides and floods. Furthermore, spatial and temporal distribution patterns not apparent within written reports can be highlighted through appropriate maps and early warning systems can be developed, which would help to provide effective information for geo-hazards management. However, it should be indicated that the insufficient funds allocated to obtain information in developing countries is a serious obstacle. In fact one of the barriers to sustainable development in developing countries is lack of information requisite to planning it (Bernhardsen 1992). Evidently, geo-hazards can raise awareness of risk and the need for management. Sadly, in recent times, Trinidad and Tobago has suffered a series of high-intensity rainfall events, these resulted in severe flooding. An understanding of the links between geo-hazards and societal well-being, and the promotion of effective interventions is urgently required. Reliable information is one of the most important strategic factors influencing decision-making and development. However, the Caribbean region, like other developing regions, suffers from a scarcity of reliable and compatible data sets.

The aim of this research was to indicate that a real option for transforming geo-hazard management in Trinidad and Tobago from a reactive to a proactive mode can be through developing a Geoinformatics based holistic approach for disaster management. In addition, this approach can form the basis for developing a national emergency strategy and short and long term priorities, including the establishment of national geo-hazard inventories and databases; the development of early warning systems; as well as the development of effective programmes for public awareness, education and information, and the enhancement of the implementation capabilities of relevant government agencies. Finally, this strategy will need to be implemented by utilizing reliable cutting edge technology such as geoinformatics to overcome information poverty.This research was published as chapter in a book dealing with Geo-hazards management n the Caribbean Region (Baban 2008a).

My research team also developed and published some general concepts for identifying, mapping and managing floods (Baban 2008b), using Carrying capacity and multi-criteria analysis (Baban and Aliasgar 2009), using satellite based rainfall data for predicting floods (Pathirana and Baban 2008), and proactively managing Geo-hazards (Baban 2009a, 2011). Finally, I had the privilege of editing a book dealing with Geo-hazards issues and advocating a proactive approach to Geo-hazards management in the Caribbean region (Baban 2008c).

2.6 Geo-hazards Science and Management in Australia

In Australia, coastal erosion represents a serious problem (Fig. 2.18); hence, shortly after my arrival I was keen to initiate a research project with Darwin City Council in North Australia. This research examined the coastal erosion

Fig. 2.18 Coastal erosion in Darwin, Australia (Baban et al. 2008)

processes occurring based on field observations and remotely sensed data (aerial photographs and satellite images) for the period 1978–2006 (Fig. 2.19). The coastlines were indentified and digitised, erosion was estimated at 59 locations and the distance from each location and the nearest infrastructure was calculated. Then the estimated erosion rates were categorised into low (0–5 m), medium (5–10 m) and high (10–15 m) erosion rates (Fig. 2.20). Coastal erosion ranged from 1.9–17.3 m over a 28 year period with an average shoreline recession of 30 cm per year, these estimates are corresponding well with historical observations. Field observations showed that cliff erosion in Darwin has been exacerbated by surface, groundwater and storm water flows sited near or close to the highly erodible cliffs. Whilst the average erosion rate is not extreme, due to the ongoing caving process, parts of the shoreline could recede by by 5–10 m over a period of weeks, particularly during intense storm events. A range of possible coastal protection measures and recommendations for a coastal management plan was recommended. This project produced a consultancy report (Jones et al. 2008), a conference paper published in *Second International Conference on Geoinformatics Technology for Natural Disaster Management and Rehabilitation* (Pathirana and Baban 2008) and another conference paper in the *Asian Conference on Remote Sensing (ACRS)* (Pathirana and Baban 2008).

Fig. 2.19 Fieldwork examining coastal in Darwin, Australia

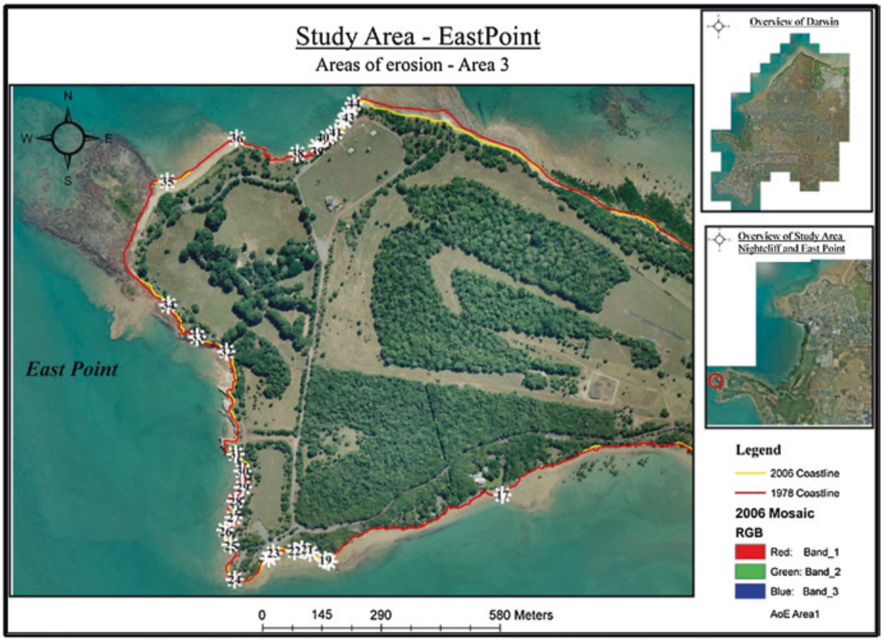

Fig. 2.20 Examining coastal erosion in Darwin, Australia (Jones et al. 2008)

2.7 Geo-hazards Science and Management: A Conclusion

Fundamentally, my research in this field started in Iraq, affording me with an opportunity to understand the research process, to present in national and international conferences and to have my first publication in a refereed journal paper. These early achievements provided me with a standard to aim for, and made me familiar with, the thought processes involved to develop a serious interest in and to focus, understand and attempt to find solutions for geo-based environmental issues. My Geo-sciences background coloured my view of the world and my basic approach to problem solving within my immediate environment and environmental issues that emerged during my employment and relocations from the UK to the Caribbean and Australia.

I learned that the economic, environmental, and social effects of Geo-hazards in developing countries cause loss of life, economic loss and serious degradation to the environment and natural resources. I noted that current management of Geo-hazards in these countries tends to be reactive and focused on cleaning-up operations, repairing infrastructure and providing comfort to affected population post-event. Evidently, there is a need for a proactive approach, planning and informed decision-making. However, the lack of an effective and reliable information base and system makes this transformation difficult. My research developed a focus for advancing a Geoinformatics founded holistic method as the basis for developing a proactive approach for Geo-hazards management in developing countries. I, with the support of my research students and team, have managed to;

1. Develop and implement a reactive and a holistic management approach using Geoinformatics, which contains the necessary tools (Remote sensing, GIS, GPS) to collect, handle and analyse the necessary data sets, as well as through developing early warning systems.
2. Indicate that the focus must be on assisting the most vulnerable groups in society and to develop practical analytical methods: that is, it must be possible for a wide range of Geo-hazards professionals and institutions to use them, and these groups must see an advantage in doing so.
3. Acknowledged that improved data and analysis are not enough by themselves. There should be a vigorous effort to use its results together with other campaigning methods, in order to influence decision makers at every level.
4. I came to realise that the real challenge is in developing practical solutions i.e. science based holistic management options that are;

    i. Simple (easy to understand, coordinate and implement)
    ii. Local/regional in nature (infrastructure, resources and coverage)
    iii. Supported (by decision makers and the local population)

My research team has made significant contributions to several international conferences dealing with the management of Geo-hazard a conference in Fiji (Fig. 2.21) and Thailand (Fig. 2.22). Weg My team achieved several tangible results for Trinidad and Tobago, these included; the development of a national

Fig. 2.21 At the United Nations regional UN-SPIDER workshop, Suva, Fiji, Sept. 2008 and at USP with Dr. Gennady Gienko, head of environmental sciences (last two)

Fig. 2.22 At the second international conference on geo-informatics technology for natural disaster management and rehabilitation, Asian institute of technology (AIT), Bangkok, Thailand, 2008

level emergency strategy; establishing national Geo-hazards inventories and databases; developing an early warning system for floods; using predictive understanding of the processes and triggering mechanisms of Geo-hazards (floods and landslides); setting international level standards for all consultancies and research projects. In addition, to highlighting the need for developing effective programs for public awareness, education and information, as well as enhancing the implementation capabilities of relevant government agencies.

References

Alsinawi SA, Baban SMJ, Issa AS (1985) Historical seismicity of the arab region. In: Proceedings of the symposium on historical seismogrames and earthquakes of the world, Tokyo, pp 59–83

Alsinawi SA, Baban SMJ (1986) Seismicity of the hemrin area north central Iraq. In: Proceedings of the 27th international geological congress, Moscow, p 14

Alsinawi SA, Baban SMJ (1984) Seismological engineering considerations for the hemrin dam area. In: Proceedings of second Iraqi hydrological conference, Baghdad, p 10
Baban SMJ, Alsinawi S (1984a) Seismicity of hemren area, north−central Iraq. In: Proceedings of 27th world geological conference, USSR
Baban SMJ, Alsinawi S (1984b) Seismological engineering considerations for hemren area, Iraq. In: 2nd Iraqi hydrological conference. Baghdad, pp 1–3, Feb 1984
Baban SMJ, Alsinawi S (1985) Historical seismicity of the Arab region. In: Proceedings of symposium on historical seismograms and earthquakes. Tokyo, 27−28 Aug 1985
Baban SMJ (1985a) Glaciers and the awaited ice age. Science and medicine, a scientific weekly supplement to the AL-Jumhuria news paper (National news paper published in Iraq) No. 5738, p 4
Baban SMJ (1985b) Causes for the formation, development and distributions of deserts on the planet earth. Uloom (Sci) J 11:16–17
Baban SMJ (1999) Use of remote sensing and geographical information systems in developing lake management strategies. Hdyrobiologia 395/396:211–226
Baban SMJ (2008a) Developing a proactive approach to geo-hazard management in Trinidad and Tobago from reactive to a proactive mode. In: Baban SMJ (ed) Enduring geo-hazards in the Caribbean region, moving from the reactive to the proactive. (181–191) University of the West Indies Press, Jamaica, 256 p. ISBN: 978-976-640-204-4
Baban SMJ (2008b) A geoinformatics based approach to manage floods in the Caribbean region, examining Trinidad as a case study. United Nations regional UN-SPIDER workshop, CD Rom. Suva, 10 p, 16–19 Sept
Baban SMJ (ed) (2008c) Enduring geo-hazards in the Caribbean, moving from the reactive to the proactive. University of the West Indies Press, Jamaica, 256 p. ISBN: 978-976-640-204-4
Baban SMJ (2009a) A proactive approach to geo-hazards management in developing countries using geoinformatics; the Caribbean experience. J Disaster Adv 2(1):14–21
Baban SMJ (2011) It's about time: a proactive approach to geo-hazards management in developing countries. Editor J Disaster Adv 4(2):3–4
Baban SMJ, Sant K (2008) Developing a GIS based landslide susceptibility map for tropical mountainous environments, using geo-environmental indicators. In: Baban SMJ (ed) Enduring geo-hazards in the Caribbean region, moving from the reactive to the proactive (64–80), Chapter 4. University of the West Indies Press, Jamaica. 256 p. ISBN: 978-976-640-204-4
Baban SMJ, Kantasingh R (2008) Using GIS to develop and evaluate flood risk assessment and flood sensitivity maps for a watershed in Trinidad and Tobago. In: Baban SMJ (ed) Enduring geo-hazards in the Caribbean region, moving from the reactive to the proactive (124–140), Chapter 7. University of the West Indies Press, Jamaica. 256 p. ISBN: 978-976-640-204-4
Baban SMJ, Cannisus F (2008) Mapping flood prone areas, a geoinformatics approach. In: Baban SMJ (ed) Enduring geo-hazards in the caribbean region, moving from the reactive to the proactive (157–178), Chapter 9. University of the West Indies Press, Jamaica. 256 p. ISBN: 978-976-640-204-4
Baban SMJ, Aliasgar K (2008) Developing early warning systems for managing geo-hazards (Landslides and floods) in the Caribbean region. In: Baban SMJ (ed) Enduring geo-hazards in the Caribbean region, moving from the reactive to the proactive (225–243), Chapter 13. University of the West Indies Press, Jamaica. 256 p. ISBN: 978-976-640-204-4
Baban SMJ (2009b) Developing a rapid field based approach for non specialists to indentify landslide prone areas. J Disaster Adv 2(4):43–47
Baban SMJ, Aliasgar K (2009) Using carrying capacity and multi-criteria analysis to proactively manage floods in the Caribbean. Int J Geoinf 5(4):55–62
Baban SMJ, Sant KJ (2006) Mapping critical slopes to landslide occurrence in a tropical environments using geographic information science: examining the case of tobago. West Indian J Eng 29(1):33–43
Baban SMJ, Foster I, Al-Adamat R (2006) Using geoinformatics to estimate nitrate leaching to groundwater in the Azraq Basin in jordan due to human activities. In: Proceedings of international association of hydrological sciences (IAHS) Publication no: 302, 147157

Baban SMJ, Wan-Yusof K (2001) Modelling soil erosion in tropical environments using remote sensing and geographical information systems. Hydrol Sci J 46(2):191–198

Baban SMJ, Ritter JB (2008) Recognising and managing unstable slopes in Trinidad and Tobago. Chapter 12, In: Baban SMJ (ed) Enduring geohazards the Caribbean Region, moving from the reactive to the proactive. 206–224. University of the West Indies Press, Jamaica, West Indies, 256 p. ISBN: 978-976-640-204-4

Baban SMJ, Sant KJ (2004) Mapping landslide susceptibility on a small mountainous tropical island using GIS. Asian J Geoinf 5(1):33–42

Baban SMJ, Sant KJ (2005) Mapping landslide susceptibility for the Caribbean island of Tobago using GIS, multi-criteria evaluation techniques with a varied weighted approach. Carib J Earth Sci 38:11–20

Baban SMJ, Thomas D, Canisius F, Sant KJ (2008) Managing development in the hillsides of Trinidad and Tobago using geoinformatics. J Sustain Dev 16:314–328

Bernhardsen T (1992) Geographic information systems. VIAK IT, Norway, 318 p

Carrara G, Bitelli A, Carla R (1997) Comparison of techniques for generating digital terrain models from contour lines. Int J Geogr Inf Sci 11:451–473

Cooke RU, Doornkamp JC (1974) Geomorphology in environmental management: an introduction. Oxford University Press, UK

Dearing JA, Hay K, Baban SMJ, Huddlson AS, Wellington EMH, Loveland PJ (1996) Magnetic secondary susceptibility of soil: an evaluation of conflicting theories using a national data set. Geophys J Int 127:728–734

De Graff JV, Bryce R, Jibson RW, Mora S, Rogers CT (1989) Landslides: their extent and significance in the Caribbean. In: Brabb EE, Harrod BL (eds) Landslides: extent and economic significance. In: Proceedings of the 28th international geologic congress symposium on landslides, Washington DC, pp 51–82, 17 July 1989

Environmental Impact Assessment Report (1992) Institutional and legislative framework for environmental management and environmental impact assessment in Trinidad and Tobago. Florabelle Grenade-Nurse, April 1992 (Revised Oct 1992)

Hay KL, Dearing JA, Baban SMJ, Loveland PJ (1997) A preliminary attempt to identify atmospherically-derived pollution particles in English topsoil's from magnetic susceptibility measurements. Phys Chem Earth 22(1–2):207–210

Jones JL, Haluska TL, Williamson AK, Martha L, Erwin ML (1998) Updating flood inundation maps efficiently: building on existing hydraulic information and modern elevation data with a GIS USGS. Water Resources Division Tacoma, WA

Jones G, Baban SMJ, Pathirana S (2008) Coastal erosion issues in the east point and Nightcliff areas of Darwin. Darwin City Council, Northern Territory 48 p

Jusoff K, Chew S (1998) Soil erosion risk assessment using satellite data in gentling highland. In: Proceedings of the international symposium of arid region soil. Izmir, 21–24 Sept

Menne B, Hajat S, Ebi LK, Kovats S, Edwards S, Haines A (2000) Floods and public health consequences, prevention and control measures. UN Document, New York

Monte-Luna P, Brook B, Zetina-Rejon M, Cruz-Escalona V (2004) The carrying capacity of ecosystems. Glob Ecol Biogeogr 13:485–495

Moore ID, Wilson JP (1992) Length-slope factors for the revised universal soil loss equation: simplified method or estimation. J Soil Water Conserv 45:423–428

Pathirana S, Baban SMJ (2008) Assessing coastal vulnerability to climate change and anthropogenic factors around Darwin, Northern territory of Australia. In: 29th Asian conference on Remote Sensing, Colombo, Sri Lanka, 8 p, 10–14 Nov 2008

Ramlal B, Baban SMJ (2008) Developing a GIS based integrated approach to flood management in Trinidad, West Indies. J Environ Manage 88:1131–1140

Report Forestry (2001) Squatting in forest reserves. Prohibited Areas and Wildlife Sanctuaries, Trinidad and Tobago

Samad R, Abdul Patah N (1997) Soil erosion and hydrological study of the Bakun dam catchment area, Sarawak using remote sensing and geographical information system (GIS). In: Proceedings of the 18th Asian conference on remote sensing (B-5-1–B-5-6). Malaysian Centre for Remote Sensing, Kuala Lumpur

Smith K (1991) Environmental hazards: assessing risk and reducing disaster. Routledge, London

Varnes D (1984) Landslide hazard zonation: a review of principles and practice, commission on landslides of the international association of engineering geology. Natural hazards, vol 3. United Nations Educational Social and Cultural Organization (UNESCO)

Wade S, Foster I, Baban SMJ (1993) The development and evaluation of GIS for mapping nitrate vulnerability. In: National hydrological society/midlands research meeting. Coventry University, UK, Jan 1993

Wade S, Foster IDL, Baban SMJ (1996) The spatial variability of soil nitrates in arable and pasture landscapes; implications for the development of geographical information system models of nitrate leaching. Soil Use Manag 12:95–101

Wan-Yusof K, Baban SMJ (1999) A preliminary attempt to develop an erosion risk map for Langkawi island, Malaysia using remote sensing and GIS. In: Proceedings of the 20th Asian conference in remote sensing, vol. 1, Hong Kong, pp 85–90

Wischmeier WH, Smith DD (1978) Predicting rainfall erosion losses: a guide to conservation planning. USDA-SEA Agriculture handbook no 537. US department of Agriculture, USA, pp 1–22

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