# The RiskCity Training Package on Multi-Hazard Risk Assessment

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## ABSTRACT

*As part of the capacity-building activities of the United Nations University – ITC School on Disaster Geo-Information Management (UNU-ITC DGIM) the International Institute for Geo-information Science and Earth Observation (ITC) has developed a training package on the application of GIS for multi-hazard risk assessment. The package, called RiskCity comprises a complete suite of exercise descriptions, together with GIS data and presentation materials on the various steps required to collect and analyze relevant spatial data for hazard, vulnerability and risk assessment in an urban environment. The package has been developed in collaboration with several partner organizations on different continents, and is used as the basis for a series of courses. Currently it is available as a distance education course.*

*Keywords:* *GIS, Hazard, Risk, Risk Assessment, Training, Vulnerability*

## INTRODUCTION

The world is confronted with a rapidly growing impact of disasters, due to many factors that cause an increase in the vulnerability of society combined with an increase in (hydrometeorological) hazard events related to climate change (Blaikie et al., 1996; IPCC, 2007; EM-DAT, 2009; Munich Re, 2009). The possible impacts of hazardous events are large, especially in developing countries and governments have to incorporate risk reduction strategies in development planning at different levels (UN-ISDR, 2004). The evaluation of the expected losses due to hazardous events requires a spatial analysis, as all components of a risk assessment differ in space and time (Van Westen, 2010). Therefore risk assessment can only be carried out effectively when it is based on extensive, multidisciplinary studies on the basis of spatial information, derived from Remote Sensing and other sources. There is an urgent need to include the concepts of disaster geo-information management into emergency preparedness planning, spatial planning and environmental impact assessment. This requires capacity building and training of disaster management experts and professionals, such as planners, engineers, architects, geographers, environmental specialists, university teachers

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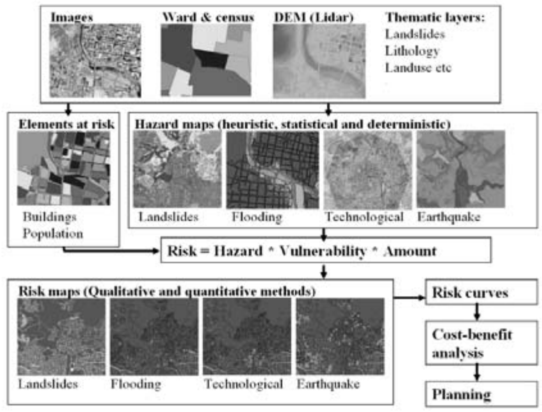
etc. (Van Westen, 2010). The Hyogo framework of action 2005-2015 of the UN-ISDR indicates risk assessment and education as two of the key areas for the development of action in the coming years (UN-ISDR, 2005).

Worldwide, a number of organizations are specialized in providing short training courses on disaster risk management-related issues (ADPC, 2005). Some organizations have also prepared training materials that are accessible through the internet; for example the Disaster Management Training Programme (DMTP), or the International Federation of Red Cross and Red Crescent Societies (IFRC). Most of these however concentrate on community-based methods (Peters Guarin, 2008). Disaster risk management courses at BSc or MSc level are now available in many Universities on all continents

Relatively few training materials are available on multi-hazard risk assessment. A good textbook on the subject is made by Smith and Petley (2009). Online training materials can be obtained for example from the websites of the US Federal Emergency Management Agency (FEMA, 2010a) and Australian Emergency Management Agency (EMA, 2002). There is a very useful guide prepared by FEMA called "Understanding your risks" that guides readers through the various phases of a risk assessment (FEMA, 2010c). The development of innovative forms of learning and teaching oriented towards building new curricula in the field of natural risk has attracted attention in European initiatives such as DEBRIS (2006) and NAHRIS (2006). As far as GIS-related material related to multi-hazard risk assessment is concerned, the HAZUS methodology developed in the US can be considered the standard. This comprehensive loss estimation software which runs under ArcGIS is a very good tool for carrying out loss estimations for earthquakes, flooding and windstorms (FEMA, 2010b), but is restricted to use in the USA, due to constraints in the data and the classifications used for elements at risk and fragility curves. The manuals of Hazus, however, provide a very good overview of the entire process of multi-hazard risk assessment. Courses on the use of HAZUS can be followed online from the ESRI Virtual Campus (ESRI, 2010). Another very promising initiative is the CAPRA project (World Bank, 2010). The Central American Probabilistic Risk Assessment (CAPRA) initiative aims to strengthen the regional capacity for assessing, understanding and communicating disaster risk in Central America. The project has developed tools for multi-hazard probabilistic risk assessment, using Open Source software tools (World Bank, 2010). However, complete GIS based training packages on spatial hazard and risk assessment using low-cost or free GIS software are still very scarce, to the knowledge of the authors. One example is a training package in English and Spanish developed for Central America in the framework of the UNESCO RAPCA project (ITC, 2004).

This paper describes the main aspects of a GIS-based training package on multi-hazard risk assessment, which has been developed by the United Nation University (UNU)– ITC School for Disaster Geoinformation Management. The International Institute of Geo-Information Science and Earth Observation (ITC), has recently been integrated in the University of Twente after a period of 60 years as an institute for postgraduate training and research in the field of geo-information directed to capacity building and institutional development of professional and academic organizations from developing countries. In 2005, ITC and the United Nations University established a collaborative programme on the use of spatial information for disaster management, which resulted in the formation of the UNU-ITC School for Disaster Geo-Information Management. The main activities of the DGIM School focus on training, education, curriculum development, knowledge development and research collaboration. This is done through the establishment of University networks in Asia, Africa and Latin America, where the member Universities exchange spatial information, course materials and jointly carry out training and research projects. The DGIM School develops training packages and courses that are given jointly with the partners of the networks in various countries. The materials

*Figure 1. Schematic representation of multi-hazard risk assessment*



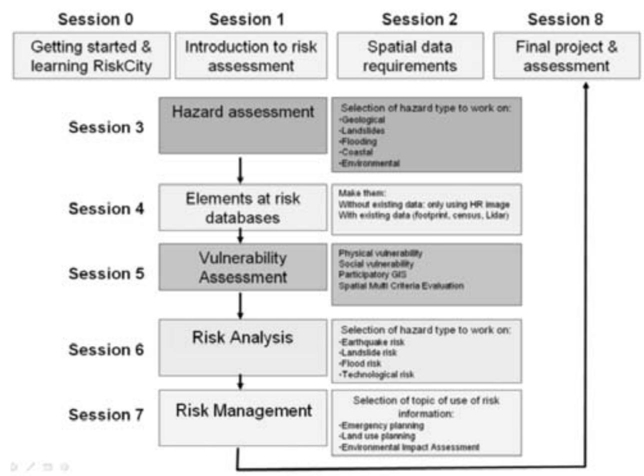

are uniform, and have been developed in different languages, and the support is given by local University staff who have followed earlier training and by staff from the UNU-ITC DGIM School. One of these courses is on Multi-hazard risk assessment, which is centered around a case study on the use of Geographic Information Systems, and Remote Sensing for the assessment of hazard, vulnerability and risk in a typical urban area representative of situations in many developing countries. Rapid urbanization, combined with a lack of planning, often leads to the spreading of squatter areas located in hazardous areas, such as steep slopes, flood prone areas etc.

## RISKCITY TRAINING PACKAGE

The package, called RiskCity, comprises a complete suite of exercise descriptions, together with GIS data and presentation materials on the various steps required to collect and analyze relevant spatial data for hazard, vulnerability and risk assessment in an urban environment. Figure 1 gives a schematic overview of the various steps involved in the process. The RiskCity training package focuses on demonstrating the procedures of risk assessment for natural and human-induced hazardous phenomena in an urban environment within a developing country. We have selected an urban area, because the elements at risk have a much higher density, the study areas are generally smaller and the scale of analysis larger as compared to a rural setting. This allows us to demonstrate which tools can be used for generating hazard as well as elements at risk databases, even in data poor environments, and to show how qualitative and quantitative techniques for risk assessment can be used, and in which situation. Also the combined effect of different hazard on the overall risk can be better demonstrated, as well as the effect of risk reduction measures.

One important consideration in designing the exercises is that people from developing countries should not be restricted in using it due to financial burdens for software acquisition. Therefore the aim was to use Open Source software as a basis. The exercises are written for the Integrated Land and Water Information System (ILWIS, 2010). It is a Geographic Information System (GIS) with integrated image processing capabilities. It also has its own attribute data analysis, spatial data entry and conversion modules. New modules have been recently added for Spatial Multi Criteria Evaluation, analysis of Digital Elevation Models and for digital stereo image interpretation (ILWIS, 2010). The strongest point of the software is the map calculation module that allows extensive modelling with raster maps, also using scripts. ILWIS, is very user-friendly software, and allows the participants to concentrate on the risk assessment application rather than on the specifics of the software.

*Figure 2. General structure of the RiskCity training package*




Each of the exercises in RiskCity has its own dataset. The data are all provided in separate directories, including the results of the previous exercises that are needed to make a subsequent one. So it is possible to carry out each of the exercises separately. Result files and PowerPoint presentations with instructions are also included.

The overall structure of the RiskCity training package is given in Figure 2, and an overview of the various components is presented in Table 1. Four different types of hazards are evaluated: landslides, floods, earthquakes and technological hazards. The training package starts with introductory exercises dealing with the software and with the study area, where students learn the various hazard problems by evaluating high resolution images. An important component of RiskCity is the generation of a database of elements at risk in order to evaluate the vulnerability of buildings and population. Here two options are considered. The first is that there is no spatial data available, except for a high resolution image, and the students have to generate mapping units with homogeneous types of buildings by stereo interpretation and digitizing on the image. Sampling is then carried out to define the number of buildings and population per mapping unit. The second option for generating the elements at risk database assumes there are digital data available in the form of building footprint maps, census information and detailed elevation data from a Lidar survey. These are used to calculate the number of buildings per mapping unit and land use type, and to characterize the buildings, for instance by calculating their height and floorspace using Lidar data. The floorspace is used then to distribute the census population over the mapping units, and population estimates are made for day- and night-time scenarios. The elements at risk database contains information on the buildings, with important attributes such as urban land use type, construction type, floorspace and height, as well as on population for a daytime and night-time scenario.

There are a wide range of hazard assessment exercises, not only those dealing with the four types of hazard mentioned before, which are based on the data of RiskCity, but also those which use data from other areas for tsunami, cyclone, volcanic, forest fires and land degradation hazard assessment. They use a variety of approaches, such as inventory-based, heuristic, statistical and deterministic. The vulnerability assessment includes exercises on the use of vulnerability curves for assessing physical vulnerability, as well as the use of expert-based

*Table 1. Overview of the exercise structure of RiskCity*

| Session | Theory | RiskCity Exercise |
|---|---|---|
| *1. Introduction to risk assessment* | Introduction to the course, objectives, structure, and set-up; Explanation of the available materials | Introduction to ILWIS and the RiskCity dataset |
| *2. Spatial data for risk assessment* | Presentation of data requirements for the various types of hazards; Sources of spatial data | Obtaining free data from the Internet; Generating a DEM using SRTM data; Download and georeferencing Google Earth images; Creating and interpreting multi-temporal images |
| *3. Hazard assessment* | Hazard types; Main concepts of hazard assessment; Frequency magnitude – relationships; Methods for use of GIS in hazard assessment | Frequency assessment; Flood modeling 2D flood propagation model, Philippines; Flood hazard monitoring with SPOT imagery, Bangladesh; Statistical landslide hazard assessment, Colombia; Deterministic landslide hazard assessment, India; Modeling pyroclastic flow deposits, Philippines; Earthquake hazard assessment: Kathmandu, Nepal; Hazard analysis of cyclone flooding in Bangladesh; Monitoring coastal erosion and sedimentation, China; Modeling land subsidence and sea level rise, Indonesia |
| *4. Elements at risk* | Types of elements at risk; Classification of buildings, infrastructure, lifelines, critical facilities; Population information; Collection of elements at risk information | Generating a database of elements at risk from scratch; Generating a database of elements at risk using existing data; Participatory GIS for risk assessment |
| *5. Vulnerability assessment* | Types; social vulnerability; physical vulnerability; Methods for vulnerability assessment; Participatory GIS; Spatial Multi Criteria Evaluation | Generating vulnerability curves; Spatial Multi-Criteria Evaluation for vulnerability and qualitative risk assessment |
| *6. Risk assessment* | Loss estimation models; HAZUS; qualitative risk assessment; QRA; Basics of flood risk, seismic risk, landslide and technological risk assessment | Flood risk assessment; Landslide risk assessment; Seismic risk assessment; Technological risk assessment; Multi-hazard risk assessment |
| *7. Risk management* | Risk evaluation; risk governance; risk communication; cost benefit analysis; Using risk information for emergency planning; spatial planning, and environmental impact assessment | Risk information for emergency preparedness & Response; Simulation exercise; Analysis of costs & benefits of risk reduction scenarios; Using risk information in environmental assessments |
| *8. Final project* | Each participant makes it own final project and does a small research | Select a topic from a list, analyze a problem and generate a report and presentation |

Spatial Multi Criteria Evaluation for the evaluation of social vulnerability and capacity.

## RISK CONCEPTS

The Risk Assessment approach adopted in RiskCity is based on the definition of risk from UN-ISDR (2009) "The potential disaster losses, in lives, health status, livelihoods, assets and services, which could occur to a particular community or a society over some specified future time period". In other words risk can be described as "the probability of losses". Risk can be presented conceptually with the following basic equation (see also Table 1 and Figure 1):

Risk = Hazard * Vulnerability * Amount of elements-at-risk [Equation 1]

and the more conceptual equation:

Risk = Hazard * Vulnerability / Capacity [Equation 2]

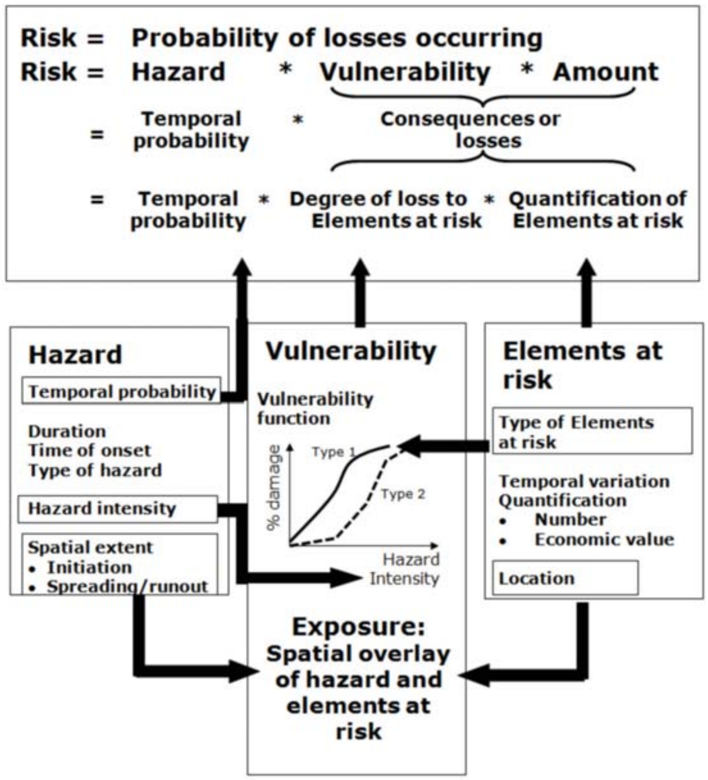
In the RiskCity training package both equations are used. Equation [2] is only conceptual, but allows incorporating the multi-dimensional aspects of vulnerability, and capacity, which are often integrated with hazard indicators using Spatial Multi-Criteria Evaluation. Equation [1], given above, is not only a conceptual one, but can also be actually calculated with spatial data in a GIS to quantify risk, with a focus on (direct) physical, population and economic losses. As illustrated in Figure 3 there are two important components, which also should be spatially represented: hazards and elements at risk. They are characterized by both spatial and non-spatial attributes. Session 2 of the RiskCity training package explains the spatial data requirements for hazard and elements-at-risk data, and how available data from the internet can be used.

Hazards are characterized by their temporal probability and magnitude or intensity derived from frequency magnitude analysis (this is treated in Session 3 of the training package). In this respect magnitude and intensity can be considered as synonymous terms that express the severity of the hazard. For instance flood depth, flow velocity, and duration in the case of flooding. For earthquakes the terms magnitude and intensity do have a different meaning, with magnitude expressing the energy level of the earthquake (on the Richter scale) and intensity expressing the local effects of the earthquake, that vary over a distance, becoming less further from the epicenter (and expressed in qualitative classes such as the Modified Mercalli Intensity). The hazard component in equation [1] actually refers to the probability of occurrence of a hazardous phenomenon with a given intensity within a specified period of time (e.g., annual probability). Hazards also have an important spatial component, both related to the initiation of the hazard (e.g., a volcano) and the spreading of the hazardous phenomena (e.g., the areas affected by volcanic products such as lava flows). Session 3 gives an overview of the approaches that can be used for the analysis of the temporal and spatial components of hazards. Table 2 gives a summary of definitions used in the GIS-based risk assessment.

Elements at risk are the population, properties, economic activities, including public services, or any other defined values exposed to hazards in a given area. They are also referred to as "assets". Elements at risk also have spatial and non-spatial characteristics. First of all there are many different types of elements at risk (which are treated in session 4 of the training package) and they can be classified in various ways. The way in which the amount of elements-at-risk are characterized (e.g., as number of buildings, number of people, economic value or the area of qualitative classes of importance) also defines the way in which the risk is presented. The interaction of elements at risk and hazard defines the exposure and the vulnerability of the elements-at-risk. Exposure refers to people, property, systems, or other elements present in hazard zones that are thereby subject to potential losses. The spatial interaction between elements-at-risk and hazard footprints, which is often referred to as "exposure" in other risk formulas, is an integral component of GIS-based risk assessment, and therefore the term exposure is not used as such in the risk equation. When we calculate the risk equation using a Geographic Information System (GIS) the elements at risk that are exposed to the hazards are automatically obtained using map overlaying techniques

Vulnerability refers to the conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards. Vulnerability can be subdivided in physical, social, economical, and environmental vulnerability. The vulnerability of communities and households can be based

*Figure 3. Basic function of risk, which can be divided into the components of hazard, the vulnerability, and the amount of elements at risk that are exposed to the hazard*




on a number of criteria, such as age, gender, source of income etc. which are analyzed using equation [2]. However, according to equation [1] vulnerability is evaluated as the interaction between the intensity of the hazard and the type of element-at-risk, making use of so-called vulnerability curves. The concept of vulnerability and the generation of vulnerability curves are treated in session 5 of the training package, including the use of participatory methods for community-based risk assessment.

The risk curves form the basis of subsequent cost-benefit analysis, in which for each hazard type, a number of risk reduction measures is evaluated. The investments to implement certain measures (e.g., relocation of houses, flood control) are estimated and compared to the reduction in annual losses that would result if they are implemented. Based on this, the most appropriate methods for risk reduction are selected. The last part of the RiskCity exercises deal with a final project in which the participants are given a particular problem they have to solve with the risk information obtained earlier.

## ABOUT THE STUDY AREA

The exercises deal with a hypothetical case study, which is originally based on an actual study area: Tegucigalpa in Honduras. Tegucigalpa suffered severe damage from landslides and flooding during Hurricane Mitch in October 1998 when the city received 281 mm of rain in 3 days (Mastin & Olsen, 2002). Due to river flooding, an old landslide was reactivated and an entire neighborhood on top of it was destroyed. The landslide caused the damming of the river and resulted in severe flooding in large parts of the city centre for several weeks (Harp et al., 2002). These events are easily identifiable

*Table 2. Summary of definitions used in the GIS-based risk assessment*

| Term | Definition |
|---|---|
| *Natural hazard* | A potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation. This event has a probability of occurrence within a specified period of time and within a given area, and has a given intensity. |
| *Elements-at-risk* | Population, properties, economic activities, including public services, or any other defined values exposed to hazards in a given area". Also referred to as "assets". The amount of elements at risk can be quantified either in numbers (of buildings, people etc), in monetary value (replacement costs, market costs etc), area or perception (importance of elements-at-risk). |
| *Exposure* | Exposure indicates the degree to which the elements at risk are exposed to a particular hazard. The spatial interaction between the elements at risk and the hazard footprints are depicted in a GIS by simple map overlaying of the hazard map with the elements at risk map. |
| *Vulnerability* | The conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards. Can be subdivided in physical, social, economical, and environmental vulnerability. |
| *Capacity* | The positive managerial capabilities of individuals, households and communities to confront the threat of disasters (e.g., through awareness raising, early warning and preparedness planning). |
| *Consequence* | The expected losses in a given area as a result of a given hazard scenario. |
| *Risk* | The probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between (natural, human-induced or man-made) hazards and vulnerable conditions in a given area and time period. |

on the high resolution image which serves as the basis for the exercises (Figure 4). After Hurricane Mitch, USGS and JICA carried out extensive work in Honduras and produced extensive datasets.

Only part of the exercises is based on the actual situation in Tegucigalpa. In order to be able to reach the learning objectives, modifications and additions were made to the original data. It is very difficult to have a dataset for a particular area where all aspects of multi-hazard risk assessment can be properly demonstrated, either because particular hazard types do not happen in the city or because particular data sets are incomplete, restricted or erroneous. The time required to prepare a suitable dataset and related exercises is very large. Therefore we have decided to make a generic case study that is representative for many cities in developing countries. When the training package is used in local course, often also local data sets are used to illustrate part of the procedure.

In the case of RiskCity several types of remote sensing data were used. Aerial photographs for several periods, including the period of the major disaster event in 1998, and two sets of satellite data from 2001 and 2006 were the basis for landslide mapping. High resolution satellite data was used for mapping elements-at-risk, and medium resolution Aster data for generating a land use map of the area. Elements-at-risk data can be obtained at different levels of detail. In the RiskCity case study this is done at the urban level, where information needs to be as detailed as possible, preferably at the individual building level, or at a slightly more aggregated level of mapping units or building blocks with homogenous land use and building type. Figure 4 gives an example of the high resolution image used with some information on the areas affected in 1998.

## CONCLUSION

The course is designed in such a way that even non-GIS specialists can follow the course, since the instructions are describing the steps in a cook-book manner, at least in the initial

*Figure 4. High-resolution image of the center of RiskCity with some of the hazard and vulnerability features indicated*


phases. In the later part of the course, when participants are more used to the ILWIS software the exercises becoming more demanding, and participants have to design the steps to solve problems themselves. The course is also designed in such a way that participants can also follow it without hands-on exercises with the ILWIS GIS for the exercises. This may be the case for courses at decision makers' level, when the participants are not that much interested in the particular steps to follow in a risk assessment, but want to know more about the overall procedure and what can be done with the (intermediate) results. Therefore we have made the course also in a WebGIS version. The WebGIS version allows participants to evaluate the individual steps of the methodology without actually doing GIS analysis. They will not use ILWIS, but will use the WebGIS version. The WebGIS exercises will take much less time than the GIS version, and have separate exercise descriptions. The WebGIS version can be accessed at: http://geoserver.itc.nl:8181/cartoweb3/htdocs/RISKCITY.php

The RiskCity training package is constantly being updated and further improved. The plan is to incorporate more Participatory GIS approaches in the training package, as well as to include more examples of the use of risk information in environmental assessment and spatial planning. There is also a plan to make a separate version focusing on risk occurring in rural areas, taking into account flooding, forest fires, drought, and land degradation as the main types of hazards. The training package is used regularly in courses. The duration of this course can vary between 2 days and 3 months. The standard duration is 6 weeks (distance education version) or 3-4 weeks (fulltime course), depending on the option for doing the final project in session 8. The course materials are available in English, with major parts also translated in Spanish, Vietnamese, Chinese, and Georgian languages. The RiskCity training package is given annually as a distance education course on Multi-hazard risk assessment. Courses on multi-hazard risk assessment are offered annually in the Netherlands, Mexico, Bolivia, and Thailand, and frequently also in India and China. We are currently exploring the option to organize an annual course on multi-hazard risk assessment with partner organizations from Africa. Information can be found on http://www.itc.nl/CourseFinder (Select the option disaster management for an overview of all courses).

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