J. Hydrol. Hydromech., 65, 2017, 2, 134–145
DOI: 10.1515/johh-2017-0007

Developing an index model for flood risk assessment in the western coastal region of Mazandaran, Iran

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Abstract: This paper represents an index model developed for the assessment of risk caused by river floods. The main purpose of this model is to evaluate the flood risk in the western coastal region of Mazandaran Province/Iran. The model assesses the risk at triple components, i.e. the flood occurrence probability, vulnerability and consequences, through identification and evaluation of effective criteria categorized into seven indexes (environmental, technical, economic, social, depth, population and sensitivity ones) that are involved in all stages of flooding (source, pathway and receptor). The flood risk in the developed model is defined by a dimensionless magnitude called as risk score between 0 and 100 for each zone of the area under assessment by calculating and combining of two newly defined factors: occurrence and vulnerability factor and impact factor. The model was applied in a case study, the Nowshahr flood in 2012. The results showed that: (i) the flood risk zoning was compared with observed data for aspect of the damages, and general agreement between them was obtained; (ii) for urban zones, which surrounded by two rivers, would easily be in critical condition and rescue operations face difficulties; and (iii) it is necessary to review the location of the emergency services, according the flood risk zoning.

Keywords: Flood risk; Index model; Source-pathway-receptor; Mazandaran.

INTRODUCTION

Flood disasters have been extremely severe in recent decades, and they account for about one third of all natural catastrophes throughout the world (Wang and Huang, 2013). By their nature, floods are generated by the random coincidence of several meteorological factors, but man's use of the river catchment also has an impact upon the severity and consequences of the events (Smith, 2013).

Over time interactions with floods have undergone evolutionary transitions, including aversion to flood risk, flood defense and flood risk management, each serving as a mindset. Over the past decades there has been a shift away from structural and large-scale flood defense towards integrated flood risk management. The modern flood risk management approach acknowledges that floods cannot be stopped from occurring and places emphasis on how to reduce hardship and vulnerability of risk prone communities (Bharwani et al., 2008; Krywkow et al., 2009; Vis et al., 2003). Various models have been developed for runoff estimation by considering only the most significant hydrologic cycle components. More complicated models normally require more input data and are difficult to apply, especially for catchments with insufficient or no hydrologic data (known as ungauged catchments) (Mapiam and Sriwongsitanon, 2009). A common way of quantifying and communicating climate vulnerability is to calculate composite indices from indicators, visualizing these as maps (Wiréhn et al., 2015).

Flood risk management deals with identification and evaluation of risks called "flood risk assessment". To this end, numerous methods and models have been developed, yet they are not viable in all parts of the world. Observational difficulties of flash floods, barriers in data collection and lack of a complete documentary of flood events hinder using the available models and methods for analysis of flood climatology, hazard and vulnerability at these areas.

The western coastal lowlands of Mazandaran are one of the most densely populated areas in Iran. Due to an increasing trend of river flood incidents in recent decades as well as the existing conditions of vulnerability to floods, these regions are faced with a high flood. Accordingly, it is essential to provide model that can appropriately assess the flood risk in the study area. There are serious obstacles that make the application of the available models deficient. The main novelty of this study is to develop a new model that can assess the flood risk when there is a lack of data provision and experts. The developed model represents the risk situation as a dimensionless magnitude called as risk score for each zone of the area under assessment. The risk score is obtained by evaluating the criteria developing the indexes, which represent the flood risk components. Applying the developed model and calculating the risk score beside a spatial analysis results in a flood risk mapping. The flood risk mapping in the studied area has not been yet provided and can be considered as the marginal novelty of this study.

NECESSITY FOR A NEW MODEL DEVELOPMENT

Different methods to assess or determine hazard, risk and vulnerability to flooding have evolved through ongoing research and practice in recent decades (Gichamo et al., 2012; Hartanto et al., 2011; Xia et al., 2011). Two distinct method types can be distinguished (Balica et al., 2013): (I) Deterministic modeling approaches, which use physically-based modeling approaches coupled with damage assessment models to provide an assessment of flood risk in an area; and (II) Parametric approaches, which aim to use readily available data of information to build a picture of the vulnerability of an area. Once relies on a significant amount of detailed topographic, hydrographic and economic information in the area studied. If the information for the model construction is not available, the method is likely to incur significant anomalies, for example the area number of rainfall stations in the catchment can have a significant impact on the accuracy of flood estimations (Mapiam and Sriwongsitanon, 2008). In this context it becomes important to evaluate the hazard, risk and vulnerability to flooding also from a different perspective: the parametric approach. The parametric approach aims to estimate the complete vulnerability value of a system by using only a few readily available parameters relating to that system (Balica et al., 2013) and tries to design a methodology that would allow the experts to assess the vulnerability results depend on the system characteristics (Serrat et Gómez, 2001).

There are serious barriers that affect negatively the application of the available models for flood risk evaluation in the studied area. Regarding the parametric approach, which to be applied, needs to develop relating to the system characteristics and available parameters. Especially about the deterministic models, the barriers include:

- the limited number of gauged watersheds that can provide a useful hydrometrical data collection
- the limited number of weather stations that can provide a real picture of hydrometeorological conditions
- the lack of comprehensive river studies that obtain detailed hydraulic and geologic parameters
- the lack of a significant amount of detailed topographic and economic information
- the lack of a complete archive of past flood events

Therefore, a model developed in proportion with the properties and limitations of the region of interest for flood risk assessment should be simple to use, time saving, and based on applicability by local experts using available data and information.

Overview of the Study area

High flood occurrences with large environmental damages have a growing trend in Iran (Boudaghpour et al., 2015). In the north of Iran and southern margin of Caspian Sea, there are coastal regions facing ever-increasing river flood incidents in recent decades. Among these regions, the western coastal region of Mazandaran has particular conditions with a high risk of flood. These plain lowlands are limited to Alborz Mountain Range from the south (adjacent to this forest covered area) and to the largest closed sea of the world (Caspian Sea) from the North (as shown in Figure 1). This low-width coastal band reaching a lower-than-5-km width in some places is one of the most populated areas of the country. Mazandaran Province with an area of 23756.4 km^2 (1.46% of Iran) has accommodated a population of 3073943 (4.09% of the population living in Iran). It is the fourth province in terms of population density among 30 provinces of Iran. A significant proportion of this population resides in numerous small cities in the western areas of the province. Annually, Mazandaran hosts 12 million domestic tourists, ranking the first in attracting tourists.

Despite the fact that Iran is situated in an arid region with an average annual precipitation of 250 mm, Mazandaran with a 338 km coastal line enjoys an average precipitation of 750 mm (at most 1400 mm in the west and at least 700 mm in the east). As many as 60 rivers flow within the province together with 38 sub-basins, most of which are flowing permanently. The flow rate of the province rivers is estimated 5 billion cubic meters per year, of which 1.5 billion is consumed and the rest is unused flowing to the sea. The length of the province rivers is 4200 km (74% mountainous, 26% plain) of which 1600 km is flood prone. 80 % of the province total plain area is situated in the center and the east and 20 % is located in the west, due to closeness of the mountain to the sea in the west. The rivers flow northwards. Rainfall falls on southern mountains covered in forest, then changes into runoff, and flows into the sea after passing through coastal cities.

Mazandaran Province has 42% forest coverage that 33487 hectares (about 3%) of its forest area has been decreased, whereas 21367 and 13155 hectares have been added to agricultural lands and residential areas, respectively from 2006 to 2011. This province, particularly in recent years, has always been facing flood plight, bearing in mind that flood damage is higher than that of earthquake and drought. The floods of this area are river floods and according to presented data and statistics in 2012 by the Ministry of Interior, 70% of the credit related to

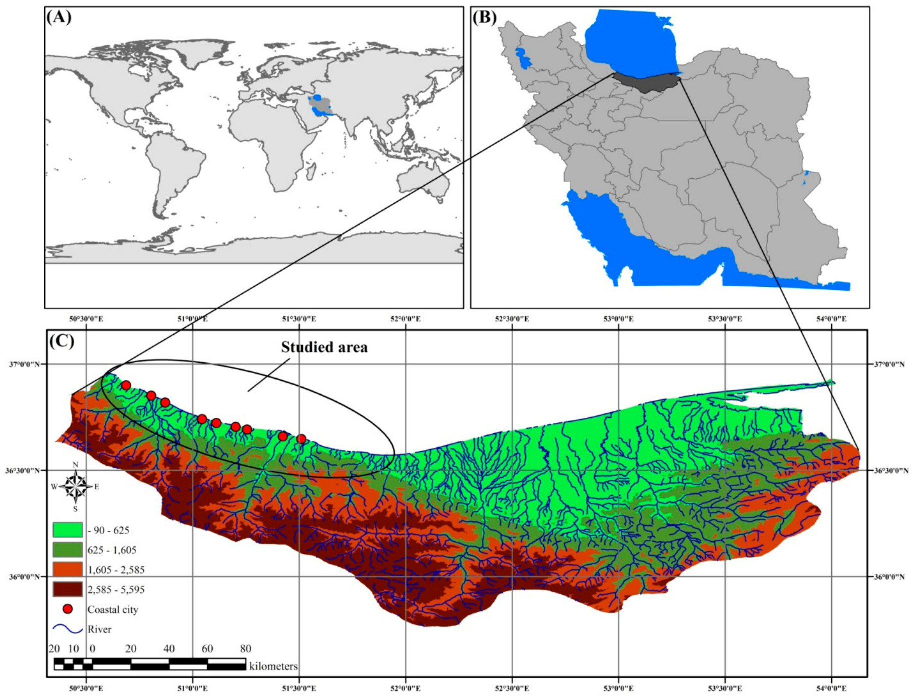

Fig. 1. Location of the studied area: (A) Iran in the world, (B) Mazandaran Province in Iran, and (C) western coastal region of Mazandaran Province (the displayed oval).

damage compensation in the province belongs to floods. However, the flow rate of the floods is generally lower than 100 cubic meters per second. Indeed, the river does not have the capacity for the volume of flowing runoff resulting in overflow and eventually flood.

Studies have shown that the main reasons beyond the occurrence of floods in western coastal region of Mazandaran are: considerable amount of rainfall, flood-prone basins, improper exploitation from forests, indiscriminate cattle grazing, land-use change (changing a wide area of forests and farms to cities and towns), occupation the riverside, sand and gravel harvesting, and short length of rivers along the plain (the short distance between the basin outlet and the sea). The main reasons of high vulnerability and huge damages caused by floods in the cities of this region are urban population development and high population density in the low-width coastal band, passage of at least one river through the city, settlement and closeness of populated and vulnerable centers to the river, inappropriate urban development that has disregarded flood zoning and reduced cross-section of the rivers.

THE SOURCE-PATHWAY-RECEPTOR INDEX MODEL

This section introduces the Source-Pathway-Receptor Index (SPRI) model, which was developed in this study. The model was developed based on: (i) flood risk concept; (ii) risk indexing methods; and (iii) Source-Pathway-Receptor concept.

The probability of the occurrence of potentially damaging flood events is called flood hazard (Schanze, 2006). But ‘‘People’s vulnerability is generated by social, economic, and political processes that influence how hazards affect people in varying ways and differing intensities. By ‘vulnerability’ we mean the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist, and recover from the impact of a natural hazard.’’ (Blaikie et al., 1994). Flood risk can be broken down into two notions of different nature (Casale and Margottini, 1999): (a) the possibility of flooding and (b) the resulting damage and losses if flooding occurs. In fact, risk is the product of two main components, i.e. probability and consequence (Smith, 2013). The natural phenomenon of random overflowing of a river constitutes the first component of the risk. The susceptibility of the area concerned to damage when flooding occurs, i.e. its impact or the damage inflicted (Wind et al., 1999) is the second component of the risk. Risk is therefore a spatial notion, since it varies according to the space in question, as do possible flooding and potential damage. Flood risk management deals with the outcomes, which are the combinations of the probabilities of an event occurring and the impacts associated with that event (Ran and Nedovic-Budic, 2016). However, flood risk assessment deals with the estimation of the flood hazard, the potential impact on human activities, and the latter is usually identified as the product of exposure and vulnerability (Alfieri et al., 2015). Therefore, flood risk assessment tries to assess flood risk based on flood hazard assessment and vulnerability of social, economic and environmental systems assessment. The SPRI model aims to assess flood risk in three components: (i) the occurrence probability of flooding; (ii) the vulnerability to floods; and (iii) the consequences if flooding occurs.

Risk indexing methods assign values to selected variables based on professional judgment and past experience. The assigned values are then operated on by some combination of arithmetic functions to arrive at a single value. This single value can be compared to other similar assessments or to a standard. This method is a useful and powerful cost-effective tool that can provide valuable risk assessment, especially when an in-depth analysis is not appropriate (Hadjisophocleous and Fu, 2004). The SPRI model tries to assess the flood risk by evaluating the indexes, which represents the triple above-mentioned components. This representation is achieved by identifying and selecting the criteria, which develop the indexes.

A popular conceptual model for the description of coastal flooding is the Source-Pathway-Receptor (SPR) concept. The SPR concept has its origins in environmental engineering to describe the flow of environmental pollutants from a source, through different pathways to potential receptors (Holdgate, 1979). It was subsequently adopted for coastal flooding by the UK Environment Agency (H R Wallingford, 2002). The use of the Source-Pathway-Receptor model was recommended to understand the linkage between the hazard and consequences (Sayers et al., 2003) and to describe the propagation of a flood from a source through pathways to the floodplain beyond (Narayan et al., 2012). For coastal flooding however, the Source-Pathway-Receptor-Consequence (SPRC) model is believed to provide a better instantaneous representation of the physical flooding process with regard to the propagation and consequences of a particular flood event (Narayan et al., 2011). Source refers to a source of hazard (e.g. heavy rainfall, strong winds etc.). Pathway provides the connection between a particular source and a receptor (e.g. property) that may be harmed. Receptor refers to the entity that may be harmed. Consequence refers to an impact such as economic, social or environmental damage/improvement. For example, in the event of heavy rainfall (the source) flood water may propagate across the flood plain (the pathway) and inundate housing (the receptor) that may suffer material damage (the harm or consequence) (Sayers et al., 2003). In this study the SPR concept was applied to identify and select the criteria, which develop the indexes based on an investigation and understanding of mechanism of flood occurrence and damages in the study area.

In summary, the main purpose of the SPRI model is to assess the flood risk by evaluating the indexes, which represent the occurrence probability of flooding, the vulnerability to floods, and the consequences if flooding occurs. The criteria developing the indexes were identified and selected in three main components (source, pathway and receptor) of mechanism of flood occurrence and damages in the western coastal cities of Mazandaran Province.

Description and structure of the SPRI model

The main output of the SPRI model is the score of flood risk that is named risk score (RS). Indeed, the area under assessment is divided into smaller zones and RS is calculated for each zone by two factors and seven indexes:

- Occurrence and vulnerability factor (OVF)
  - Environmental index
  - Technical index
  - Economic index
  - Social index
  - Depth index
- Impact factor (IF)
  - Population index
  - Sensitivity index

Each index includes a set of criteria. Indeed, the identified and selected criteria were classified into the seven indexes concerning the nature of their influences on the flood risk. OVF is combined with IF to achieve at a final RS. By scoring the criteria and summing up the scores, a certain score for each index is obtained. Some criteria have sub-criteria. The score of such criteria is obtained by adding the sub-criteria scores

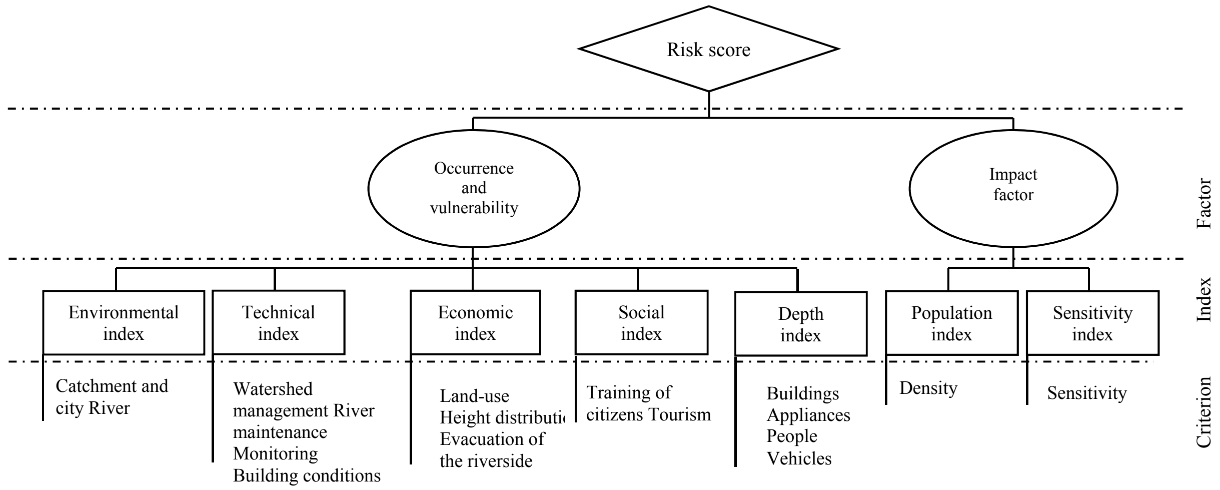

Fig. 2. Flowchart of the source-pathway-receptor index model.

together. In other words, the sub-criteria are considered the lowest level of scoring in this model. Figure 2 shows a flowchart of the SPRI model.

OVF

The two flood occurrence probability and vulnerability components are seen in OVF. The criteria, which influence on the occurrence probability or the vulnerability were classified into the environmental, technical, economic, social and depth indexes. Thus, the flood occurrence probability and the vulnerability are assessed by OVF, which includes the abovementioned five indexes. The environmental, technical, economic and social indexes are summed. This sum is divided by the depth index to obtain a numerical value that is called OVF representing the overall flood occurrence probability and vulnerability:

$$\mathrm{OVF} = \frac{\text{Environmental index + Technical index + Economic index + Social index}}{\text{Depth index}} \quad (1)$$

Some criteria (and sub-criteria) of the five indexes simultaneously influence both the occurrence probability and the vulnerability components. Hence, the categorization and assessment of criteria in two separate factors (i. e. the occurrence probability and the vulnerability) is not simply and accurately possible. Therefore, the occurrence probability factor and the vulnerability factor are at once evaluated by OVF. By categorizing the criteria in the five separate indexes, there is no overlap among them. Therefore, there is not any possibility of multiple and additional effects in the assessment.

IF

The environment, which flood overflows into, and its internal components receive the flood risk and are influenced by the flood. In other words, it is thought that eventually the water overflows off the river and runoff flows and pours into streets and buildings. Under these circumstances, the level of possible damages and the amount of losses have a direct relationship with the total present population in the flooded area. Environmental sensitivities also add to this issue. These issues are developed in the population and sensitivity indexes. These indexes are effective in the flood consequences. Accordingly, the consequences of flood are assessed by IF. After determining the values of population and sensitivity indexes, IF is calculated as follows:

$$\mathrm{IF} = \text{Population index + Sensitivity index} \quad (2)$$

RS

RS for each zone of the area under assessment is calculated by multiplying OVF by IF as follows:

$$\mathrm{RS} = \mathrm{OVF} \times \mathrm{IF} \quad (3)$$

As it was previously mentioned, the criteria affecting the occurrence probability and the vulnerability to floods are evaluated by OVF. Also the criteria affecting the consequences are evaluated by IF. Therefore, RS assesses the occurrence probability of flooding, the vulnerability to floods and the consequences if flooding occurs. Since these components contribute to the flood risk, the SPRI model assesses the flood risk.

The criterion, based on which the area under assessment is divided into zones, is the size of the cells that their essential data for scoring the SPRI model sub-criteria have been prepared by the numerous relevant organizations. In the study area, the data in relation to urban and population characteristics have been prepared in the city block scale. A city block is the smallest area that is surrounded by streets. The city blocks are the space for buildings within the street pattern of the city. In this context the criteria (and sub-criteria) are evaluated for each block of the under assessment city.

Scoring the sub-criteria

The procedure of scoring the sub-criteria is described in this subsection. The scoring options of sub-criteria and related scores are presented in the Tables (1)–(7). For each sub-criterion some options are selected, with regard to under assessment conditions. The score of under assessment sub-criterion is obtained from adding the scores of selected options. Regarding the direction of scoring scale, in a scoring-type risk assessment, one of two scoring layouts is possible: increasing scores versus decreasing scores to represent increased risk. This study uses an “increasing scores = improving risk situation” layout.

Environmental index

The environmental index is mostly related to natural and physical properties of the basin on which rainfall precipitates, runoff is formed and flows. This index (Table 1) includes two criteria as follows:

(I) *Catchment and city*: this criterion considers mainly the upstream basin conditions of the city as the source of runoff generation and indeed, evaluates its flood potential in the flood risk level.

(II) *River*: the river as the runoff pathway has an important role in the probability of flooding. This issue is assessed by this criterion.

Technical index

The technical index concentrates on the analysis of measures that are taken by humans and directly or indirectly influence the flood occurrence probability and the vulnerability. This index (Table 2) includes four criteria as follows:

(I) *Watershed management*: watershed management that effectively reduces the flood risk is usually started by studies. Based on the results of the studies, it leads to measures under two mechanical and biological categories.

(II) *River maintenance*: river protection refers to as measures such as dredging operations, river path improvements and besides the surveillance river path in order to its prevention the riverside encroachment.

(III) *Monitoring*: installation and enhancement of the observation and monitoring systems play a major role in observation of hydro-meteorological parameters, which is important in flood forecasting.

(IV) *Building conditions*: this criterion refers to the specifications of buildings affect in flood vulnerability.

Table 1. Environmental index scores.

Criteria	Sub-criteria	Option	Score (pts.)
Catchment and city	Forest exploitation	Studies were conducted before exploitation	+2
		Exploitation is done under supervision of the relevant governmental organizations	+3
		Exploitation is done by single-selection method	+2
		After exploitation tree planting is done	+2
		Miscellaneous exploitation compared with legal exploitation is:	–
		negligible	+1
		moderate	+0
		significant	–2
	Infiltration and vegetation	CN is the curve number in method introduced by American Soil Conservation Service for prediction of the amount of runoff generation:	–
		$0 \le CN \le 10$	10
		$10 < CN \le 20$	9
		$20 < CN \le 40$	7
		$40 < CN \le 60$	5
		$60 < CN \le 80$	3
		$80 < CN \le 90$	1
		$90 < CN \le 100$	0
	Slope and land cover	C is the runoff coefficient:	–
		$0.00 \le C \le 0.10$	10
		$0.10 < C \le 0.20$	9
		$0.20 < C \le 0.30$	8
		$0.30 < C \le 0.40$	7
		$0.40 < C \le 0.50$	6
		$0.50 < C \le 0.60$	5
		$0.60 < C \le 0.70$	4
		$0.70 < C \le 0.80$	3
		$0.80 < C \le 0.90$	2
		$0.90 < C \le 0.95$	1
		$0.95 < C \le 1.00$	0
River	Wall condition	The river does not pass the assessing zone	10
		The river passes the assessing zone and retaining wall has been constructed:	–
		Reinforced wall	10
		Masonry wall	8
		Gabion wall	6
		Dry stone wall	4
		The river passes the assessing zone and no retaining wall has been constructed	0
	Fall barrier	The river does not pass the assessing zone	10
		The river passes the assessing zone and fall barrier has been installed:	
		Solid wall for increase in discharge capacity	9
		Solid wall only as fall barrier	8
		Fencing wall for vehicles and people	7
		Fencing only for people	5
		Sidewalk garden covered with trees	2
		The river passes the assessing zone and no fall barrier has been installed	0

Table 2. Technical index scores.

Criteria	Sub-criteria	Option	Score (pts.)
Watershed management	Studies	Comprehensive study	10
		Flood zoning	8
		Boundary and bed	7
		General studies	5
		Sporadic and partial studies	3
		No studies	0
	Measures	No mechanical and biological measures have been done	0
		Mechanical and biological measures incoherently and in a scattered way	3
		Mechanical and biological measures are being done and the amount of progress is less than %50	4
		Mechanical and biological measures are being done and the amount of progress is more than %50	6
		Mechanical and biological measures have been done according to the studies	8
		Maintenance program for mechanical measures is running	+1
		Monitoring program and caring plan for biological measures is running	+1
	Urban detailed plan	There is no urban detailed plan	0
		There is a general urban detailed plan	5
		There is an urban detailed plan considering to flood zoning	8
		The amount of assessing zone constructed after plan approval is:	–
		more than %50	+2
		less than %50	+1
River maintenance	Surveillance	No surveillance	0
		Municipality surveys in the city	+3
		Water resources affairs surveys out of the city	+2
		Surveillance measures:	–
		Construction permits	+1
		Patrolling	+2
		Destruction measures	+2
	Dredging and reopening	Dredging is done periodically less than 1 year	10
		Dredging is done periodically more than 1 year	8
		Dredging is done occasionally when it is necessary	5
		Dredging is done irregularly	3
		Dredging is not done	0
	Improvement	No improvement	0
		Improvement measures are taken	3
		Improvement measures were taken completely	6
		Improvement measures include:	–
		modification the arches and slope of the bed	+1
		construction of diversion channel	+1
		overflow to open space	+1
		development of the section width	+1
Monitoring	Hydrometry	No hydrometric station	0
		The main river have hydrometric station of:	–
		entrance to the city	+5
		outlet to the sea	+3
		The hydrometric station is equipped with data logger	+1 (per each station)
	Meteorology	A: the total number of sub-basins; B: the number of sub-basins have synoptic station C: the number of sub-basins have rain gauge	–
		All sub-basins have synoptic station	10
		Some sub-basins have synoptic station and the others have only rain gauge	(B/A)*6 +(C/A)*4
		No sub-basins have synoptic station and rain gauge	0
Building conditions	Quality	Brick and wood	0
		Masonry structure	5
		Steel or reinforced concrete structure	8
		Flood-proof	+2
	Age	New neighborhood	10
		Less than 10 years	8
		More than 10 years and less than 20 years	6
		More than 20 years and less than 30 years	4
		More than 30 years	2
		Old urban fabric	0
		Reconstruction and structural reinforcement measures are being done	+2

Economic index

The potential of the incurred damage related to the economic properties of the flood-stricken region is represented in the economic index. Similarly, the implementation of some flood management plans requires substantial budget, is evaluated by this index (Table 3), which includes three criteria as follows:

(I) *Land-use*: the financial damages and injuries and fatalities caused by floods are a direct function of the use of each zone.

(II) *Height distribution*: a higher level from the ground is representative of a higher safety in the context of flood risk. Apparently, buildings with more floors in a zone distribute the flood receptors in height. It should be noted that the nature of height distribution criterion influence on the flood risk is economic. Therefore, this criterion was classified into the economic index. Moreover, the number of floors (as a building attribute) is just considered as the parameter to assess this criterion.

(III) *Evacuation of the riverside*: there are some flood-prone zones at risk of inundation especially near the river. The authorized organizations evacuate the dangerous part of riverside through purchasing the properties.

Social index

Plans, subjects and social attentions that have capacity for flood risk reduction, are covered in this index because a part of the flood management plans always deals with reducing the vulnerability of citizens as social capital. The primary focus of this index is on the society's citizens and cultural issues. Social index (Table 4) includes two criteria as follows:

(I) *Training of citizens*: citizen training is run with the aim of enhancing their preparation when a flood occurs. It also tries to promote the culture and the society's awareness regarding the impacts of illegally constructed riverside and natural valuable resources.

(II) *Tourism*: due to unfamiliarity with the region and lack of knowledge of safe evacuation sites, there is a high chance for tourists to get trapped in sudden floods.

Depth index

Damages and losses due to city inundation and the proximity of flood flow to the properties and individuals are evaluated by the depth index. The water depth at every point is the distance between the land level and the water level at that point. This parameter is called D (Table 5). The main receptors of flood risk in the city are individuals, buildings, properties and vehicles.

A great deal of research has been done about the analyses of flood damage to buildings (Corry et al., 1980; Grigg and Helweg, 1975) whose results are used in the form of functions and tables of depth-damage mainly as a criterion and guideline for flood damage determination by governmental and nongovernmental organizations including, the U.S Federal Emergency Management Administration. The results of this research have distributed the total damage in relation to water depth, based on which the damage (in the form of percentage of the building value) is in direct relationship with water depth. The latest investigations about the functions and tables of depth-damage have been carried out by the U.S. Army Corps of Engineers (USACE, 2003) which damage percentage is calculated based on the building content and has distributed the damage (in the form of percentage out of the building content value) in relation to water depth. Studies on the assessment method of people safety based on formulae derived from the mechanical analysis linked with experiments (Abt et al., 1989; Foster and Cox, 1973; Jonkman and Penning-Rowsell, 2008; Karvonen et al., 2000; Keller and Mitsch, 1992, 1993; Lind et al., 2004; Takahashi et al., 1992) result instability curves in floodwaters (Xia et al., 2011). The curves were presented between the product

Table 3. Economic index scores.

Criteria	Sub-criteria	Option	Score (pts.)
Land-use	–	Open areas	10
		Industrial	6
		Commercial	3
		Residential	0
Height distribution	–	Only first floor.	0
		A floor or some floors over the first floor	5
		The number of the floors over the first floor is:	–
		one	+2
		up to three	+4
		up to five	+5
Evacuation of the riverside	–	The assessing zone is not under compulsory plan (property purchase and evacuation)	10
		The assessing zone is under compulsory plan and the compulsory plan:	–
		has been completed	9
		is in progress	6
		has been stopped	3
		has not started yet	0

Table 4. Social index scores.

Criteria	Sub-criteria	Option	Score (pts.)
Training of citizens	–	No training	0
		Face-to-face training	+4
		Indirect method training:	–
		Radio and television	+3
		SMS, leaflet	+2
		Newspaper, postal letter	+1
		Training approach is single-issue (flood)	+2
Tourism	–	No tourist attraction	10
		There is a tourist attraction in the assessing zone and:	0
		immunization measures have been done (collapse-prone lands, fencing etc.)	+3
		safe evacuation site has been constructed	+1
		warning signs has been installed	+1
		loudspeaker system has been installed	+2

of the flow velocity and the incoming depth at the point of human instability. Flow velocity at the point of human instability depends on the parameters of flow, and friction coefficient, and individual parameters. Height and weight are among these parameters. Since they are different in adults and children, for a certain level of water depth, the flow velocity at the point of human instability is also different. Therefore, instability curves for a child and an adult in floodwaters are different. Existing studies on the stability limit of vehicles in floodwaters are limited (Xia et al., 2011). In the recent study, all of the forces acting on a flooded vehicle were analyzed and the corresponding expression for incipient velocity was derived for commonly used vehicles parking on flooded roads or streets. There is a relationship between incoming water depths and incipient velocities that can be presented a curve. The curves were produced for three types of vehicles, including a Mini Cooper, BMW M5 and Pajero Jeep (Xia et al., 2010).

Therefore, the depth index (Table 5) includes four criteria as follows:

(I) *Buildings*

(II) *Home appliances and furniture*

(III) *People*: for a certain flow depth, the degree of risk is different for adults and children. Accordingly, this criterion includes two sub-criteria of children and adults.

(IV) *Vehicles*: since the majority of the vehicles present in the cities of the studied region were mid-weight vehicles, BMW M5 was considered as the basis for scoring.

Population index

The population size exposure to the flood risk affects the severity of resulting consequences. While the depth index is representing the susceptibility of damages and fatalities incurred to the unit of individuals, buildings, properties, assets and vehicles, the population index weighs it and expresses the susceptibility of damages and fatalities incurred to all of them in that region. This issue is investigated in an index called "population" (Table 6), which includes a criterion as follows:

(I) *Density*: the population in danger of being flooded is an effective parameter in the degree of potential damages and fatalities. The most appropriate and available parameter to involve this criterion is the population density. Accordingly, the score is determined according to a region's population density.

Sensitivity index

There are numerous regions with environmental value or sensitivity being located within the city or the countryside that affects the severity of resulting consequences. This issue is investigated in an index called "sensitivity" (Table 7), which includes a criterion as follows:

(I) *Sensitivity*: In some wetlands and where the river flows to the sea, some plant and animal species (especially those that are valuable) rare, and at-risk, live, grow and reproduce. If such environments become damaged, restoration and returning it to its initial state is difficult. Based on to what extent the evaluated zone contains conservation areas or wetlands, or it has plant and animal species, or reproduction and hatching activities happen in them, the instance of a neutral region, a region with serious consequences, or a region with severe consequences are identified and are allocated with scores of 0, –0.5 and –1, respectively.

The negative score of the sensitivity index that is added to the positive score of the population index signifies that in terms of impact factor (Eqs. 2), the region has environmental implications, which is equally evaluated with a region that stands at most one rank higher in terms of population density. It should be noted that if the score of IF score is obtained found to be less than 1, then it is considered to be 1.

By considering the scores mentioned in the tables (1) – (7) and in accordance with Eqs. (1) – (3), the score range of OVF, IF and RS respectively relies in the range of 0 – 20, 1 – 5 and 0 – 100. It should be noted that RS is inversely correlated with the depth index. Therefore, the depth is the exclusive index whose increase manifests a deteriorated risk situation.

Table 5. Depth index scores.

Criteria	Sub-criteria	Option	Score (pts.)
Buildings	–	$0cm < D \leq 30cm$	1
		$30cm < D \leq 90cm$	4
		$90cm < D \leq 180cm$	5
		$180cm < D \leq 240cm$	7
		$240cm < D$	10
Home appliances and furniture	–	$0cm < D \leq 30cm$	0
		$30cm < D \leq 90cm$	4
		$90cm < D \leq 120cm$	6
		$120cm < D \leq 180cm$	8
		$180cm < D$	10
People	Children	$0cm < D \leq 30cm$	4
		$30cm < D \leq 60cm$	7
		$60cm < D \leq 90cm$	9
		$90cm < D$	10
	Adults	$0cm < D \leq 30cm$	3
		$30cm < D \leq 60cm$	6
		$60cm < D \leq 90cm$	8
		$90cm < D \leq 120cm$	9
		$120cm < D$	10
Vehicles	–	$0cm < D \leq 30cm$	2
		$30cm < D \leq 60cm$	6
		$60cm < D \leq 90cm$	8
		$90cm < D$	10

Table 6. Population index scores.

Criteria	Sub-criteria	Option	Score (pts.)
Density	–	Very high	1
		High	2
		Medium	3
		Low	4
		Very low	5

Table 7. Sensitivity index scores.

Criteria	Sub-criteria	Option	Score (pts.)
Sensitivity	–	Neutral	0
		With serious consequences	–0.5
		With severe consequences	–1

Classification of conditions considering RS

Considering the risk score, five groups are considered for the risk level are as follows:

- safe ($80 < RS \leq 100$): the risk situation is considered as wholly satisfactory, thus such zones should be under monitoring. The reasons behind the high scores should be identified in order to manage the strengths and the weaknesses.

- moderate ($60 < RS \leq 80$): the risk situation is considered as moderate, thus such zones should be under continuous improvement. They are not included in the first priority of flood management but their weaknesses and the reasons behind not-very-high score should be identified in order to solve them and improve the situation (increase the safety). In these zones the first measures are identification and study followed by practical measures.
- hazardous for sensitive receptors ($40 < RS \leq 60$): the risk situation is considered as unfavorable particularly for sensitive receptors. It means that the risk situation for other groups is also considered as moderate. The major sensitive receptor groups are children, old buildings, and light-weight vehicles. Such regions are regarded as high priority in flood management. The criteria and sub-criteria have been given low and moderate scores should be considered and managed further. In these zones, a part of the measures are emergency-type and the others are identification and study in parallel.
- hazardous ($20 < RS \leq 40$): the risk situation is considered as completely unfavorable and in the occurrence of floods serious losses and damages are expected. Such zones are thus included at the top of flood management list. In these zones measures are taken in such a way that they immediately reduce the flood risk so that the studies are conducted and solutions are identified as quickly as possible.
- critical ($0 \leq RS \leq 20$): in the occurrence of floods, severe losses and damages are expected thus such zones are the first priority of flood management. The measures are intervention type and even can result in immediate evacuation and residents' displacement so that the solutions are identified and practical measures are immediately taken.

THE SPRI MODEL APPLICATION IN AN EXAMPLE

The SPRI model was used to simulate a past flood in the city of Nowshahr, a coastal city in the west of Mazandaran Province, and to evaluate the risk score, thereby assessing the flood risk throughout the city. The Geographical Information Systems (GIS) with their ability to handle spatial data are an appropriate tool for processing spatial data on flood risk (Meyer et al., 2009). The ArcView has become the preferred desktop GIS software. While the ArcView GIS is treated as the core module, the ArcView GIS Spatial Analyst is used as specialized extensions for creating, querying, mapping, and analyzing data (ESRI, 1996). The SPRI model was applied using the ArcView GIS 9.3 with Spatial Analyst to express the spatial variability of the flood risk. Nowshahr with a population of 47000, a dense urban texture especially in the central area and a topologically complex network of major and minor roads has been flooded in recent years and three main floods occurred in 1994, 2003 and 2012. Fig. 3 shows that three major rivers cross the city. The Neyrang River is the main source of floods in Nowshahr. This river also has a minor branch called Shahrroud and both of them pass through the city central area. This part of the city, which is the oldest and the densest, includes the bazaar, the central hospital, the offices and the central mosque. At the point of the branch of Neyrang River, there is a gate, which blocks the flow of water into Shahrroud branch during flood. But flooding of Neyrang River causes to spill into the central area. The gate lies at the distance of 50 m from a bridge, which is a main connector between the east and the west part of the city, and the overflowing always occurs at the bridge spot.

On 13th October 2012, Nowshahr coastal city was flooded, especially in a large portion of the central area, by a result of a series of torrential precipitations depositing over 120 mm of rainfall within 10 h, into the catchment of Neyrang River. This flood was caused by the combination of heavy rain, the saturation of the soils due to antecedent rains and the nature of the catchment in generating high runoff. Flooding has been observed to occur as a result of the discharge exceeding the capacity of the river in the bridge spot and spilling into the street network. The observed water depths on the streets were less than 1 m, with significant damage to buildings and carrying vehicles, and with no loss of life reported. Subsequent field and computational data about the flood have been published by Natural Resource and Water Management Affairs of Mazandaran Province, including distributions of maximum water depths (Fig. 4).

For the representative points of the blocks throughout the city, the scores of the sub-criteria were imported into the ArcGIS and subsequently spatial analysis was performed to obtain relevant results. Fig. 5 demonstrates the distributions of the risk scores in the study domain (Nowshahr city). It can be seen from Fig. 5 that: (i) almost all of the domain was assessed in the hazardous for sensitive receptors or hazardous conditions; (ii) almost all of the central area was affected seriously by this flood, which contains the main places of population presence, therefore these zones need to be noticeably consid-

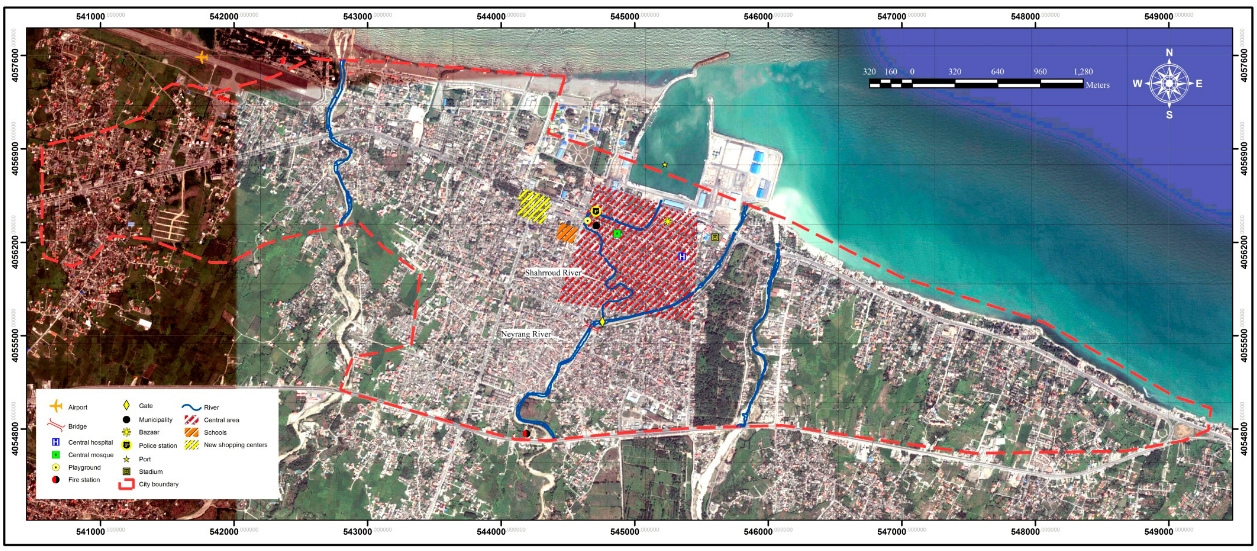

Fig. 3. Sketch map of the study domain.

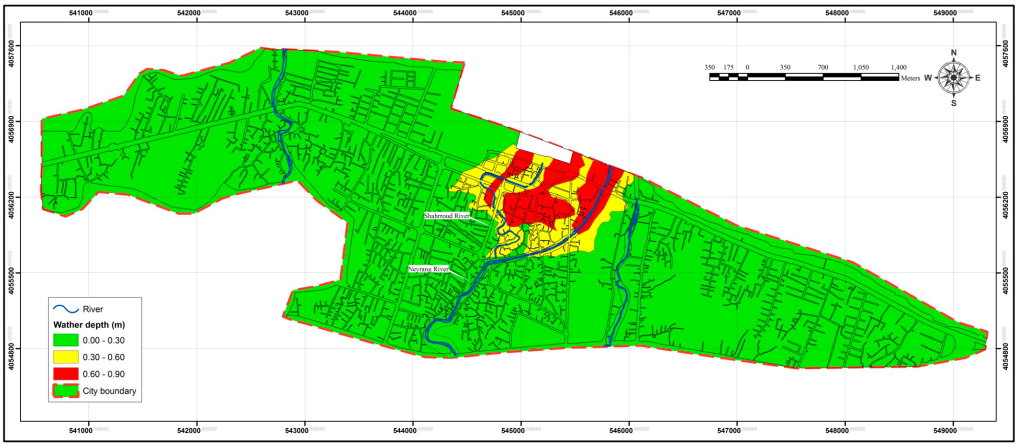

Fig. 4. Distributions of water depths.

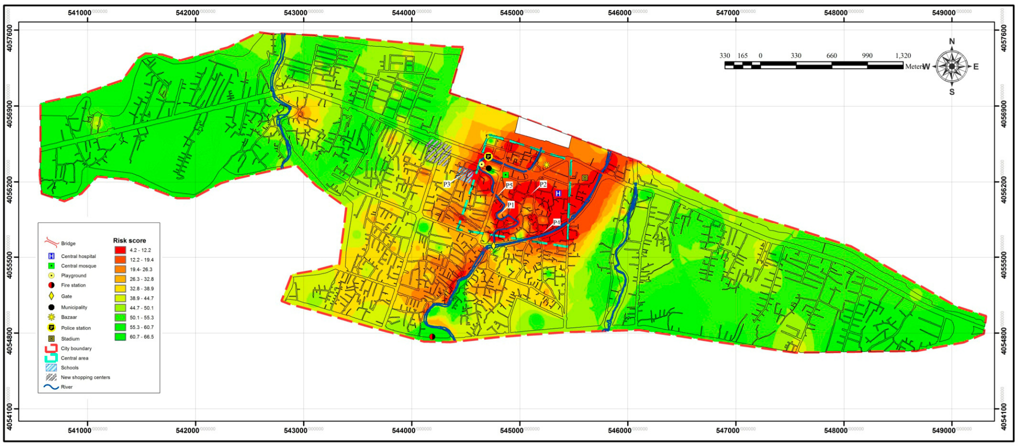

Fig. 5. Distributions of the risk scores.

ered in the context of flood risk management, and the schools are located beside this area; (iii) the new shopping centers compared with the bazaar is safer; and (iv) the public organizations, which deal with emergencies, place in zones with high risk of flood, except the fire station.

The analysis of zones with the most serious risk situation indicated that almost all of these zones are located in the central area and close to the flooding river (Neyrang River). In this area, with residential land-use and the most population density, most of the buildings are old in age and have inappropriate structural quality. From the wall condition and fall barrier subcriteria viewpoints, the passing river has either no retaining wall and fall barrier or has a weak one in these zones. Distributions of water depths showed that these zones face more depth of water. Moreover, most of the buildings have only one floor and as a result, there is a vulnerable situation regarding the height distribution criterion.

The results of observations following the flood event can be used to verify the performance of the SPRI model. Fig. 6 shows 6 pictures from 5 points (P1–P5) as shown in the Fig. 5 and the playground, which are damaged or affected by the flood, and locate in the zones with the minimum values of the risk scores.

The model predictions can generally be seen to have agreed well with these observations. It can be seen that the values of the risk scores at the flooded cells, the cells on the old or dense urban textures, and the cells near the river is low and increase by going along way, which can testify and approve the model potential of prediction the zones with high risk and the assessment method of flood risk.

Fig. 6. Observations following the flood event: (A) Wall collapse and flood flow to a house at (P1), (B) Inundated first floor and home appliance and furniture damages at (P2), (C) Flood has passed through the playground, (D) Flood has affected the school yard at (P3), (E) Damaged urban infrastructure at (P4), and (F) Flood has carried cars at (P5).

DISCUSSION

Similar methodologies for the assessment of flood risk in different areas around the world have been applied up to now by earlier scholars. A brief comparison of the present study with some previous researches is provided as follows.

While in the study carried out by Camarasa-Belmonte and Soriano-García (2012) for developing a methodology in order to map the flood risk, a panel of experts assigned ordinal scales of hazard, exposure or risk, in our study, we formulated the options for scoring the criteria. These criteria develop the indexes, which represent the flood risk components. This formulation provides a specified framework for assessors, who apply the SPRI model.

Zhaoli et al. (2012) have evaluated the flood risk and represented the detailed distribution of the zones of five different level of risk with specified area. While their results are useful as a reference for flood control and flood assessment in the context of policy and decision making, in our study the SPRI model results are capable for being applied in a detailed-scale in the context of urban planning. The food risk mapping obtained from our study is a practical tool for identification of high-risk zones and prioritization the treatment measures, identification of weaknesses and strengths of zones, analysis of vulnerability, improvement of emergency and rescue plans, calculation of flood damages and determination of annual flood insurance premium.

While Müller et al. (2011) have categorized the assessment variables of flood vulnerability into physical vulnerability and social vulnerability by a methodology that uses indicators, in our study, we assessed the flood risk by evaluating the effective criteria categorized into seven indexes (environmental, technical, economic, social, depth, population and sensitivity ones) that are involved in all stages of flooding (source, pathway and receptor). Whereas Müller et al. (2011) have assigned the vulnerability values to each building block of the city in a map, the SPRI model developed in our study uses spatial analysis in order to extrapolate the risk scores of building blocks for flood risk mapping.

While Xia et al. (2011) have represented the distribution of maximum hazard degrees for people and vehicle safety separately around the flood flow, in our study, the SPRI model represents the overall flood risk situation as a dimensionless magnitude called as risk score. Furthermore, this model results in a flood risk mapping all over the area under assessing.

While Sinnakaudan et al. (2003) have used the ArcView GIS in order to develop an extension for manipulating the output of the HEC-6 model to produce flood maps, in our study, we applied using the ArcView GIS with Spatial Analyst to express the spatial variability of the flood risk. Whereas the extension developed by Sinnakaudan et al. (2003) only concentrates on the flood risk within the boundary of the bunds, the SPRI model evaluates the criteria of flood risk throughout the area under assessing.

CONCLUSIONS

In this study, the SPRI model for the flood risk assessment was developed. The model is an index model, which assesses the flood risk, by scoring technique. To this end, it identifies and evaluates the flood risk criteria and forms RS, which ranges between 0 and 100. A higher RS is representative of an improved risk situation. The model attains a relative sense of the flood risk and an overall picture of the flood system in the area under assessment.

The SPRI model was used to assess the flood risk in the destructive flood of Nowshahr city in 2012. The results showed that: (i) the flood risk zoning were compared with observed data for aspect of the damages, and general agreement between them was obtained; (ii) for urban zones, which surrounded by two rivers, such as the Nowshahr flood, would easily be in critical condition, and rescue operations face difficulties; (iii) considering first floor inundation in the zones with high risk of flood, first floors should be constructed in a certain level from the ground, and the gate of these buildings should be flood proof; and (iv) it is necessary to review the location of the emergency services, according the flood risk zoning.

We believe that the developed model has ample potential for further application in context of urban planning and flood risk management, for instance in the context of identification of high-risk zones and prioritization the treatment measures, identification of weaknesses and strengths of zones, analysis of vulnerability, improvement of emergency and rescue plans, calculation of flood damages and determining of annual flood insurance premium. However, further validation processes and more fine-tuning are needed to check the reliability and the sensitivity of the model if, and when, further observed field data or results of the other assessment become available in the future.

Acknowledgements. The authors would like to wholeheartedly to acknowledge Prof. Juraj Parajka, Prof. Pavol Miklanek and two anonymous reviewers for their valuable and constructive comments/suggestions on an earlier draft of this paper.

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Received 4 November 2015
Accepted 23 June 2016