Design and Development of Early Warning System for Desertification and Land Degradation

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Abstract

Early warning systems are key components of strategies to reduce risk. This research, by adopting a systematic approach in the management of desertification risk and including previously developed models and systems, offers an integrated efficient structure in terms of early warning for the risk of desertification as a pilot system for semi-arid areas of west Golestan Province, Iran. During recent years, desertification has taken place in the province in different ways. The offered system is an expert domain which according to security levels and access to data could be utilized by organizations, experts, users, and senior executives. In the architecture of the system, data processing, decision-making control panels, and early warning systems are also adaptable to the national scale. The entries in the system include vector, raster, etc; processing sector is comprised of management and process sections. In the system's output, a variety of tools for the assessment of desertification risk severity, alarming based on various scenarios, and reporting are available. The output data structure is often vector and image which are evaluated and verified in the system. Lack of a long-term network monitoring, data transmission, interaction between stakeholders and decision makers, and communication infrastructure are considered obstacles facing the development of integrated early warning systems for desertification in the study area. This system as a unique and fundamental tool in the context of desertification assessment could provide unprecedented assistance to the managers.

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1. Introduction

Risk-based management is an effective solution to tackle and reduce natural disasters (Messner and Mayer, 2005). According to the definition of the UN Secretariat of International Strategy for Disaster and risk management (ISDR), performance and systematic approach to uncertainty are compound measures to minimize the risk of potential vulnerabilities which include risk assessment, analysis of the risk intensity, long-term monitoring of effective indices, timely alerting and informing people, the implementation of strategies, specific actions to control, reduce, and transfer the risk (UNISDR, 2013). Arid regions of the world for various reasons are constantly exposed to degradation and desertification (Green facts, 2007). As a result, a wide range of environmental, cultural, economic, and political impacts, at the local, national, and global scales have been created. Much of the concern around desertification arises from reduced land productivity, especially in the arid areas. According to statistics, about 70 percent of the arid regions are experiencing some degrees of degradation (UNCCD, 2006).

The Millennium Ecosystem Assessment[1] studies showed that the world's arid regions are about 41.3 percent and 34.7 percent of the world's population live in these areas (MA, 2005). Given the extent of the land affected by desertification in the world, this trend has not been well measured and it is poorly documented, so that many estimates are largely subjective. As a result, and as an important priority, it requires effort and planning at national, regional, and local scales to tackle this problem (Lantieri, 2003).

Early warning systems are part of the preparation strategy and implementation of information systems which help identify risk and critical situations. In fact, these systems are managers' assistants regarding the collection, processing, and distribution in a systematic manner. Forecasting systems have applications in other areas such as natural hazards and geophysical, biological, social, political, industrial, and medical contexts. A global survey of early warning systems was undertaken at the request of the Secretary-General in 2006 with a view to advance the development of a global early warning system for all natural hazards (Sixty-first session ISDR, 2006). In current terms of ISDR, early warning systems are defined as "systems that provide timely and effective information through recognized institutions that allows individuals at risk to be prepared to respond effectively or reduce the risk" (ISDR, 2004). The early warning systems have been recognized as key components of strategies to reduce the occurrence and the effects of natural disasters which has also been recognized in the agenda 21 as the result of the 2002 UN Convention in the World Summit on Sustainable Development (ICCD/COP, 2007).

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1. Millennium Ecosystem Assessment, MA

Disasters occur when a natural hazard event overwhelms a community's capacity to cope, and the rise in impacts is largely due to growing populations and vulnerability to natural hazards. Unsustainable development practices are key factors in the increase of disasters, while disasters are threats to livelihoods as well as international and national efforts to advance socioeconomic development and eradicate poverty, posing a serious obstacle to the achievement of the Millennium Development Goals (Sixty-first session ISDR, 2006). Warning initiates by measuring the elements at risk and vulnerability (Amman, 2016). Desertification such as natural disaster with slow onset develops due to land mismanagement and through the interaction of the natural ecosystem with human social system. Evaluation and prediction of desertification depends heavily on the availability of information on biophysical, socio-economy, and other aspects. Desertification is a major environmental problem that should be checked on a global scale. More than 110 developed and underdeveloped countries have been affected by the desertification process (MA, 2005), moreover, about 10 to 20 percent of the world's dry lands have been affected by these processes (Rubio and Recatala, 2005). According to statistics, 74% of arid regions in North America, 13 countries in European Union members, and 18 developed countries of the world are under the influence of desertification (Joint Research Center, 2008).

Predicting desertification is difficult owing to the complexity and interaction of multiple driving forces with its long-term nature. Still, large scientific gaps exist in the widespread acceptance of the principles of the early warning systems and their functions. In the UN Program of Action, several innovative projects have been planned to develop and implement early-warning systems for drought and desertification assessment on national and global scales, but there is still no operating system that could successfully implement these strategies, plans, and programs to combat desertification. The main goal of desertification's early warning systems is warning people exposed to land degradation and its potential effects of the risk (UNEP, 2012). Desertification assessment is possible through revealing the criteria and indicators specific to each area, their monitoring during specific time intervals, analyzing time series data, and designing and development of early warning systems (Nunez et al, 2009).

Early warning systems are totally novel; the first one for drought and food security was designed in the late 1970s (ICCD/COP, 2005). Different countries depending on the intensity, frequency, and type of the disasters that threaten their lives or assets, have conducted studies in this line. Desrtlinks, MEDACTION, LADAMER, SCAPE SURVEY and DESKTOP (ICCD/COP, 2007) are a number of projects conducted so far on the issue.

Monitoring and assessment are only part of the early warning process and if integrated with a communications system and response program can be considered as an efficient early warning system (Glantz, 2003)

The main aim of this study is to offer a design for an early warning system for desertification and land degradation and to create a control, management, information (data), and decision-making center in the area of desertification for Golestan Province as a pilot province in Iran. The reason for choosing Golestan Province has been ongoing development of desertification conditions in recent years in the area. Abbasabadi (1999), in his quantitative assessment of desertification in Aq-Qala-Gomishan plain of the Province, concluded that processes such as waterlogging, salinization, vegetation degradation, and soil erosion are the important causes of desertification. Sabeti *et al.* (2007), investigated the mechanism of wind erosion and its effect on the risk of desertification in the northern plains of Aq-Qala and found that 58.45% of the area fell into high risk class of wind erosion with the largest area in the very high risk class of desertification. Afkhami Ardeshir *et al.* (2007) evaluated the effect of land use changes in the development of desertification in Aq-Qala – Incheh Borun region; their results showed significant land-use changes during the last 50 years. Ownegh (2009), assessed the risk severity and corresponding management plants in Gorgan plain using the analytic hierarchy process and a subjective model, and showed the classes of desertification increase from the forest covered areas in the south to the lowland steppes in the north. Honardoust *et al.* (2011), assessed the severity and risk of desertification in the northern part of Gorgan and showed that more than 52% of the area was affected by severe desertification due to the dominant roles of soil and waterlogging factors.

This has led to land degradation, intensification of natural hazard, reduction of land production, poverty expansion, and immigration. Therefore, the development of early warning systems can reduce the mentioned problems in the study area. Since the drought EWSs which currently exist have not yet introduced such a system, this can be expected to be a highly original contribution to the desertification research field (Khosravi, 2012). Given that, Akbari (2016) in his studies developed the first desertification early warning system for the semi-arid areas of the western Golestan Province.

By implementing Early warning system for desertification and land degradation (EWSD), the following goals might be fulfilled;

- Contributing to the elimination of paper-based systems as well as protecting the environment and natural resources in accordance with the general environmental policies of the country,
- Providing quick and timely alert to prevent hazards or mitigate them,
- Creating a data center to be accessed for management decisions,
- Creating an appropriate atmosphere to share information and avoid duplication of related tasks,
- Creating an integrated forecasting model for desertification,

- Standardization of observation method for long-term monitoring of desertification indicators, and
- Assessing the vulnerability of land through field observations and monitoring.

2. Materials and Methods
2.1. Study Area

Golestan Province, with an area of about 20 thousand square kilometers, lies between 36^0 30' to 38^0 8' N and 53^0 51' to 51^0 22' E in the northern part of Iran and east of the Caspian Sea. This province is limited to Turkmenistan in the north, northern Khorasan in the east, to Mazandaran and the Caspian Sea in the west, and Alborz Mountain in the south.

Golestan Province is significant for its geographical conditions and natural climatic variability. The southern regions have mountainous climate with forest areas, trees and shrubs; central and south-western areas are marked with Mediterranean temperate climates which include urban areas, industries, and agricultural lands; northern part has a semi-arid and arid climate and includes desert lands, salt marsh, lowland wilderness areas with low and very sparse land cover. Annual rainfall of the province varies between 355.8 to 594.3 mm, and also various geological deposits could be seen in the province. A steep environmental and geomorphological gradient between the forest and the sea makes this province unique with typical forest, plain, and desert facies such as areas of dense rainforest in the south to the dunes, playa and coastal micro topographies in northern parts which are rarely seen in the interior deserts. Vast areas of the province are covered by recent sediments (fluvial, deltaic and coastal) while its eastern border is covered with thick layers of loess.

In addition, various forms of natural and environmental hazards such as prolonged droughts as the results of climate change, flooding, landslides, water and wind erosion, sharp capillary fluctuations, earthquakes, land degradation, desertification and salinization, drastically threaten the province (Topographic analysis report, 2013). Figure 1 shows the geographical location of Golestan Province in Iran and three photos taken of the area.
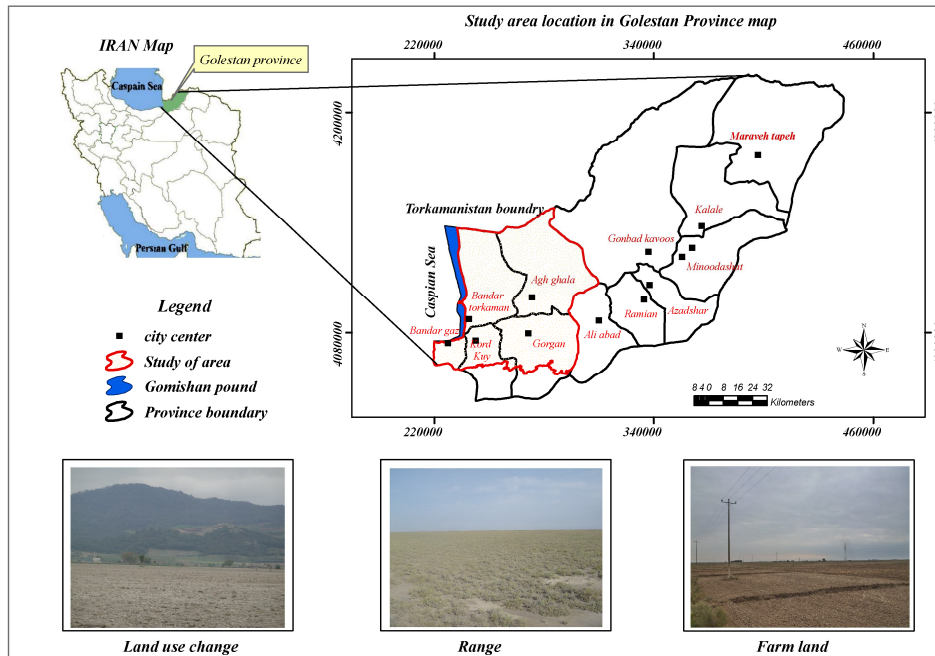
Figure 1. Geographical location of Golestan Province in Iran

2.2. The Structure of Early Warning Systems

The early warning systems are sophisticated systems with enterprise applications such as constant monitoring of the changing phenomena, missions, strategies, response in times of crisis, and applied scientific programs (Balis et al., 2009).

An early warning system to be applicable in time of natural disasters depends on four key factors: risk knowledge, monitoring and warning services, broadcasting and communications, and the ability to respond (Grasso, 2012). Figure 2 shows four key and dependent factors in the early warning systems.
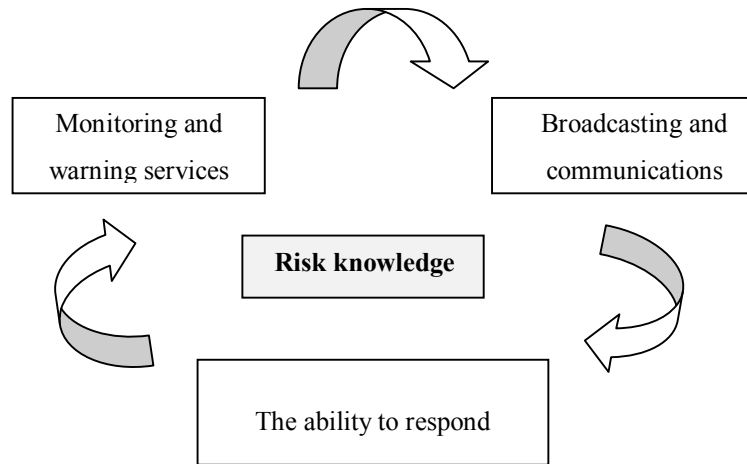
Figure 2. Four important factors associated with early warning systems (Source: Grasso, 2012)

2.3. The Initial Design (prototype) of the Early Warning System for Desertification in the Study Area

Based on the structure and requirements mentioned in Figure 2, design process of an early version of the system is as follows:

- Definition of the subject,
- Thinking, analysis, algorithm production (problem solving method),
- A detailed analysis of the system and identification of the various elements according to the algorithm,
- Coding (production) the application,
- Providing basic version,
- Testing and receiving feedback from the early version,
- Correction of the possible weaknesses and problematic components, and
- Presentation of the final version.

Analysis of a system is now commonly implemented with object-oriented approach, especially using the UML[1] method. So, the system analysis needs correct understanding of system implementation process and also its constituents. In fact, UML is a public and targeted modeling language in the field of software engineering that offers a standard method for designing a system. Figure 3 shows the flow process of the prototype version of an early-warning system (Salkhordeh Haghighi, 2011).

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1. Unified Modeling Language
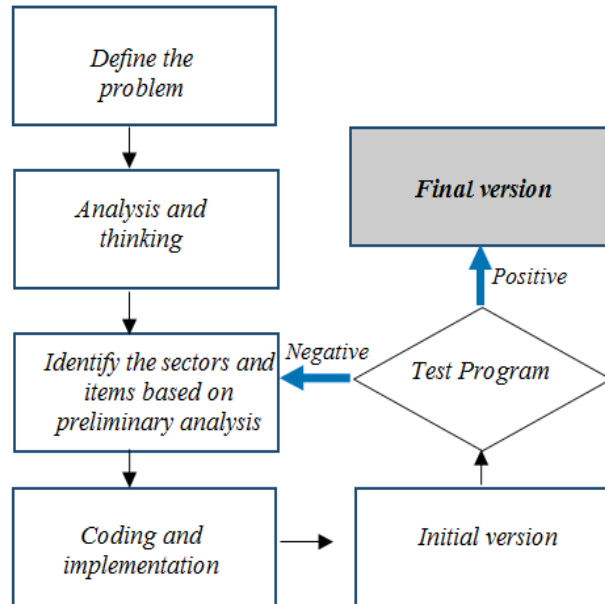
Figure 3. Flow diagram of the early-warning system development
(Source: Salkhordeh Haghighi, 2011)

In this regard, with the initial design of the system (in the form of a demo), weaknesses can be easily modified, edited, and fixed. Prototype which can usually be provided in paper or digital form (Walker et al., 2002), is a draft version of a product that allows designers study the economic value (benefit-cost ratio) of their ideas with time management and system development capital, before the final design.

2.4. Comparison of the Designed Early Warning System with Linear Models

The designed early warning system is an integrated model (people–centered) that is different from linear systems in terms of performance. At the moment, linear models are the most common type of early warning systems which include a warning chain and linear set of alerting connections to communicate the risk to the user. In the linear models, early warning systems largely focus on risk in a top-down manner with expert-based systems where little or no interaction with end-users or their representatives occur. In the meteorological sciences, linear-warning system conveys a sense of "end-to-end systems" (Basher, 2006). Some types of these systems are WinDisp, DISMED[1] and DESIRE[2] system.

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1. Desertification Indicator System for Mediterranean Europe, DISMED
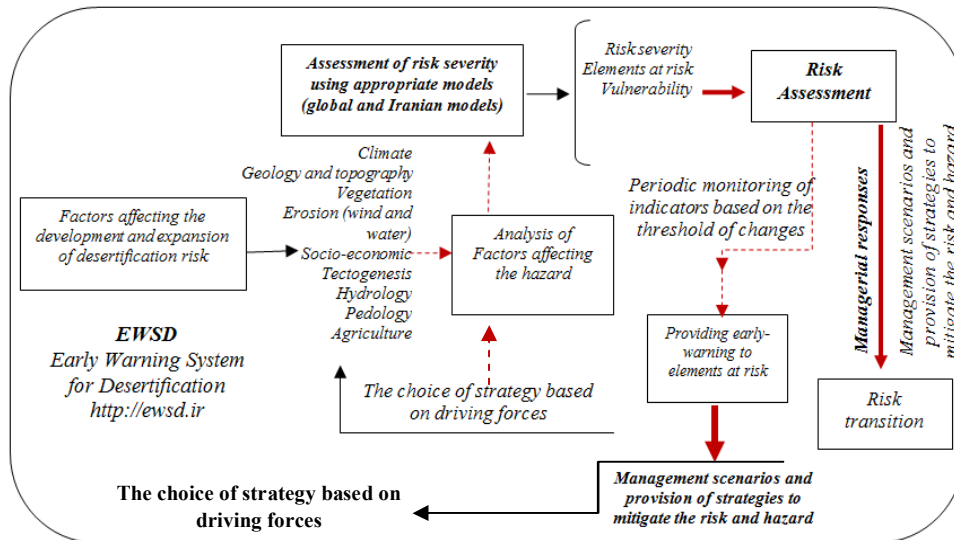2. Desertification Risk Assessment

3. Results and Discussion

3.1. Structure and Function of Early Warning System for Desertification and Land Degradation (EWSD)

Early warning system for desertification and land degradation (EWSD) was developed based on the technical knowledge of the hazard and with regard to national and local policy and technical capacities. This system is conceived of as a network of systems with collaboration among the responsible authorities to exchange data and knowledge, to complement operational capacities, and to prepare the public in a coordinated way using the latest world-class frameworks such as ASP.NET, MSSQL, HTML[1], CSS[2], JQuery, IIS, MAP SERVER, XML[3], WSDL[4], MVCN-Layer on the Web as the server (central unit), while Android mobile platform and also web applications (Web Apps - Web client) have been used for user's interaction with the system (data input and analysis). Features of the system are also available in parallel form on the internal network, virtual private network (VPN), and Internet. In terms of information access levels, desertification and land degradation early warning system is divided into four layers of management, and utilization:

- **System administrators**: It includes features related to reporting, monitoring, access to information related to prediction, granting access and notification of management scenarios which could be used by means of the two mentioned platforms.
- **System experts**: This layer comprises of the features related to data analysis (input, edit, delete, etc.) and operational facilities of the first level by complying with data security.
- **Users of the system**: Features such as data analysis (input, edit, delete, etc.) and operational facilities of the second level and in compliance with data security are provided to the users in this layer.
- **End users (Project Managers, stakeholders)**: End users will only have access to information that is defined by the system according to security levels and these users can view the information and receive early warning alerts directly (i.e. notification alerts for the beneficiaries). Figure 4 shows a conceptual model for desertification and land degradation prognosis.

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1. Hypertext Markup Language
2. Cascading Style Sheets
3. Extensible Markup Language
4. Web Services Description Language

Figure 4. The conceptual model of desertification and land
degradation early-warning system

In the conceptual model, the inner and outer relationships between system components are shown. So, the importance of relations between the components are highlighted. In Figure 4, the dark red arrows indicate stages of managerial decision making, while thin red arrows indicate steps in data processing. Dark arrows represent the initiation of the processing stages.

3.2. The Ability of Integrated Early Warning System for Desertification and Land Degradation (EWSD)
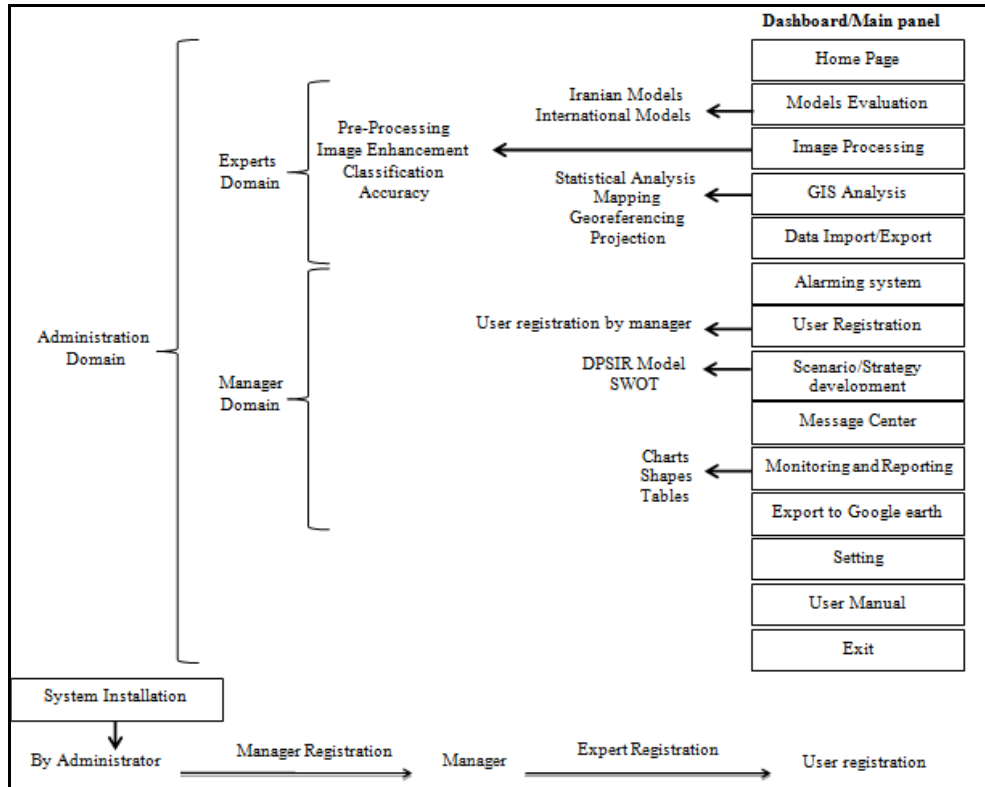
Desertification and land degradation early warning system allows users to perform the following:
- Import and export raster, vector as well as Grid data structure,
- Use global and Iranian models of desertification risk assessment,
- Estimate the risk of desertification and produce threshold maps accompanied by legends,
- Include the spatio-temporal changes in the severity of effective indices and monitoring desertification,
- Forecast short-term risk based on the existing models,
- Set a risk threshold and provide its maps,
- Process information layers (GIS and RS), data analysis, and image display and analysis,
- Assess the accuracy of the generated maps based on validation models,
- Change map scale in the format of SVG,

- Display the processed data over other browsers in different display sizes,
- Online data registration during field operations,
- Define users (managers and experts) based on the security and access levels,
- Issue warnings (automatic and manual) to the users via SMS messages or on social and other national networks,
- Store and export processed data in web-based formats such as XML, RSS, html, CSV,
- Develop the early-warning system applications for mobile devices,
- Report the processed data as text, charts and graphs,
- Enjoy an appropriate and user-friendly design (interface, font, color maps, links, dashboards, etc.),
- Expand the system to other models, including models of land degradation, and
- Provide scenarios and management strategy based on DPSIR and SWOT conceptual models.

The structural foundation of the strategies used in the system is based on land use management and soil conservation strategies provided by UNEP (2004). These strategies, in addition to studying various aspects of land degradation and desertification, offer important management practices to prevent land degradation provided that it includes a mixed management of land, water and living resources of ecosystems for optimal utilization and to maintain the quality of ecosystem sustainably. Ecosystem assessments have direct correlation with soil, environment, sustainable development, and poverty reduction issues. In this regard, the role of state actors as the performers of management programs is very impressive (UNEP's Strategy, 2004). Below features are important for the system.

- Ability to be specified and applied for different users,
- Ability to develop the early warning system for multiple languages,
- Ability to provide user manual for the correct use of the system,
- Direct links to other related tools such as Google Earth and Google Map,
- Ability to provide changes as text and graphical alerts,
- Creation of a database for temporal comparison and evaluation of changes,
- Ability to track changes, acquiring information from user, and importing and exporting the results, and
- Ability to receive online GCP data recorded on devices in the field and compare recorded values with the defined system's thresholds to decide on whether to broadcast warning message (for instance, recorded EC values, tagged with the coordination systems via GPS). Figure5 shows menus and tools designed in the early warning system.

Figure 5. Menus and tools designed in the early warning system for desertification and land degradation

Domains in the figure are divided on the basis of security level (users, experts and managers).

It should be noted that after system installation on the server of the related organization, administrators will be able to define the managers (through the defined tool in the dashboard). Subsequently, managers could define users and experts with limited capabilities (this limitation, for instance, includes access to broadcast warning messages as well as scenario and strategy development).

As given previously, stakeholders and beneficiaries are the end-users who directly receive the alert from the system through message broadcasting. The designed early warning system functions as a purposeful and intelligent system and because of its special architecture, warns the people at risk manually or automatically.

It is important to note that prediction is not important in solos, unless timely and understandable warning can be delivered to people. In fact, study of the current early-warning systems shows that in most cases, communication systems lack

appropriate response programs. Monitoring and assessment are only part of the early warning process and if integrated with a communications system and response program, can be considered a good early warning system, (Glantz, 2003).

In early warning system, data plays an important role in the process of data analysis, processing, and notification. Inputs of this system usually consist of data from ground reconnaissance, local, and regional scale based maps such as topographic maps, slope, elevation, roads and transportation lines, etc. It also includes interpreted aerial photos and satellite images, data on climate and drought, information about the quantity and quality of surface water, borders of provinces and counties and municipalities' and specific maps. Geology, soil maps, vegetation, agriculture, land use and land cover, towns, townships, villages and counties, industrial and economic facilities and other maps that can vary according to climatic and ecological conditions are examples of such maps. Usually the structure for input data are vector, raster and grid. The processing sector includes management practices and processes.

The managerial panel provides the possibility of defining accounts for senior manager, and monitoring and strategy development. The processing panel includes statistical analysis, image processing, overlaying layers, intra- and interpolation of spatial data, changing imaging coordination systems, georeferencing of maps, exporting data to other graphical environments like Google earth, Google map etc. System outputs includes charts and graphs related to areas affected by land degradation and desertification with different intensities, areas with higher sensitivity to variables' thresholds, desertification risk and hazard maps, strategy development based on different scenarios, and finally reporting.
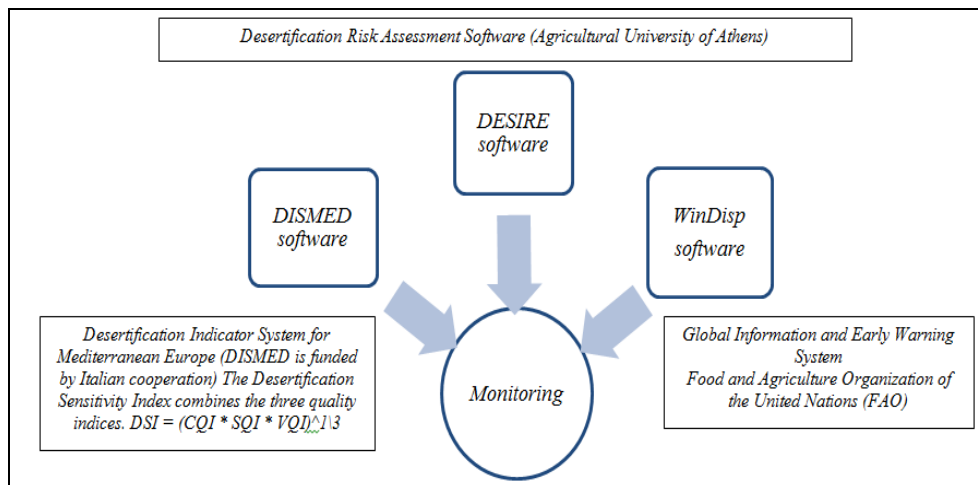
3.3. The Comparison of the Integrated Early Warning System Model for Desertification and Land Degradation (people-centered model) with Linear Models (end-to-end models)

Regarding land degradation risk assessment with systematic and integrated early warning approaches (end-to-end models), the following systems are commonplace which are solely intended for measurement and monitoring:
- WinDisp system which is a public domain for display and analysis of satellite images, maps, and associated databases with an emphasis on early warning for food security. The system has been developed by FAO for global scale and early warning systems (www.fao.org).
- DISMED as a European method system, is suitable for measurement of land degradation indicators and has been developed by an Italian company based on MEDALUS model. In this version, indicators of climate change, soil, vegetation, and land management quality are used to assess land degradation in Europe (www.unibas.it).

- Desertification risk assessment or DESIRE system was designed and provided by the Agricultural University of Athens. The system gives users the ability to do the following:

- Analysis of a wide range of alternatives for land management practices to reduce the risk of land degradation,
- Evaluation and selection of the most significant predictors of the risk of land degradation, and
- Development of coordination between different groups such as politicians, managers, and experts (www.desire-his.eu).

Figure 6. Comparison of early warning systems (end-to-end) in terms of structure and function

Unlike linear models that depend solely on observations and field operations (end-to-end models), the structure of integrated early warning model, is based on scientific knowledge (people-centered models) and field observations. Early warning system is continually in communication and interaction with all the elements of the warning and risk management.

4. Discussion

Since the semi-desert areas of west Golestan Province are faced with the problem of desertification and land degradation (based on studies of Abbas Abadi, 1999, Sabeti *et al.,* 2007, Afkhami Ardeshiri *et al.,* 2007, Ownegh, 2009 and Honardoust *et al.,* 2011) in terms of natural conditions such as geology, soil, physiographic and climatic (according to topographic analysis report. 2013) and anthropogenic impacts (on water resources, agriculture and economic-social), risk

management has been developed with regard to the uncertainty in this area which is useful in reduces the impact of desertification and land degradation.

These desertification early warning systems, as the main factor in the context of natural hazards mitigation strategy (ISDR, 2004) were performed for the first time in Golestan Province so that its implementation can reduce the damage caused by desertification in these areas.

Since the EWSs drought which currently exists in the area, no such system has been offered and this can be expected to be a highly original contribution to the desertification research field (Khosravi, 2012).

In this regard, with the initial design of the system or the prototype (in the form of a demo), weaknesses can be easily modified, edited, and fixed. Prototype which usually can be provided in paper or digital form is a draft version of a product that allows designers to study the economic value (benefit-cost ratio) of their ideas with time management and system development capital before the final design. These results are consistent with studies of Walker *et al.*, 2002.

After the initial design for the prototype system, EWSD is designed which is a dedicated expert domain (www.EWSD.ir). This system has been developed to display the spatio-temporal changes of desertification criteria using data from satellite images, raster and vector data, and also other databases for the sake of early warning. One of the EWSD's capabilities, is the use of GIS data input as an important part of the system, derived from the analysis of satellite imagery emphasized in studies of Grasso, (2012).

The offered early warning system of desertification and land degradation is an integrated, comprehensive, knowledge-based, and people-centered system which provides the ground to assess and implement four key factors such as risk knowledge, monitoring, broadcasting, communications, and the ability to respond to the risks. This has been emphasized in studies of Glantz, (2003). Unlike linear models that depend solely on observations and field operations (end-to-end models), the structure of this model is based on scientific knowledge (people-centered models) and the field observations.

The early warning system is continually in the communication and interaction with all the elements of the warning and risk management. In this model, the factors and symptoms effective in hazard occurrence, are considered on the basis of scientific principles where system responses are also compatible with local conditions.

Based on the Hyogo and Sendai's frameworks and in line with the meetings of the International Secretariat on reduction of natural hazards (Ammann, 2016) on integrated systems, the focus has been on the ultimate goal of reducing natural hazards and empowering nations and communities in the face of disasters and poverty. From this perspective, early warning systems are efficiently applicable for monitoring and providing early warning not only for rapid and short-term risks, but

also long-term consequences such as deterioration of environment, development projects with high risks, policy changes, social relationships and capacities, immigration, war, and health issues.

5. Conclusions

Early warning system of desertification and land degradation is an integrated, comprehensive, knowledge-based, and people-centered system which provides the ground to assess and implement four key factors such as risk knowledge, monitoring, broadcasting, communications, and the ability to respond to the risks. Since no early warning system of desertification is fully operational at the moment and given the fact that existing systems are based on end-to-end paradigm and specialized approaches, the designed system in this study has been intended to include data transfer mechanisms (to reach the target population in an efficient and timely manner), long-term monitoring and evaluation network, risk assessment mechanisms, and management strategies.

The system includes two key features, one section of the system incorporates political institutions, authorities, local and regional people as well as research community. The other includes the affected population which will receive responses to counter the risk according to the specifications given to the system.

Early warning system of desertification and land degradation will facilitate achieving the goal of "a safer world in the 21st century" by receiving feedbacks from the shortcomings of existing systems (in the design and not in the operation) and by trying to channel the focus to the risk-based management instead of hazard mitigation. Desertification early warning systems will activate the other warning systems operating at different levels of authorities which will be expanded to the lower-level officials all of which are essential for effective and timely warning.

Based on the Hyogo framework and ISDR, the issue of risk and early-warning systems is among the first five areas for national action plan. The failure of any part of the system will be a total system failure. Therefore, accurate warnings will not have any effect if people to receive the alert are not prepared or if the warning message has not been broadcast in a timely and fast manner by the authority. The main idea behind the early warning is to be agile and more accurately able to predict short-term and long-term potential natural and human hazards.

Early warning system by means of geographic information system (GIS) and remote sensing (RS) provides functions such as image processing, detection and classification of satellite imageries, and composition and validation of data layers which could produce accurate and explanatory layers for declaration of readiness to beneficiaries and authorities.

As the system is web-based, risk-based importing and exporting data and information will be online which per se reduces the risk consequences and provides its long-term mental peace for the society. In this context, the possibility of

creating a database which is one of the problems in the implementation of the warning systems will be achieved in the long term.

Although the design of this system is in its early stages, it is unique and fundamental as an applied research for managers and executives. So, with the development of tools and their applications (which has been considered in the basic architecture of the system for its further development), it can help reduce the human and financial consequences of the hazards in the national risk management scheme.

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