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# Land use changes and restraining environmental risks via mitigation approach (The case study: Darkeh-Velenjak watershed, Iran)

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**A B S T R A C T**

Widespread land use changes and unusual uses of highlands in Northern Tehran *(Darakeh-Velenjak Watershed*) have markedly caused to pose environmental risks and unsustainability. This research aims to study land use changes in *Darakeh-Velenjak Watershed*, to identify the key risks which can be posed by land use changes, and to present appropriate strategies using mitigation approach. To study land uses changes, satellite images were used (TM 1987, ETM+ 2000, and IRS 2018) and assessed by concentrating on four classes of land including vegetation, arid, roads and built-up areas. To extract the necessary information from the satellite images, Supervised Maximum Likelihood Classification algorithm was used, further complemented by visual interpretation methods. The sample population for conducting the Delphi technique consisted of 34 experts. The results of this research exhibited that from 1987 to 2018, vegetation had dramatically decreased, while arid, roads and built-up areas had increased. The results also revealed that in 1987, around 37.3% of the study area was covered with vegetation while in 2018, less than 14.54% of the area was covered with vegetation. In contrast, built-up, roads and arid areas which respectively covered 8.96%, 1.75%, and 51.99%, increased to 15.18%, 3.19% and 67.08% in 2018. In addition, the results of this study illustrated that key risks of land use changes in the *Darakeh-Velenjak Watershed* could be divided into natural and human risks. The human risks with an average score of 4.21 were more than natural risks. Finally, strategies have been presented using mitigation approach in the study area. Results revealed that avoidance strategies with an average score of 3.37 were situated in the first rank because unfortunately this watershed has been damaged by excessive land use changes in an aspect of developing buildings, roads, tourism infrastructures and etc.

**A R T I C L E  I N F O**

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## 1. Introduction

Growth of population and urbanization has caused to develop cities and decrease vegetation level in recent decades (Li et al., 2013; Wu et al., 2006; Alberti, 2005), and this trend is expected to continue in the future, with triple the land and a 60% increase in the urban population by 2030 (Elmqvist et al., 2013; Seto et al., 2012). Nowadays, more than 3.9 billion the world population are urban dwellers, and it probably will increase to 6.3 billion until 2050. Growth of urban population has led to critical environmental problems include the loss of fertile lands, open space and biodiversity (Harris, 1984; Benfield et al., 1999; McKinney, 2002; Atu et al., 2013), spoiling water quality (Allen and Lu, 2003; Wilson et al., 2003; Tu et al., 2007), higher GHG emissions and pollutions levels (Glaeser and Kahn, 2004) and increasing runoff and flood potential, and increase of energy consumption. (Reise, 2009; EEA, 2006; Sung et al., 2013). Generally, arid areas and vegetation alter onto built-up areas (such as buildings, roads, factories, etc.) by growing number of population and enlarging the territory of cities. This trend commonly supports ruin natural environments, growth of environmental risks and unsustainability.

According to sustainability approach, natural resources such as land, biodiversity, climate, water, soil, natural hazards, energy, population, and etc. must be conserved and improved (Smith et al., 2001; United Nations, 2015), therefore changing land use in ecosystems can create environmental risks and unsustainability. Since the adoption of the Hyogo Framework for Action in 2005, as documented in national and regional progress reports on its implementation as well as in other global reports, progress has been accomplished in decreasing disaster risks at local, national, regional and global levels by countries and other relevant stakeholders, leading to a reduction in mortality in the case of some risks. Undoubtedly, effective disaster risk management causes to sustainable development. Countries and governments have improved their capabilities in disaster risk management. International procedures for strategic advice and coordination development for disaster risk decreasing, such as the Global Platform for Disaster Risk Reduction and the regional platforms for disaster risk reduction, as well as other relevant international and regional forums for cooperation have been instrumental in the development of policies and strategies and the advancement of knowledge and mutual learning. As forecasted in the Sendai Framework for Disaster Risk Reduction 2015-2030, integrating sustainable development goals into disaster risk mitigation and adaptation at all levels and in all stages of policy activities is extremely consequential for achieving the sustainability of communities. This Framework has a three-fold goal, includes impeding the pose of risk, the reduction of existing risk, and strengthen of resilience of people and assets to the resilience residual risk (UNISDR, 2015). Both mitigation and adaptation are obviously fundamental in any comprehensive approach to controlling risk disaster (Klein and others, 2007; Dowlatabadi, 2007; Klein et al., 2007). Even the most strict mitigation efforts cannot escape more impacts of disasters, because of historically obligated emissions, making action on adaptation essential. Simultaneously, we cannot conform indefinitely to these impacts, so compelling mitigation is necessary to avoid the worst effects of disaster (Klein et al., 2007). Like most of the developing countries, Iran has experienced high urban population growth in the last five decades. According to the Statistical Center of Iran, more than 71.4 percent of the Iran population (53.646.661 people) living in towns and cities in 2011 (Statistical Center of Iran, 2011). In Iran, urbanization growth has been fueled by governments' incentives and policies particularly after the Islamic Revolution and disparity in regional development, which resulted in urban-rural migrations. Since the big cities and metropolitans in Iran are situated at the heart of fertile agricultural regions, understanding and monitoring the urban growth and land use changes is crucial and would be helpful for the city planners and policy makers to direct future developments and for environmental management (Sudhira et al., 2004; Knox, 1993; Simmons, 2007). Darakeh-Velenjak Watershed, as study area of this research, which has been situated in North of Tehran (capital of Iran), has experienced many changes in the last four decades. Growth of environmental risks, because of rapid land use changes, has created variety of threats in natural and human aspects such as urban flood, soil erosion, earthquake, land subsidence, urban sprawl, etc. Therefore, unsustainability trend has markedly been dominated in this area, in spite of some positive activities in developing vegetation. Undoubtedly, land use changes are mostly caused by mismanagement of agricultural, urban, range, and forest lands that this issue generally leads to critical environmental problems (Reis, 2009). Accordingly, this paper aims to indicate and monitor land use changes in the Darakeh-Velenjak Watershed, to identify the basic risks that can be posed by land use changes, and to present appropriate strategies using mitigation approach. The presented method can be used in areas that have environmental risks because of considerable changes in land uses.

### *1.1. Literature review*

#### *1.1.1. Risks and environmental policies*

Generally, risk is defined as the combination of the likelihood of an event and its results; there may be more than one occurrence, results can be both positive and negative, and probabilities can be evaluated in qualitative or quantitative aspect (ISO, 2009). US Presidential/ Congressional Commission on Risk Assessment and Risk Management (USPCC RARM) has defined risk as to *the* probability that a substance or situation will produce harm

under specified conditions. Risk is a combination of two criteria:
-The probability that an adverse occurrence will occur.
-The consequences of the adverse occurrence (USPCC RARM, 1997).
A Land use change is one of the most popular reasons which cause to develop environmental risks. It is undeniable that changing land use/ land cover not only disrupts ecosystems' balance but support to make risks and unsustainability. There are varieties of environmental risks of land use changes such as climate change, flood, soil erosion, land subsidence, earthquake, storm, etc., and it is necessary to control and manage widespread land use changes and environmental risks. Environmental risk management is the process of identifying, evaluating, selecting, and implementing actions to reduce risk to human health and ecosystems (USPCC RARM, 1997). There are some environmental strategies which help to control risks and attain sustainability. Some of them are mitigation, adaptation etc. The origin of the literature mitigation and adaptation approaches goes back to the work of Shibata and Winrich (1983). Kane and Shogren (2000), which have examined the problem with uncertainty, is another research in this literature (Kane and Shogren, 2000). Ingham et al. (2013) emphasized to substitute mitigation-adaptation investment problems (Ingham et al., 2013). Esmaeilzadeh et al. (2014) researched impacts of land use change in expanding environmental risks, then stressed to employ avoidance strategies using mitigation approach to resolve risks and unsustainability (Esmaeilzadeh et al., 2014). Zemel (2015) concentrates more on the dynamic aspect of the problem and relates the optimal timing of commencing investments in adaptation measures to the number of existing pollution stocks (Zemel, 2015). Bretschger and Valente (2011) analyzed how adaptation efficiency acted reciprocally with economic growth and revealed that poor countries are likely to be injured more, because of faster depreciation of capital assets due to environmental risk (Bretschger and Valente, 2011). Brechet et al. (2013) examined the relationship between the level of production efficiency and the efficient share of adaptation relative to mitigation. They report a critical result that an economy with very low creativeness should employ mitigation only and that the optimum ratio of adaptation investment to mitigation investment increases as productivity increases up to a threshold level, beyond which the ratio decreases under a specific set of functional forms (Brechet et al., 2013). Mitigation, as an effective tool to achieve sustainability, emphasizes to avoid, minimize, and, if possible, remedy significant adverse effects (European Union, 1985). Treweek (1999) expressed that mitigation as 'any deliberate action that is taken to diminish adverse impacts, whether by controlling the sources of effects or the exposure of receptors to them' (Treweek, 1999). Rundcrantz and Skarback (2003) explained mitigation as something that 'restricts or reduces the degree, extent, magnitude of adverse effects' (Rundcrantz and Skarback, 2003). A particular influential definition of mitigation in the context of designated European Wildlife Sites was provided by the European Commission's guidance that defined mitigation as 'measures at minimizing or even negating the negative effect of a plan or project, during or rather its completion' (European Commission, 2000). Therefore mitigation can be appropriate environmental policy to control the negative impacts of land use changes and achieve sustainability. This research aims to control environmental risks of land use changes via mitigation approach; therefore, strategies of this approach have been described.

### *1.2. Measures of mitigation approach*

#### *1.2.1. Avoiding environmental impacts*

Avoidance measures are the initial strategies for managing the potentially important effects of a proposed action … Offsets will not be considered until all logical avoidance and mitigation measures are considered (Australian Government, 2012). There are varieties of pre-emptive measures to avoid environmental effects, includes the identification of alternatives, sensitive design, environmentally sustainable technology, development restrictions in sensitive areas, avoidance of certain key areas, adopting the ‘precautionary approach’, Suitable timing of activities, and finally, refraining from certain impact-causing action (Rajvanshi, 2008). These measures are illustrated below. Identification of the least impacting alternative can mean, for instance, planning the route of new linear projects through existing route corridors such as road, rail, pipeline, and transmission line. This can eventually lead to avoiding impacts on sensitive environments, such as human settlements, biodiversity-rich areas, habitats of endangered species, archeological, and cultural sites within the route corridor of the proposed projects. Adopting sensitive design, as a second avoiding measure, can be a useful approach to prevent impacts at the project planning stage itself. The application of 'nature engineering' concepts have been greatly exhibited (Forman and Sperling, 2003; Spellerberg, 1998; Kanters et al., 1997) in the designing of culverts, underpasses, and bridges to avoid obstruction of animal movement across home ranges and landscapes. The third measure in avoiding environmental impacts is using environmentally sustainable technologies during construction, post construction, and progressive phases of the project. In many countries, limitations on site selecting projects in sensitive areas are governed by siting ordinances and regulations. For instance, larger energy facilities similarly are regulated by the Oregon Energy Facility Siting Council ("Siting Council"); In India, the Coastal Zone Regulation (MEF, 2002), limits any development within 500 m of the high tide line; and in Germany also, the landscape planning system identifies, sites suitable for defined developments and sites with development restrictions (Hanusch and Fischer, 2011). There is a consensus on the 'no go' zones based on different guidelines (WWF, 2002; EBI, 2004; IFC, 2004) that have been developed in the context of sector-specific developments around the world. This approach ('no go' zones) has been already adopted by many institutions. The International Council on Mining and Metals, a consortium of mining companies, as well as some of the Equator Principles Banks, including JP Morgan Chase and ABN AMRO, have agreed not to finance projects in World Heritage Sites. Additionally, the Bank of America will not finance projects which include resource extraction from high conservation value forests, primary tropical moist forests, or primary forests in temperate or boreal forest regions (IUCN, 2005). Therefore, this issue is a significant measure in avoiding environmental impacts. Moreover, recommending suitable timing for scheduling various activities under a project to avoid overlaps with key life cycle events (e.g., flowering and seeding, nesting or breeding seasons) is as a usual and effective approach for preventing impacts on protected species. The precautionary approach is also necessary to make avoidance decisions in the face of uncertainty and to drive actions that will protect public health and the environment. The Rio Declaration from the 1992 United Nations Conference on Environment and Development, also known as Agenda 21, is one of the most important expressions of the Precautionary Principle internationally. Application of the Precautionary Principle identifies the merit of delaying development consent until the best available information can be achieved through consultation with local stakeholders/experts, and new information can be merged. It promotes action to avoid risks of irreversible damage to the environment (Cooney and Dickson, 2006). The Principle has been merged into numerous international conventions including the Barcelona Convention (1976), Maastricht Treaty on the European Union (1992), Global Climate Change Convention (1992) and Bergen Declaration on Sustainable Development (1997). Germany is one of the first countries to have included the precautionary principle into environmental legislation, where the idea can be followed back to the first draft of the clean air legislation in 1970 (Wurzel, 2009). Finally, refraining from certain development, which is another measure in avoiding environmental impacts, means refraining from certain impact-causing actions.

#### *1.2.2. Minimizing environmental impacts*

Another measure of mitigation approach is minimizing the impacts of developments on the receiving environment. There is a range of approaches aimed to restrict the degree, extent, magnitude, or duration of adverse impacts, includes control measures for preventing pollution, minimization of physical disturbances, 'good housekeeping', the installation of physical barriers, creative land management, technological fixes, promotion of compatibility, and translocation of affected species (Rajvanshi, 2008). One of the most important tools can decrease the extent and difficulty of project-related effects, is control measure for preventing pollution of air, water, and natural environment and adopting innovative design and technology. Another measure in this field is the minimization of physical disturbances. Responsible operations and adoption of good practices while undertaking activities involving a physical change of land can bring about a meaningful reduction in land degradation, for instance, during dredging and drilling for mineral extraction; when clearing land and preparing sites for industrial development and when digging and entrenching for roads and pipelines. It is necessary to develop non-intrusive techniques, such as remote sensing and global positioning systems, for exploration activities (White et al., 1996). Good housekeeping, use of energy-saving devices, and cleaner production technologies are being inclusively promoted as minimum safeguards in industrial units for decreasing environmental pollution and emission of greenhouse gases especially. Another measure of minimizing effects environmentally is installing physical barriers, which creates views capes and develops landscape buffers to decrease visual effects of roads and buildings. Creative land management, landscaping, and development of alternative land-use also can help to decrease physical effects during construction/operation and improve post project aesthetics. Technologies of passages construction also increasingly help to impede wildlife road mortality while conserving connectivity across highways. In many countries, transportation departments are incorporating innovative plans in the development of roadways to decrease barrier impacts of roads and to improve connectivity functions of routes for animals across highways. Promoting compatibility between adjoining land uses where any important degree of incompatibility is likely to result from development related changes in land use can best be secured by developing a green belt between the specific action and nearby properties. Translocation of plants, animals, and habitats from the sites of the proposed development is another measure of minimizing environmental impacts which can make secure long term protection of biodiversity. In many countries, moving animals within their domain is a legal necessity that supports the protection of species endangered by habitat disturbances and losses caused by development plans. Correspondingly, relocating plant species from sites of development endangered by removal of native vegetation can also decrease the decline of native species (Rajvanshi, 2008).

*1.2.3. Remedial environmental impacts*

The third measures of mitigation approach are remedial measures which include efforts of compensation measures; on-site compensation measures; off-site compensation measures; in-kind compensation measures; and out-of-kind or monetary compensation. These measures attempt to repair, reinstatement, restoration, rehabilitation, and compensation (Rajvanshi, 2008). Compensation measures include measures that remedy for the residual, inevitable damage caused by a development plan, to try to at least offset the damage. Such measures are hence initially aimed to make secure at least ‘no net loss’ but may donate to positive planning (Kuiper, 1997; Vagverket, 2002; ten Kate et al., 2004). Other measures in this kind are on-site compensation measures. These measures concentrate on-site remediation measures. Examples of this form of compensation include the restoration of natural areas in an urban context, where an original ecological or hydrologic situation cannot be restored or where a changed environment can no longer support any previously occurring type of regional ecosystem forest. Off-site compensation measures also involve the creation of new habitat on off-site areas by reinforcing protection of species endangered by a suggested activity at another site or off-site offset through a third party where a developer purchases biodiversity credits or pays a third party to provide an offset ex-ante. In-kind compensation, as another remedial measure, is proper when important or net residual harm to the environment is likely. A variety of in-kind compensation measures, including the use of trading tools to offset effects and to ensure the sustainability of development proposals are being promoted. Customarily, compensation has meant payment for loss of land or amenity resulting from a proposal. This approach can be proper in specific conditions; for instance, when a private property must be expropriated to make way for a road, pipeline, or other public infrastructure project. Additionally, compensation packs, involving an area of offsets, may be discussed with affected communities (Bräuer, 2006) (Table 1).

**Table 1.** Mitigation strategies and variables of avoidance, reduction and remedy solutions

| Mitigation strategies | variables |
|---|---|
| **Mitigation by avoidance** | Avoidance of destroying vegetation and green spaces |
| | Avoidance of developing built-up areas in high altitude ecosystems of 1800m |
| | Avoidance of developing built-up areas in green spaces |
| | Avoidance of invasion to sensitive environments, such as biodiversity and endangered species |
| | Avoidance of invasion to archeological and cultural sites |
| | Avoidance of invasion to groundwater resources in expanding infrastructures |
| | Avoidance of invasion to natural resources areas |
| | Using sustainable technology options for avoiding environmental impacts |
| | Avoidance of adverse impacts on natural landscapes |
| | Avoidance of adverse impacts on key areas (such as estuaries, wetlands etc. during construction and implementation phases. |
| | Designation of 'no development' zones for providing additional controls in some areas such as critical natural habitats |
| | Recommending suitable timing for various activities under a project to avoid overlaps with key life cycle events (such as flowering and seeding, nesting or breeding seasons) |
| | Adopting the 'precautionary approach' and 'buy time' for developing appropriate and effective action |
| **Mitigation by reduction** | Installing control measures for preventing pollution from reducing the magnitude ad severity of project-related impacts |
| | Responsible operations and adoption of good practices about a significant reduction in land degradation, such as mineral or industrial activities |
| | Use of energy-saving appliances and cleaner production technologies for minimizing environmental pollution and emission of greenhouse gases |
| | Installing physical barriers and developing buffers to reduce the visual impacts of roads and buildings |
| | Creative land management, landscaping, and development of alternative land use to reduce physical impacts during construction/ operation |
| | Using transport technologies for minimizing barrier effects of roads, and preserving connectivity functions of passages for animals |
| | Promoting compatibility between adjacent land uses |
| | Translocation of plants, animals, and habitats from the sites of a proposed development to ensure long term conservation of biodiversity |
| **Mitigation by remedy** | Developing compensation measures for the residual/ unavoidable harm caused by a development project |
| | Developing on-site compensation measures |
| | Developing off-site compensation measures |
| | Developing in-kind compensation measures |
| | Developing out-of-kind/ monetary compensation measures |

Source: Rajvanshi, 2008

### *1.3. Research setting and design*

#### *1.3.1. The Study Area*

The study area was the Darakeh-Velenjak Watershed, which was defined by methodologies used at Forest, Rangeland and Watershed Organization of Iran. The Darakeh-Velenjak Watershed is located in Northern Tehran. The geographical area extends $35^0$ 48′ 30″N to $35^0$ 54′ 30″N and $51^0$ 20′ 30″E to $51^0$ 25′ 01″E. Minimum rainfall in August (10.30mm), and Average temperature varies between 15 degrees centigrade to 48 degrees centigrade. The maximum number of frost days is observed in January and February with a total number of 30 days. The climate of the study area is classified as Semi-wet (Meteorological Organization of Tehran province, 2018) (Fig. 1).

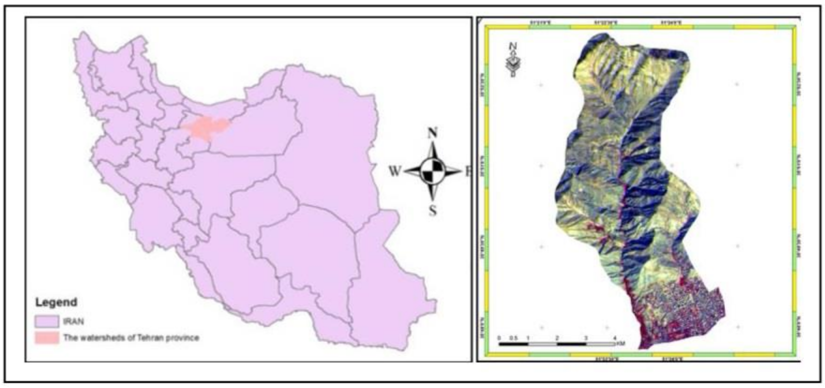

**Fig. 1.** Location of the Darakeh-Velenjak Watershed and Tehran province in Iran

The study, which has been situated in zones 1 and 2 of Tehran municipality, has the most valuable of Tehran lands economically and tourism aspect, because of proximity for Alborz mountain ranges and having proper climate, and this subject has caused to attract more dwellers, more buildings establishment, and more pressure for land, that has led to increasing environmental risks. This region has affluent of ecological and cultural attractions, which affect to grow irregular tourism, to demolish widespread natural resources and to pose environmental risks. Moreover, the existence of the main fault in North of Tehran has increased vulnerability level of this region against earthquake disaster (Research and planning center of Tehran municipality, 2017).

*1.3.2. Methodology*

The research methodology for this study was both descriptive and analytical. By comparing satellite images and extracting the necessary information from them, using GIS, land-use change was observed in four different years (1975, 2000, 2018). Four different classes of data were extracted based on the type of land use (includes vegetation, arid, roads, and built-up areas). Finally, factors affecting land-use changes were discussed with experts groups using the Delphi technique. To extract the necessary data, documentary and survey research methods were combined as follows:

*a) Documentary search*

Satellite images (TM 1987, ETM$^+$ 2000, and IRS 2018) were studied to determine the level of change in land use in the Darakeh-Velenjak Watershed in northern Tehran. Data belonging to each period was produced by different sensor equipment. The spatial resolution of bands (Visible and Infra-red) of images was 30*30 in 1987 until 2018. Radiometric resolution of images in 1987 and 2000 times was 8 Bit, and it had 16 Bit in 2018. Finally, images in 1988 had not panchromatic band resolution, while it was 15*15 m in during 2000 and 2018 (Table 2).

**Table 2.** Satellite images used to reveal changes in land-use in the Darakeh-Velenjak Watershed

| Row | Name of Satellite | Name of Sensor | Date |
|---|---|---|---|
| 1 | Landsat | TM | 1987 |
| 2 | Landsat | ETM+ | 2000 |
| 3 | Landsat | IRS | 2018 |

Source: Iran Space Agency, and the United States Geological Survey, 2018

*b) Field work*

Data from satellite images was then double checked by controlling the reference points on the ground with a GPS.

In analyzing the above data, the following methods were used:

- *Quantitative method:* By using ArcGIS, the data on land use change were analyzed based on the time series of the satellite images as mentioned above. To extract the necessary information, Supervised Maximum Likelihood Classification algorithm was used, further complemented by visual interpretation methods.

- *Qualitative method:* The Delphi technique was used by interviewing 40 expert groups (34 were valid) and questions were asked about key factors affecting changes in land use in the Darakeh-Velenjak Watershed, and about appropriate strategies of controlling environmental risks using mitigation approach.

There is no scientific method in selecting the sample size of an expert group in the Delphi technique and usually has been nominated more than 30 experts. It is necessary to obtain a consensus among the expert group (Stahl and Stahl, 1991) and the sample size of this research has been done by respecting this subject.

*1.3.3 Process of research methodology*

Ideally, to compare and assess satellite images, it is best to have satellite images of the same day in different years, however, considering the difficulty in accessing such images, and uncertainties about the time satellite passes the study area or cloudiness, etc. it would be better to use images that are near each other (Zhang et al., 2011). In this research, the following satellite images were used: Landsat-3 (TM 1987), Landsat-7 (ETM+ 2000), and Landsat-8 (IRS 2018). To digitize and process the data extracted from these images, ARC GIS 10.3 and ENV 14.7, as well as Google Earth, were used.

## 2. Material and Methods

*2.1. Pre-evaluation of the images*

To correct the images from a geometric point of view, satellite images of years 1987 and 2000 and geo-referenced image of 2018 were used. Furthermore, using 30 reference points on the ground with a GPS, the margin of error of RMS was determined to be 58.0 pixels, which is an acceptable level of accuracy. As in classification of the images, Maximum Likelihood the Classification algorithm was used and classes were obtained separately for each image, there was no need for atmospheric corrections.

*2.1.1. Extraction of data and its processing*

To extract data, from the satellite images, Supervised Maximum Likelihood Classification algorithm was used, complemented by visual interpretation methods. MLC is a widely used technique for classification of data in statistics, which is based on pixels. In classification of the data spectral values of image pixels were used. This technique allows the study and the classification of pixels with different resolutions. Considering that digital classification in based on different spectral values of various phenomena over different spectral bands, this doesn't mean that every phenomenon on each band are distinguished. To this end, MLC is an appropriate method for classification of data. In this classification system, a class will be assigned to the designated pixel, which has the most likelihood to be related to that pixel. The mathematical formula for this calculation is as follows (Rajesh Bahador and Youji Murijana, 2006) (Equation 1):

$$X \in wi \text{ if } p(wi|x) > p(wj|x) \quad \text{for all } j \neq i \tag{1}$$

This means that pixel x belongs to class wi, if pixel x is likely to belong to the class P (wi|x) which is larger than other classes. To calculate these probabilities, the Bayes theorem was used, which could be reflected in equation two as follows:

$$P(wi|x) = \frac{P(x|wi)\, p(wi)}{P(x)} \tag{2}$$

In this equation, x is the spectral value; wi is the ith spectral class. P (wi|x) is considered as the secondary probability of class wi. Secondary probability in MLC would be the basis for decision-making. P (wi|x) is the probability of finding a pixel from class wi in location x in a multi-spectral space. P (wi) is known as the primary probability of class wi. Primary probability refers to % of presence of a class in an image. After calculation of different components of the Bayes theorem, P (wi| x) may be produced, which supports the final decision. Therefore, the algorithm for this classification will include calculation of these components, and after that, the comparison of the secondary probability of various classes with each other (Arkhi et al., 2011).

*2.1.2. Highlighting the changes*

To highlight the changes in various classes of land-use within the study area, after the classification of data, a comparative method was used. Using MLC images from different periods, four land use classes were identified (vegetation, arid, roads, and built-up areas). Once the necessary maps were produced, their accuracy was checked through control point on the ground and the level of land use change in the four designated classes in different periods was assessed by comparing the results.

## 3. Results and Discussion

### *3.1. Results and Discussion*

The supplied table, figure, and maps depict land use changes of Darakeh-Velenjak Watershed between 1987 until 2017. Overall, built-up lands, road and arid areas indicate a significant rise over the period, while the percentage of vegetation has experienced a downward trend. The study of changes in land use in the Darakeh-Velenjak Watershed located in Northern Tehran revealed that built-up areas had been increasing gradually from 3.2ha (8.96% of the total area of the Watershed) in 1987 to 4.3ha (11.97%) in 2000, and finally to 5.4ha (15.18%) in 2018. Road areas also increased between 1987 until 2018, so that its area was 0.63 ha (1.75%) in 1987, then increased to 1.05 ha (2.95%) in 2000, and finally reached to 1.14ha (3.19%) in 2018. The area of arid lands in the study area was 18.50ha (51.99%) in 1987 gradually increased to 22.76ha (63.79%) in 2000, and finally to 23.93ha (67.08%) in 2018. During the study period, the vegetative cover has been decreased from 1987 data to 2018. Area of vegetation was 13.3ha (37.3%) in 1987, which gradually decreased to 7.59ha (21.3%) in 2000, and finally to 5.18ha (14.54%) in 2018. The trend of land use changes of Darakeh-Velenjak Watershed has been shown in table 3 and fig. 2.

**Table 3.** Land use changes of Darakeh-Velenjak watershed in during 1987 until 2018

| Year | Space | Arid Area | Vegetation | Built-up Area | Roads | Total |
|---|---|---|---|---|---|---|
| **2018** | Percent | 67.08 | 14.54 | 15.18 | 3.19 | 35.7 |
| | Hr. | 23.93 | 5.18 | 5.4 | 1.14 | 100 |
| **2000** | Percent | 63.79 | 21.3 | 11.97 | 2.95 | 35.7 |
| | Hr. | 22.76 | 7.59 | 4.3 | 1.05 | 100 |
| **1987** | Percent | 51.99 | 37.3 | 8.96 | 1.75 | 35.7 |
| | Hr. | 18.50 | 13.3 | 3.2 | 0.63 | 100 |
| **A decreased/ increased trend** | | + | - | + | + | • |

Source: Spatial calculation of authors, 2018

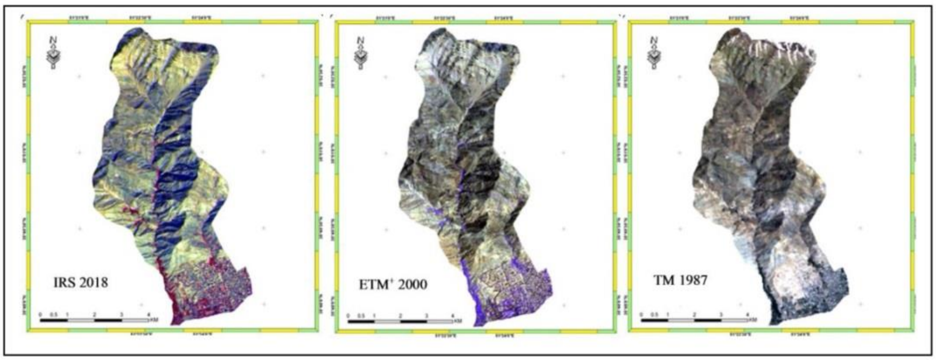


**Fig. 2.** Vegetation Changes of Darakeh- Velenjak Watershed in during 1987 until 2018
Source: Spatial calculation of authors, 2018

To analyze the reasons for such growth in the development of land in the Darakeh-Velenjak Watershed from 1987 to 2018, and decrease in the vegetative cover (which contributes to unsustainability), interviews were conducted with experts using the Delphi technique. The extracted data were then classified into *natural* and *human risks*. The results of the study indicated that the human risks with an average score of 4.21 were more than natural risks 3.62. Moreover, Increase of soil erosion level and sedimentation and decrease of soil fertility level (with an average score of 4.59), Increase of runoff quantity and urban flood (with an average score of 4.47), and Increase of abrupt environmental crises (such as storm, flood earthquake, etc.) (With an average score of 4.44) were the highest risks in this area. To the overall, overall mean of risks in this area has been with an average score of 3.70 (table 4).

**Table 4.** Weights of various environmental risks resulted in from land use changes in the study area

| Main Factors | Mean of factors | Variables | n | Mean | SD | *V* | Rank |
|---|---|---|---|---|---|---|---|
| **Natural Risks** | 3.62 | Increase of runoff quantity and urban flood | 34 | 4.47 | 1.000 | 1.000 | 2 |
| | | Change of the surface water regime and decrease of the reservoirs of groundwater aquifers | 34 | 4.03 | 1.029 | 1.060 | 5 |
| | | Change of geo -bio chemicals cycles | 34 | 3.03 | 1.000 | 1.000 | 18 |
| | | Increase of water evaporation level | 34 | 3.50 | 1.000 | 2.000 | 12 |
| | | Increase of soil erosion level (and sedimentation and decrease of soil fertility level) | 34 | 4.59 | .000 | .000 | 1 |
| | | Loosen of soil and increase in the amount of land subsidence | 34 | 3.79 | 1.000 | 1.000 | 9 |
| | | Increase of climate change, such as the growth of thermal islands | 34 | 3.58 | 1.000 | 2.000 | 11 |
| | | Increase of imbalances and unsustainability in ecological networks | 34 | 3.82 | 1.000 | 1.000 | 8 |
| | | Decrease of urban open and vacant spaces level | 34 | 3.23 | 1.000 | 1.000 | 17 |
| | | Decrease of natural environment resilience | 34 | 3.29 | 1.000 | 1.000 | 15 |
| | | Disturbance of landscape and environmental desirability | 34 | 2.71 | 1.000 | 2.032 | 21 |
| | | Increase of abrupt environmental crises (such as storm, flood earthquake, etc.) | 34 | 4.44 | 1.050 | 1.000 | 3 |
| | | Decrease of ecosystem services | 34 | 3.79 | 1.000 | 1.000 | 9 |
| | | Destruction of ecosystems and decrease of biodiversity and genetic | 34 | 4.00 | .000 | .000 | 6 |
| | | Growth of pests because of planting non-native species | 34 | 3.00 | 1.000 | 1.000 | 19 |
| | | Change of food Networks | 34 | 2.62 | 1.000 | 2.000 | 22 |
| **Human Risks** | 4.21 | The threat of human health | 34 | 3.41 | 1.000 | 2.000 | 13 |
| | | Settle of land uses in sensitive areas of natural hazards such as faults, valleys buffers, etc. | 34 | 3.88 | 1.000 | 1.000 | 7 |
| | | Increase of environmental pollution level (water, soil, air, visual, sonic and optical) | 34 | 3.35 | 1.000 | 2.000 | 14 |
| | | Growth of industrial and mineral activities | 34 | 3.26 | 1.000 | 2.000 | 16 |
| | | Growth of urban wastes level | 34 | 2.94 | 1.000 | 2.000 | |
| | | Decrease in Human environment resilience | 34 | 3.74 | 1.000 | 1.000 | 10 |
| | | Development of high voltage electric lines | 34 | 2.97 | 1.000 | 1.000 | 20 |
| | | Destruction of high altitude ecosystems of 1800m because of developing built-up land use | 34 | 4.09 | .000 | .000 | 4 |
| | | Decrease in food security because of urban sprawl | 34 | 4.00 | .000 | .000 | 6 |
| | | Decrease of tourism attractions | 34 | 3.74 | 1.000 | 1.000 | 10 |
| Overall mean | | | 34 | 3.70 | | | - |

Source: Analysis of Delphi technique, 2018

Finally, strategies have been presented using mitigation approach in the study area. According to this approach, strategies were classified into three types, includes avoidance, reduction, and remedy. The extracted data, which were conducted with expert groups, revealed that avoidance strategy with an average score of 3.37 was situated in the first rank because unfortunately this watershed has been damaged by excessive land use changes in the aspect of developing buildings, roads, tourism infrastructures, etc. The result exhibited that reduction and remedy strategies, with an average score of 2.87 and 2.48, have been situated in second and third rank respectively. Furthermore, Avoidance of destroying vegetation and green spaces (with an average score of 4.44), Avoidance of developing built-up areas in green spaces (with an average score of 4.26), Avoidance of developing built-up areas in high altitude ecosystems of 1800m (with an average score of 4.00), and Avoidance of invasion to sensitive environments, such as biodiversity and endangered species (with an average score of 3.53) were the best solutions in this area (table 5).

**Table 5.** Weights of mitigation strategies in the aspect of avoidance, reduction, and remedy in the study area

| Mitigation strategies | Mean of strategies | Solutions | n | Mean | SD | V | Rank |
|---|---|---|---|---|---|---|---|
| Mitigation by avoidance | 3.37 | Avoidance of destroying vegetation and green spaces | 34 | 4.44 | .000 | .000 | 1 |
| | | Avoidance of developing built-up areas in high altitude ecosystems of 1800m | 34 | 4.00 | 1.000 | 1.000 | 3 |
| | | Avoidance of developing built-up areas in green spaces | 34 | 4.26 | 1.000 | 1.000 | 2 |
| | | Avoidance of invasion to sensitive environments, such as biodiversity and endangered species | 34 | 3.53 | 1.000 | 1.000 | 4 |
| | | Avoidance of invasion to archeological and cultural sites | 34 | 3.06 | 1.000 | 1.000 | 9 |
| | | Avoidance of invasion to groundwater resources in expanding infrastructures | 34 | 3.29 | 1.000 | 1.000 | 7 |
| | | Avoidance of invasion to natural resources areas | 34 | 3.38 | 1.000 | 1.000 | 5 |
| | | Using sustainable technology options for avoiding environmental impacts | | 3.38 | 1.000 | 1.000 | 5 |
| | | Avoidance of adverse impacts on natural landscapes | 34 | 2.94 | 1.000 | 1.000 | 13 |
| | | Avoidance of adverse impacts on key areas (such as estuaries, wetlands, etc. during construction and implementation phases. | 34 | 2.88 | 1.094 | 1.000 | 14 |
| | | Designation of 'no development' zones for providing additional controls in some areas such as critical natural habitats | 34 | 3.00 | 1.000 | 1.000 | 11 |
| | | Recommending suitable timing for various activities under a project to avoid overlaps with key life cycle events (such as flowering and seeding, nesting or breeding seasons) | 34 | 2.44 | 1.000 | 1.000 | 18 |
| | | Adopting the 'precautionary approach' and 'buy time' for developing appropriate and effective action | 34 | 3.15 | 1.000 | 1.000 | 8 |
| Mitigation by reduction | 2.87 | Installing control measures for preventing pollution from reducing the magnitude ad severity of project-related impacts | 34 | 2.97 | 1.000 | 1.000 | 12 |
| | | Responsible operations and adoption of good practices about the significant reduction in land degradation, such as mineral or industrial activities | 34 | 3.32 | 1.000 | 1.000 | 6 |
| | | Use of energy-saving appliances and cleaner production technologies for minimizing environmental pollution and emission of greenhouse gases | 34 | 3.03 | 1.000 | 1.000 | 10 |
| | | Installing physical barriers and developing buffers to reduce the visual impacts of roads and buildings | 34 | 2.71 | 1.000 | 1.000 | 16 |
| | | Creative land management, landscaping, and development of alternative land use to reduce physical impacts during construction/ operation | 34 | 3.06 | 1.000 | 1.000 | 9 |
| | | Using transport technologies for minimizing barrier effects of roads, and preserving connectivity functions of passages for animals | 34 | 2.85 | 1.000 | 1.000 | 15 |
| | | Promoting compatibility between adjacent land uses | 34 | 2.56 | 1.000 | 1.000 | 17 |
| | | Translocation of plants, animals, and habitats from the sites of the proposed development to ensure long term conservation of biodiversity | 34 | 2.44 | 1.000 | 1.000 | 18 |
| Mitigation by remedy | 2.48 | Developing compensation measures for the residual/ unavoidable harm caused by a development project | 34 | 2.88 | 1.000 | 1.000 | 14 |
| | | Developing on-site compensation measures | 34 | 2.24 | 1.000 | 1.000 | 19 |
| | | Developing off-site compensation measures | 34 | 2.12 | 1.000 | 1.000 | 21 |

Source: Analysis of Delphi technique, 2018

## 4. Conclusion

We studied land use changes of the Darakeh-Velenjak Watershed in four classes of land including vegetation, arid, roads and built-up areas between 1987 and 2018, and identified the key natural and human risks could be posed by land use changes. Both quantitative and qualitative methods have been used in this research. To extract the essential data from the satellite images, Supervised Maximum Likelihood Classification algorithm was used in the study area, and the results revealed a dramatic decline in vegetation, while built-up lands, roads, and arid areas have been considerable growth between 1987 and 2018. In this period, the vegetative cover was 13.3ha in 1987; while it had decreased to 5.18ha in 2018. On the other hand, built-up areas had increased from 3.2ha in 1987 to

5.4ha in 2018. Moreover, roads and arid areas increased respectively from 0.63 ha and 18.50ha in 1987 to 1.14ha and 23.93ha in 2018. The results indicated a drop of 16 percent in vegetation cover and a rise of 6.22, 1.44, and 15.09 percent respectively in built-up, roads and arid areas. The study area has been situated in the most popular district of Tehran in the aspect of climate and having tourism attractions, and these capabilities have been caused to increase land use changes and environmental risks. This increasing trend of built-up, roads and arid areas reflects a threat to the ecosystem itself and with continuing of these trends, the highland ecosystems of Tehran will be seriously degraded. Also the results of the study depicted that this alteration has had considerable risks that contributed to the unsustainability of the Darakeh-Velenjak Watershed. This increasing trend developmental area reflects a range of risks to the ecosystem itself, and with continuing of these trends, the highland ecosystems of Tehran will be seriously degraded. In addition, the results of the study depicted that this alteration has had considerable risks that contributed to unsustainability of the Darakeh-Velenjak Watershed. The results of the Delphi technique delineated that the human risks were more than natural risks in the study area. Furthermore, Increase of soil erosion level and sedimentation, and decrease of soil fertility level, Increase of runoff quantity and urban flood, and Increase of abrupt environmental crises (such as storm, flood earthquake, etc.) have been the most risks in study area. To control environmental risks, mitigation strategies have been used in this Watershed. As it has been quoted above, this approach has three main strategies includes avoidance, reduction and remedy. Results of the study exhibited that avoidance strategy with an average score of 3.37 was the proper solution to control environmental risks from experts' views. Afterward, reduction and remedy strategies were respectively appropriate solutions in preventing risks. Furthermore, Avoidance of destroying vegetation and green spaces, Avoidance of developing built-up areas in green spaces, Avoidance of developing built-up areas in high altitude ecosystems of 1800m, and Avoidance of invasion to sensitive environments, such as biodiversity and endangered species were the best solutions in the study area (Fig. 3).

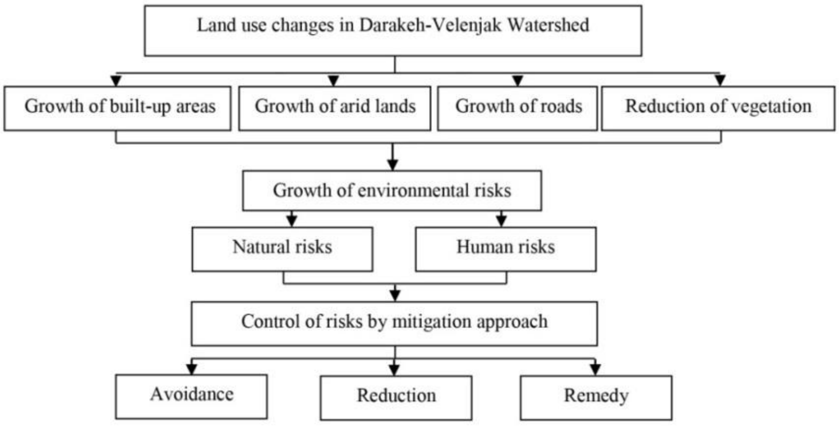


**Fig. 3.** Control of environmental risks of land use changes using mitigation strategies in Darakeh-Velenjak Watershed

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