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# LAND COVER BASED WATERSHED HEALTH ASSESSMENT

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## ABSTRACT

The adoption of appropriate managerial approaches mainly depends upon proper monitoring and consequent assessment of ecosystems health. Towards that, the watershed health monitoring has gained recognition among regulating agencies such as Environmental Protection Agency (EPA). However, its importance has not been considerably taken into account by authorities in developing countries where the outcome of such approach is essentially needed for effective and efficient management of the ever-degrading ecosystems. To this end, the present article introduces a simple and standardized approach of describing the overall watershed health situation using risk based $R_{el}R_{es}V_{ul}$ framework. Towards this, three indicators of reliability ($R_{el}$), resilience ($R_{es}$) and vulnerability ($V_{ul}$) have been conceptualized and calculated based on the normalized difference vegetation index (NDVI) for the Shazand Watershed, Markazi Province, Iran, as a case study. NDVI is an important and commonly used vegetation index in research on global environmental change. The primary data collected to create NDVI maps was multi-spectral satellite images of path 165 and rows of 36 and 37, with a spatial resolution of 30 m from the Landsat Satellite images for the sample year of 2014. The results of $R_{el}R_{es}V_{ul}$ analysis showed that the overall condition of the Shazand Watershed health in terms of $R_{el}$, $R_{es}$ and $V_{ul}$ was healthy, un-healthy and moderately healthy, respectively with scores of 0.82, 0.17 and 0.50 out of 1.0. The average watershed health index based on $R_{el}R_{es}V_{ul}$ framework was also obtained 0.34 varying from 0.04 to 0.46. Hence, it can be concluded that the Shazand Watershed was in relatively un-healthy state from view of vegetation cover. The maintenance and recovery of the Shazand Watershed health should be considered as fundamental step to reach the integrated watershed management objectives.

**Keywords**: *Health indicator, land degradation, productivity assessment, remote sensing, watershed best management.*

## INTRODUCTION

Over the last decades, human pressures have unambiguously led to global environmental degradation and disruption to a degree that currently requires assessment, intervention, and remediation (Galvani et al., 2016; Liao et al., 2018). To implement remediation options, it is essential to have sound monitoring and assessment tools to know the general status of the watershed. The watershed health concept looking at a watershed as a system, instead of determining the functions of each separated part of a watershed is also implemented in other research approaches, such as soil functions, ecosystems (Keesstra et al., 2016) and the implementation of nature-based solutions to remediated degraded systems (Keesstra et al., 2017). Development of managerial tools for highlighting the valuing of ecosystem functions of watersheds is high important and valuable to manage the environment. To this end, various agencies like Environmental Protection Agency (EPA) and different researches tried to develop different watershed health monitoring tools. One of the emerging approaches developed in watershed health monitoring is the reliability, resilience and vulnerability ($R_{el}R_{es}V_{ul}$) framework initially developed by Hashimoto et al. (1982) in water resources management context. $R_{el}R_{es}V_{ul}$ was then applied to watershed health assessment with respect to water quality by Hoque et al. (2012). Consequently, $R_{el}R_{es}V_{ul}$ framework with respect to hydrological criteria was conceptualized for watershed health assessment by Hazbavi and Sadeghi (2017). In addition, Sadeghi and Hazbavi (2017) and Hazbavi et al. (2018a) applied this framework in viewpoint of drought criterion of standardized precipitation index (SPI). Recently, Hazbavi et al. (2018b) and Sadeghi et al. (2018) customized the $R_{el}R_{es}V_{ul}$ framework for different study watersheds and criteria. However, more insight investigations and minute monitoring are needed for effective and efficient management of the ever-degrading watersheds of developing countries like Iran. To this end, the present endeavor introduces a potential of a simple and standardized framework of $R_{el}R_{es}V_{ul}$ for describing the overall watershed health situation in viewpoint of land cover. The Normalized difference vegetation index (NDVI) as an important and commonly used vegetation index was therefore considered for watershed health assessment for 2014 as a sample year.

## MATERIALS AND METHODS

### Study Area

The Shazand Watershed (≈ 1740 $km^2$) is located in the southwest of Markazi Province, Iran. The watershed with 24 sub-watersheds falls within geographical coordinates from 44′42″ to 34° 12′ 13″ N and from 49° 04′ 15″ to 49° 52′ 12″ E, respectively (Figure 1). The annual mean precipitation is 430 mm and the annual mean temperature is 13.7 °C. This watershed occupies approximately 50 % highlands and hard formations, and 45 % alluvial sediments and/or sub-mountain screes. Population of the Shazand Watershed is over 102000. The Shazand Watershed has been confronted rapid urban growth and industrial development (Davudirad et al., 2016; Hazbavi et al., 2018a and b).

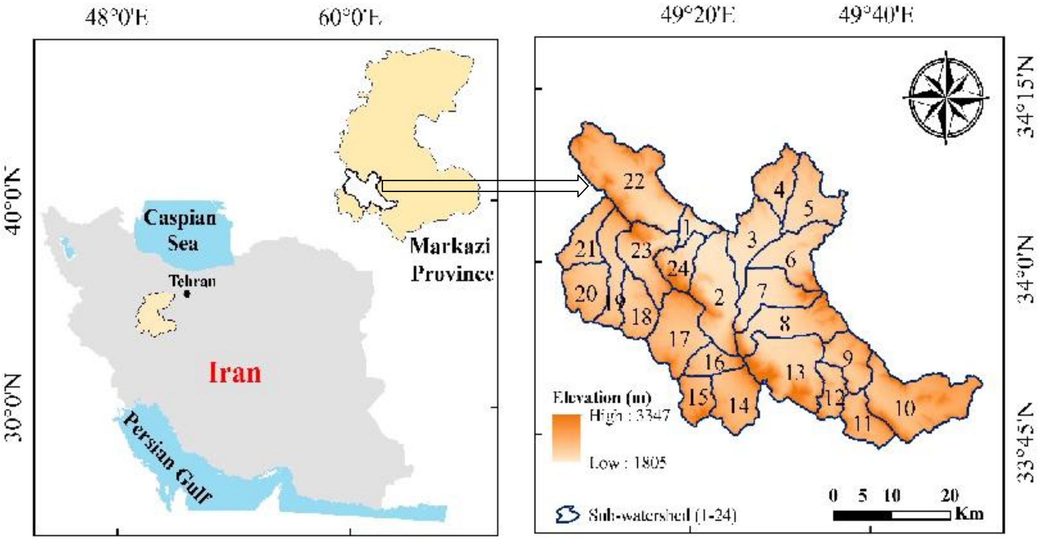


Figure 1. Location of the Shazand Watershed in Iran

Data Source

The normalized difference vegetation index (NDVI) as a representative index of land cover status was applied for the Shazand Watershed to assess the watershed health. During the recent decades, the increasing number of satellite sensors provided a great opportunity for NDVI derivation at various scales, and enabled the synergistic use of observations from multiple satellite sensors to better understand land processes. Accordingly, the data used in this study includes multi-spectral satellite images of 16-days 30-m products of path 165 and rows of 36 and 37 for year of 2014 obtained from USGS (https://earthexplorer.usgs.gov). Then the spectral reflectance measurements acquired in the near-infrared (NIR) and visible (RED) regions of the images were used based on Eq. (1) to generate NDVI in TerrSet 18.21 Software (Tucker, 1979).

$$\mathrm{NDVI} = \frac{NIR - RED}{NIR + RED} \quad (1)$$

Conceptual Framework of Watershed Health Assessment

Three different categories of reliability, resilience and vulnerability indicators were organized to apply $R_{el}R_{es}V_{ul}$ conceptual framework. In this framework, $R_{el}$ characterizes the frequency of failures. A failure event was defined when the watershed was failed to function within acceptable limits and was calculated from the Eq. (2):

$$R_{el} = (1 - \frac{N_s}{N}) \quad (2)$$

where $N_r$ and N are the number of periods when the watershed is not able to meet the study criteria (failure event) and the total number of time periods in the analysis, respectively. Additionally, the $R_{es}$ characterizes the duration of the failure events as defined in Eq. (3).

$$R_{es} = \frac{N_{fs}}{N_r} \quad (3)$$

where $N_{fs}$ is the total number of failure sequences and $N_r$ has the same meaning as in Eq. (2).

Furthermore, the vulnerability ($V_{ul}$), was defined as the average of the maximum failure occurring in each continuous failure sequence and computed through Eq. (4).

$$\text{Vulnerability } (V_{ul}) = \frac{1}{N_{fs}} \sum_{k=1}^{N} \left\{ \left[ \frac{L_{obs}(k) - L_{std}(k)}{L_{std}(k)} \right] H[L_{obs}(k) - L_{std}(k)] \right\} \quad (4)$$

where $N_{fs}$ has the same meaning as in Eq. (3), $L_{obs}$ (k) is the observed study criteria at the $k^{th}$ time step, $L_{std}$ (k) is the corresponding compliance standard, and H[ ] is the heaviside function which ensures that only failure events were involved in calculation of $V_{ul}$. The heaviside function is a mathematical and discontinuous function whose value is zero for negative argument and one for positive argument (Hashimoto et al., 1982; Silva, 2010; Hoque et al., 2012). The acceptable limits or standard for NDVI status of study watershed was determined based on its mean value in the protected (exclosure) area where located in the center of the Shazand Watershed.

Three aspects of $R_{el}$, $R_{es}$ and $V_{ul}$ for NDVI criterion were accordingly computed. The aggregated $R_{el}R_{es}V_{ul}$ index was then calculated using geometric mean of standardized $R_{el}$, $R_{es}$ and $V_{ul}$ indicators (Loucks, 1997; Cude, 2001; Zhao et al., 2006; Hazbavi and Sadeghi, 2017) to provide a comprehensive characterization of a watershed ability to maintain its structure and function.

## RESULTS AND DISCUSSION

The spatial distribution of NDVI in the Shazand Watershed for different months of 2014 has been presented in Table 1. Furthermore, the results of $R_{el}$, $R_{es,}$ $V_{ul}$ indicators and aggregated index based on NDVI criterion have been shown in Table 2. In addition, the spatial distribution of the land cover based watershed health index has been visualized in Figure 2.

Table 1. Spatiotemporal distribution of NDVI for different months in 2014 for the Shazand Watershed, Iran

| SW | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct. | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -0.07 | -0.15 | -0.13 | -0.12 | 0.03 | 0.09 | 0.05 | 0.04 | 0.05 | 0.09 | -0.07 | -0.08 |
| 2 | -0.07 | -0.15 | -0.14 | -0.12 | 0.01 | 0.14 | 0.06 | 0.07 | 0.08 | 0.11 | -0.07 | -0.06 |
| 3 | -0.07 | -0.15 | -0.14 | -0.12 | 0.02 | 0.10 | 0.04 | 0.06 | 0.06 | 0.08 | -0.07 | -0.07 |
| 4 | -0.06 | -0.15 | -0.13 | -0.11 | 0.04 | 0.05 | 0.02 | 0.02 | 0.00 | 0.08 | -0.06 | -0.09 |
| 5 | -0.06 | -0.15 | -0.13 | -0.11 | 0.03 | 0.11 | -0.01 | 0.02 | 0.05 | 0.07 | -0.06 | -0.09 |
| 6 | -0.06 | -0.15 | -0.13 | -0.11 | 0.04 | 0.08 | 0.04 | 0.03 | 0.03 | 0.08 | -0.06 | -0.09 |
| 7 | -0.07 | -0.16 | -0.14 | -0.12 | 0.01 | 0.10 | -0.03 | 0.03 | 0.07 | 0.08 | -0.07 | -0.09 |
| 8 | -0.07 | -0.16 | -0.14 | -0.12 | 0.02 | 0.12 | 0.04 | 0.03 | 0.07 | 0.07 | -0.07 | -0.09 |
| 9 | -0.07 | -0.15 | -0.14 | -0.12 | 0.03 | 0.06 | 0.02 | 0.02 | 0.03 | 0.07 | -0.07 | -0.10 |
| 10 | -0.06 | -0.15 | -0.13 | -0.11 | 0.03 | 0.11 | 0.07 | 0.04 | 0.06 | 0.09 | -0.06 | -0.08 |
| 11 | -0.08 | -0.16 | -0.14 | -0.13 | 0.04 | 0.05 | 0.02 | 0.02 | 0.01 | 0.07 | -0.08 | -0.09 |
| 12 | -0.06 | -0.14 | -0.13 | -0.11 | 0.02 | 0.12 | 0.02 | 0.05 | 0.08 | 0.10 | -0.06 | -0.07 |
| 13 | -0.04 | -0.13 | -0.12 | -0.09 | 0.03 | 0.12 | 0.06 | 0.07 | 0.08 | 0.11 | -0.04 | -0.06 |
| 14 | -0.08 | -0.15 | -0.14 | -0.13 | 0.05 | 0.07 | 0.03 | 0.03 | 0.01 | 0.07 | -0.08 | -0.09 |
| 15 | -0.06 | -0.14 | -0.13 | -0.11 | 0.03 | 0.10 | -0.02 | 0.03 | 0.06 | 0.08 | -0.06 | -0.08 |
| 16 | -0.06 | -0.15 | -0.13 | -0.11 | 0.03 | 0.09 | -0.02 | 0.03 | 0.05 | 0.08 | -0.06 | -0.08 |
| 17 | -0.07 | -0.15 | -0.13 | -0.12 | 0.04 | 0.07 | 0.03 | 0.03 | 0.02 | 0.08 | -0.07 | -0.09 |
| 18 | -0.06 | -0.15 | -0.13 | -0.11 | 0.03 | 0.09 | -0.01 | 0.03 | 0.05 | 0.08 | -0.06 | -0.08 |
| 19 | -0.06 | -0.15 | -0.14 | -0.11 | 0.02 | 0.11 | 0.07 | 0.06 | 0.08 | 0.09 | -0.06 | -0.07 |
| 20 | -0.06 | -0.14 | -0.13 | -0.11 | 0.03 | 0.09 | 0.06 | 0.09 | 0.07 | 0.09 | -0.06 | -0.07 |
| 21 | -0.05 | -0.14 | -0.13 | -0.10 | 0.02 | 0.10 | 0.06 | 0.09 | 0.09 | 0.10 | -0.05 | -0.06 |
| 22 | -0.05 | -0.13 | -0.12 | -0.10 | 0.03 | 0.09 | 0.06 | 0.09 | 0.06 | 0.11 | -0.05 | -0.05 |
| 23 | -0.05 | -0.14 | -0.13 | -0.10 | 0.02 | 0.11 | 0.07 | 0.08 | 0.08 | 0.10 | -0.05 | -0.06 |
| 24 | -0.04 | -0.13 | -0.12 | -0.09 | 0.01 | 0.11 | 0.06 | 0.07 | 0.08 | 0.10 | -0.04 | -0.06 |

Totally, the Shazand Watershed had no good status in viewpoint of NDVI values. The maximum, minimum, mean and standard deviation of NDVI in 2014 for the study watershed were 0.09, -0.15, -0.03 and 0.08, respectively. As seen in Table 2, $R_{el}$ for the Shazand Watershed was almost (except sub-watersheds 7 and 16) in healthy state (= 0.89 out of one). However, the whole of the watershed except sub-watersheds 7 and 16 was in un-healthy state (= 0.11) in terms of $R_{es}$. The results also showed that $V_{ul}$ varied from 0.00 to 1.00 with mean of 0.50. Despite two indicators of $R_{el}$ and $R_{es}$, $V_{ul}$ had very high variability through different sub-watersheds. The results of the aggregated land cover based $R_{el}R_{es}V_{ul}$ index revealed that two sub-watersheds of 7 and 16 which had un-healthy state in viewpoint of $R_{el}$ and $V_{ul}$, were also in un-healthy state of aggregated $R_{el}R_{es}V_{ul}$ index. The healthy state of the Shazand Watershed in terms of $R_{es}$ could not overcome the un-healthy state of other effective indicators in $R_{el}R_{es}V_{ul}$ framework. The results proved that 6, 53 and 41 % of the watershed area were categorized in un-healthy, relatively healthy and moderate healthy conditions, respectively, in viewpoint of land cover.

Table 2. Results of land cover based $R_{el}R_{es}V_{ul}$ analysis for Shazand Watershed, Iran

| Indicators / Sub-watershed | $R_{el}$ | $R_{es}$ | $V_{ul}$ | Land cover based watershed health index |
|---|---|---|---|---|
| 1 | 0.89 | 0.11 | 0.48 | 0.36 |
| 2 | 0.89 | 0.11 | 1.00 | 0.46 |
| 3 | 0.89 | 0.11 | 0.55 | 0.38 |
| 4 | 0.89 | 0.11 | 0.11 | 0.22 |
| 5 | 0.89 | 0.11 | 0.37 | 0.33 |
| 6 | 0.89 | 0.11 | 0.28 | 0.30 |
| 7 | 0.07 | 0.87 | 0.04 | 0.13 |
| 8 | 0.89 | 0.11 | 0.56 | 0.38 |
| 9 | 0.89 | 0.11 | 0.16 | 0.25 |
| 10 | 0.89 | 0.11 | 0.63 | 0.40 |
| 11 | 0.89 | 0.11 | 0.11 | 0.22 |
| 12 | 0.89 | 0.11 | 0.66 | 0.40 |
| 13 | 0.89 | 0.11 | 0.94 | 0.45 |
| 14 | 0.89 | 0.11 | 0.22 | 0.28 |
| 15 | 0.89 | 0.11 | 0.40 | 0.34 |
| 16 | 0.07 | 0.87 | 0.00 | 0.04 |
| 17 | 0.89 | 0.11 | 0.24 | 0.29 |
| 18 | 0.89 | 0.11 | 0.31 | 0.31 |
| 19 | 0.89 | 0.11 | 0.79 | 0.43 |
| 20 | 0.89 | 0.11 | 0.69 | 0.41 |
| 21 | 0.89 | 0.11 | 0.92 | 0.45 |
| 22 | 0.89 | 0.11 | 0.77 | 0.42 |
| 23 | 0.89 | 0.11 | 0.91 | 0.45 |
| 24 | 0.89 | 0.11 | 0.80 | 0.43 |

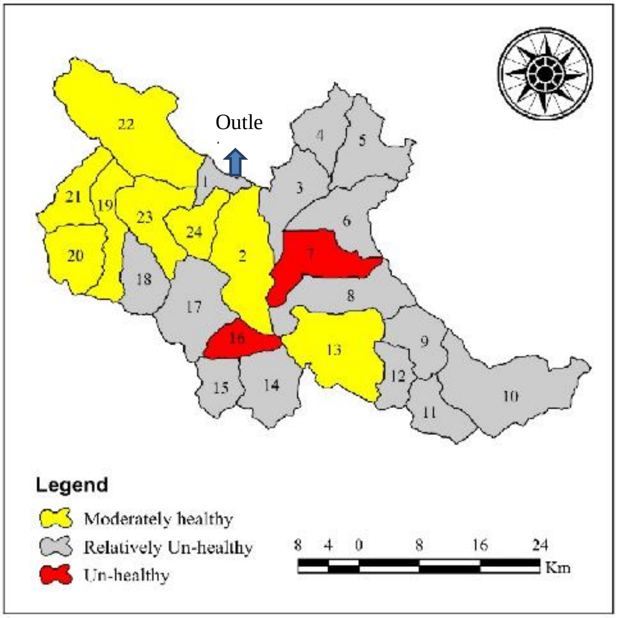


Figure 2. Distribution of land cover based watershed health index for the Shazand sub-watersheds (1-24), Iran

The vegetation cover indices such as NDVI have already been successfully applied to monitor the ecosystem state and the climatic effects (Wu et al., 2015; Damavandi et al., 2016; Sun et al., 2016; Peng et al. 2017). As Higginbottom and Symeonakis (2014) reported that an average value of NDVI < 0.1 indicating sparse biomass and influencing the soil interference, the NDVI might not be therefore considered as a good criterion. Hence, important directions for future research would be connected to the application of $R_{el}R_{es}V_{ul}$ framework with other vegetation indices to draw comprehensive conclusion on the study watershed health status.

## CONCLUSIONS

Assessing watershed health based on the land cover pattern change is central for comprehensive analysis of the human-nature coupling mechanism which is seldom considered quantitatively. The current study analysed the overall watershed health situation of the Shazand Watershed, central Iran using a simple and standardized framework of $R_{el}R_{es}V_{ul}$. In contrary to $R_{el}$ and $R_{es}$, $V_{ul}$ showed large spatial variability across different sub-watersheds. In addition, the land cover watershed health index resulted from aggregation of $R_{el}R_{es}V_{ul}$ indicators were in relatively un-healthy state with value of 0.34±0.11. This method provided more accurate statistical data clarifying the local administrative responsibilities to adopt the adaptive watershed protection and restoration strategies. According to the results, it is proposed to allocate more budgets to adopt rehabilitation activities to increase the vegetation cover of the Shazand Watershed. It is highly recommended to plant native species and with low water requirement wherever industrialization and urbanization have been developed in recent years.

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