Ecosystem Health Assessment Based On Pressure State Response Framework Using Remote Sensing and Geographical Information System

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Abstract. Ecosystem health (EH) is an important parameter for an area's sustainable development. This research work used remote sensing and GIS based ecological indicators under pressure-state-response (PSR) framework for ecological health assessment. Total 15 indicators were developed, from that 12 and 3 indicators were categorized for pressure and state indicators. Finally derive ecosystem health in Samara region, Russia under PSR framework, which provide an important decision making support for regional sustainable development with highly accurate new technology and can use for regular environmental mapping and monitoring.

1. Introduction
Recently high rate of disturbance in natural resources due to unusual and frequent human-socio-economic activities, regional ecosystem health is a hot topic and an important index for regional sustainable development [1, 2]. A healthy ecosystem means a stable ecological system, which is free from any stress [3]. In the present context, where socio-economic activities are very important, ecosystem health must be considered ecology, economy and population [4]. Earlier research studies consider: competing the reasonable need of human and at the same time preserving the organization itself, comes under healthy ecosystem [5]. In this research work, we consider healthy ecosystem, which is free from any human or natural pressure and have stable ecology, where there is not too much changes in ecology and providing good response to human at land cover level [6], also not threatening to other neighbouring ecosystem and maintain its organic health [7].

In this research work PSR framework was used to develop single ecological health index based on multiple sets of remote sensing and statistical indexes using weight system [8, 9] such as analytic hierarchy process (AHP). That’s why it was necessary to understand all used ecological indicators individually, their different dimension effects, dissimilarities, complicity, integrity, effectiveness, importance in ecology to mapping and monitoring ecosystem health [10]. Under PSR framework this research work classified all indicators in three groups: pressure indicator, which shows human and natural pressure on ecosystem or quality of natural resources in an ecosystem, than create an ecosystem status and in last generate response indicator [11]. Therefore the response indicator has
indicated undesirable changes in an ecosystem and natural resources due to pressure and state indicators and help to identify ecosystem health [12].

2. Data Acquisition

2.1. Study Area
We choose following seven districts in Samara State, Russia as a study area: Alekseevskiy, Bogatovskiy, Kinel'skiy, Krasnoarmeyskiy, Krasnoyarskiy, Neftegorskiy and Volzhskiy district. Samara region is situated in the South-East of the Eastern European Plain in the middle flow of the greatest European river, the Volga, Geographical coordinates are 53°12´10´´N and 50°08´27´´E (Fig. 1). Variations of heights in the study area have been from 21m to 364m with 100m average height. It has a humid continental climate characterized by hot summers and cold winters.

![Location map of the study area.](image)

Figure 1. Location map of the study area.

2.2. Data used
This research work used Landsat OLI data for the year of 2020. All imageries were downloaded free of cost from Earthexplorer of united states geological survey (USGS) website with less than 10% cloud cover, mainly spring and autumn seasons. Landsat OLI has 30m spatial and 16 days temporal resolution. All images were resampled by cubic method for high accuracy in ArcGIS software and then projected in WGS-1984-UTM zone-39N projection. Later on geometric and atmospheric errors were removed and used filters for noise removal at pixel level [13].
3. Methods

3.1. Ecosystem health assessment conceptual framework

We used PSR framework for ecosystem health assessment (fig. 2) as its support all required environmental management, decision making, clear causal relationship, reached the most extensive agreement and widely used in different ecosystems assessment and evaluation [8].

![Diagram of PSR framework]

Figure 2. Methodological chart for ecosystem health assessment based on PSR framework by RS/GIS.

As soil, water, vegetation, biology and atmosphere are the key components for ecological response in an ecosystem. Soil texture, biological activities and chemical properties are effects on agriculture production, which could further affect the atmosphere by moisture, temperature, structure and texture contents [7]. Water is a basic requirement for a society so water utilization, land use/cover, management or water resources are main factors in an ecosystem or its change [1]. Biological contents affect life activities of microorganisms and subsequently vegetation, atmosphere and agriculture production. Generally soil moisture and water resources bring changes in wetness, soil fertility later on vegetation type and quality of water environment, which affect plant growth and can lead by changes in greenness, soil temperature, land use/cover and further on heat, soil texture and in last dryness [14]. Therefore any disturbance or change in any ecological indicator ultimately affects or disturbs the whole ecosystems health, as all are directly or indirectly relevant.
3.2. Ecological Indicators used
In a pressure-state-response framework, pressure index refers to pressure on natural resources or ecosystems by social/artificial/human activities, whereas state index shows the health of ecosystems. Response index refers to changes in ecosystem due to pressure and state index. This research work derives ecosystem health assessment based on pressure, state and response index. The (1) Pressure indicator was derived by global environmental monitoring index (GEMI), evaporation rate (ER), land surface temperature (LST), soil adjusted vegetation index (SAVI), normalized difference moisture index (NDMI), Land use/land cover change, Road network, Railway network, night light index (LI), normalized difference water index (NDWI), terrain roughness index (TRI) and digital elevation model (DEM), (2) State indicator derived by normalized difference vegetation index (NDVI), leaf area index (LAI), fractional vegetation cover (FVC) and (3) response indicator was calculated from difference between pressure and state indicator.

3.3. Standardized the indicators
Before ecosystem health assessment all indicators were normalized from 0 to 1 range and rescale in terms of spatial and temporal resolution so that all indicators were get similar weight and importance in the result [3].

4. Results and Analysis
Ecosystem health index for the Samara region study area was extracted from 15 ecological indicators by the following process:

4.1. Pressure Indicators Analysis
This study used DEM and TRI for topographic and terrestrial features respectively. DEM was downloaded from USGS website at 30 meter resolution and then TRI (Terrain Roughness or Ruggedness Index) generated from DEM. Normally high altitude shows more stable ecological conditions or healthy ecosystem due to low socio-economic activities or low human pressure and activities.

For climate change indication, land surface temperature (LST) and evaporation (ET) were used as both components are related with temperature and humidity in the environment and its change. LST were generated from Landsat thermal bands and ET data were acquired from USGS FEWS NET data portal. In Russian climate context little bit high temperature from 20°C to 40°C is suitable for species survival and vegetation richness, means health ecosystem. Generally a very high evapotranspiration is not suitable for vegetation or stable ecology because it increases water stress condition in plants, which represent unhealthy ecosystem. But in Russian climate context due to extreme coldness, it creates favourable conditions for vegetation and ecology in a specific range as it makes a balanced moisture situation in the ecosystem.

A country's infrastructure and facilities such as light index, land use/cover, road and rail networks can be used for analysing human pressure on the ecosystem. High population density represents a high light index and its greater changes show more frequency of human activities. Light data was accessed from DMSP, the Payne Institute for Public Policy under the Colorado School of Mines. Generally higher socio-economic activities and rapid development is associated with higher light index and poor ecological condition or unhealthy ecosystem. As higher socio-economic activities or higher human pressure are negative effects on a stable environment. Road and rail network data were obtained from OpenStreetMap as it's globally available at free of cost and can be used for traffic situation and intensity. The higher transportation and socio-economic activities put a negative impact on the stability of ecology and make unhealthy ecosystem.

We used supervised maximum likelihood classification approach on Landsat images and got following six major LULC classes: agriculture, forest, mangroves, settlements, water and wetland. Therefore land use index was developed based on land cover and its intensity, effectiveness and importance in the ecosystem. High index represents extremely or peak utilized land and is unable to
further utilization of land such as fully urbanization, where humans cannot use it further. The low index value shows the beginning of the land resource utilization like open land so low index represent health ecosystem.

4.2. State indicators analysis
State indicator represented by the stability of the ecosystem, which is closely related to natural healthy vegetation conditions in the region. Vegetation changes also make an important role in global warming and biodiversity. Therefore in this study three major vegetation indexes were used for state indicator: NDVI, LAI and fractional vegetation cover (FVC). All are very significant with hydrology, ecology, regional change and can be accessed very simply and quickly [11]. Therefore the state indicator was developed by a combination of NDVI, LAI and FVC from different bands of Landsat data.

4.3. Response indicators analysis
The response indicator was assessed by the geometric overlay method in between pressure indicator (PI) and state indicator (SI), which show net effect or balance situation from pressure and state conditions. In other words, the response indicator can predict by pressure indicator minus state indicator as equation 1.

\[ RI = PI - SI \] (1)

Generally in a high pressure situation, response indicator will high, means a poor ecological situation, therefore a lot of changes in the ecosystem, so high responses were indicating high ecological disturbance or environmental change means unhealthy ecosystem. On the other hand high state indicators show a low response indicator means high stable situation or good ecological condition and an established ecosystem with very low or no change due to less human and natural pressure. Directly we can say low response indicators represent a stabilized ecosystem and sustainable development.

4.4. Ecosystem health
Based on AHP method, first assigned weigh to all 15 indicators and then generate ecosystem health index based on following equations 2 and 3 [15]:

\[ EH = \sum_{i=1}^{n} W \times C \] (2)

Where EH ecosystem health, w and c are represents weight and normalized data.

\[ EH = W \times C + \ldots \ldots n \] (3)

So with the help of all ecological response parameters, we calculate EH as Eq. 4:

\[ EH = W(\text{environment}) + w(\text{climate}) + w(\text{soil moisture}) + w(\text{greenness}) + w(\text{LULC}) + w(\text{artificial features & energy}) + w(\text{water content}) + w(\text{landscape}) \] (4)

Where
Environmental parameter: global environmental monitoring index (GEMI),
Climate parameter: evaporation rate (ER) and land surface temperature (LST);
Soil moisture: soil adjusted vegetation index (SAVI) and normalized difference moisture index (NDMI);
Greenness: normalized difference vegetation index (NDVI), leaf area index (LAI), fractional vegetation cover (FVC);
Land use/land cover: LULC change;
Artificial features and energy: Road network, Railway network and night light index (LI)
Water content: normalized difference water index (NDWI);
Landscape: terrain roughness index (TRI) and digital elevation model (DEM),

Or in other words with the help of all 15 indicators with their weight, we calculate EH as following Eq. 5:

\[
EH = 0.35(\text{GEMI}) + 0.31(\text{ER} + \text{LST}) + 0.30(\text{SAVI} + \text{NDMI}) + 0.25(\text{NDVI} + \text{LAI} + \text{FVC}) + 0.22(\text{LULC}) + 0.17(\text{Road} + \text{Railway} + \text{NLI}) + 0.15(\text{NDWI}) + 0.10(\text{TRI} + \text{DEM})
\] (5)

A higher EH values represents a favourable and stable ecological condition, means healthy ecosystem and vice versa. Figure 3 shows the PI, SI, RI and EH map of the study area. The spatial distribution of EH showed that forest area or natural resources have excellent EH condition and its neighbouring area showed excellent to moderate EH. Some cultivation and industrial areas showed fair to poor ecosystem health [16]. South part of the study area was showed fair and poor ecosystem health, where the north part shows moderate to excellent ecosystem health. Centre part of the study area and samara city comes under good to moderate ecosystem health which represents a mixed situation of governmental protection and awareness of the local population for ecosystem health (fig. 3).
Figure 3. Resulted pressure (PI), state (SI), response (RI) and ecosystem health (EH) maps of the study area.

5. Conclusions
From this research work, the ecosystem health can be evaluated under PSR framework from remote sensing and GIS technology with weight system. The remote sensing and GIS technology is the most suitable tool for ecosystem health study due to multi-spectral, spatial and temporal resolution, working in all-weather condition, even at inaccessible locations, very quickly and cheaper with less manpower and efforts and providing real time information. The selections of indicators are site/location specific and variate according to seasons so for different study area, they will variant according to local or regional situation. Besides the practicability of conceptual model, standard selection and indicator system building is also key to the success of ecosystem health assessment.

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