# Spatiotemporal ecosystem health assessment comparison under the pressure-state-response framework

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***Abstract***

A spatiotemporal ecosystem health (EH) assessment study is necessary for sustainable development and proper management of natural resources. At present higher rate of human-socio-economic activities, industrialization, and misuse of land are major factors for ecosystem degradation. Therefore this research work used remote sensing (RS) and geographical information system (GIS) technology, under pressure-state-response (PSR) framework with analytic hierarchy process (AHP) weight method based on 29 indicators were analyzed for spatiotemporal EH assessment in Tatarstan and Samara states in Russia from 2010 to 2020. Results indicate continuous degradation of EH in Tatarstan state while in Samara state first decreased and later on an improved ecosystem health condition. This is one of the most innovative analyses work for real-time accurate ecosystem health assessment, mapping, and monitoring as well as protect fragile eco-environment with sustainable development, proper policy-making, and management at any scale and region.

Keywords: spatiotemporal ecosystem health, PSR, remote sensing & GIS, AHP, indicators.

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## *Introduction*

Ecosystem health has been degraded day by day due to the high rate of exploitation of natural resources and extreme interference of humans and their socio-economic activities [1, 2]. Therefore a balance situation is required in between natural resources and human activities for sustainable development of a region. A healthy ecosystem means a stable ecological system, which is free from any stress [3]. In the present context, where socio-economic activities are play a very important role in ecosystem health thus in EH assessment ecology, economy, and population study must be considered [4, 5]. Earlier research studies consider: competing for the reasonable need of humans and at the same time preserving the organization itself, comes under a healthy ecosystem [6]). But in this research work, we consider a healthy ecosystem, which is free from any human or natural pressure and have stable ecology, where there are not too many changes in ecology and provides a good response to a human at the land cover levels [7], also not threatening to other neighboring ecosystems and maintain its organic health [8].

In this research work, the PSR framework was used to develop a single ecological health index based on multiple sets of remote sensing and statistical indexes using weight systems [9, 10] such as the analytic hierarchy process (AHP). Therefore 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 [11]. Under the PSR framework, this research work classified all indicators into three groups: pressure indicator, which shows human and natural pressure on ecosystem or quality of natural resources in an ecosystem, then create an ecosystem state and in last generate response indicator [12]. The state indicators try to reduce the pressure on an ecosystem by neutralizing the pressure indicators. And the response indicators indicate undesirable changes in an ecosystem and natural resources due to pressure and state indicators and help to identify ecosystem health [13].

## *1. Materials and methods*

### 1.1. Study area

We choose the Republic of Tatarstan, and Samara states Russia as a study area (fig. 1). Tatarstan state lies in between the biggest European river Volga and Kama River and extended till the Ural Mountains in east and joint of European and Asian Russia. Tatarstan has a 3.8 million population and covers 67800 km$^2$ areas. The main natural resource of Tatarstan is oil, natural gas, gypsum, agricultural land, etc. While Samara state is situated in the South-East of the Eastern European Plain in the middle flow of the greatest European river, the Volga. The 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.

### 1.2. Data and pre-processing

#### 1.2.1. Data

Table 1 shows the details of all used data in this research work with their sources for the years 2010, 2015, and 2020.

#### 1.2.2. Pre-processing and standardization

Before starting the analysis the whole data were preprocessed in that, all radiometric, atmospheric, and geometric errors were removed in ArcGIS software and all images were projected in WGS-1984-UTM projection at 30 m resolution. Later on, whole data were standardized from 0 to 1 range by the following equations 1 and 2 for positive and negative correlation respectively.

Positive: $Y_{ij} = (X_{ij} - X_{\min j}) / (X_{\max j} - X_{\min j})$, (1)

Negative: $Y_{ij} = (X_{\max j} - X_{ij}) / (X_{\max j} - X_{\min j})$. (2)

Where $Y_{ij}$ is the standardized value of factor $j$ in pixel $i$ ranging from 0 to 1, $x_{ij}$ is the measured value of factor $j$ in pixel $i$, and $x_{max,j}$ and $x_{min,j}$ denote the maximum and minimum values of factor $j$ in pixel $i$, respectively. $Y=0$ and $Y=1$ indicate the lowest and highest vulnerability, respectively.

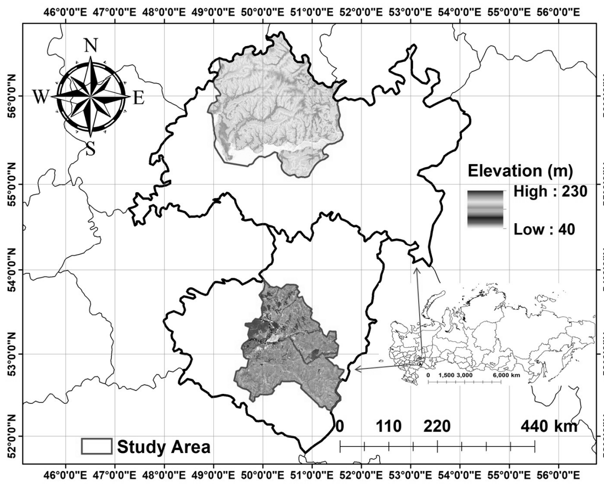


*Fig. 1. Location ap of the study area with elevation in the Republic of Tatarstan, and Samara State, Russia with google earth image*

*Tab. 1. Used data information*

| Data name | Attribute | Acquisition data | Source |
|---|---|---|---|
| Landsat ETM+ & OLI | 16-Day temporal & 30 m spatial resolution | 16/07/2010, 27/04/2015, 19/06/2020 | Earth-Explorer USGS (https://earthexplorer.usgs.gov/) |
| MODIS 13Q1 NDVI | 16-Day temporal & 250 m spatial resolution | 07/12/2010, 13/08/2015, 12/08/2020 | NASA LAADS DAAC (https://ladsweb.modaps.eosdis.nasa.gov/search) |
| MODIS 16A2 ET data | 8-Day temporal & 500 m spatial resolution | 04/07/2010, 20/07/2015, 17/06/2020 | NASA LAADS DAAC (https://ladsweb.modaps.eosdis.nasa.gov/search) |
| MODIS 11A2 Temperature & Emissivity data | 8-Day temporal & 1 km spatial resolution | 20/07/2010, 28/07/2015, 12/07/2020 | Earth-Explorer USGS (https://earthexplorer.usgs.gov/) |
| MODIS 15A2H LAI data | 8-Day temporal & 500 m spatial resolution | 20/07/2010, 12/07/2015, 20/08/2020 | Earth-Explorer USGS (https://earthexplorer.usgs.gov/) |
| MODIS 17A2H GPP data | 8-Day temporal & 500 m spatial resolution | 12/07/2010, 12/07/2015, 20/08/2020 | Earth-Explorer USGS (https://earthexplorer.usgs.gov/) |
| MODIS 12Q1 LULC data for HAI | 8-Day temporal & 500 m spatial resolution | 01/01/2010, 01/01/2015, 01/01/2020 | NASA LAADS DAAC (https://ladsweb.modaps.eosdis.nasa.gov/search) |
| DEM | 90 m spatial resolution | - | SRTM https://dwtkns.com/srtm30m/ |
| AVHRR-NOAA VHI data | 7-Day temporal & 1 km spatial resolution | 12/07/2010, 12/07/2015, 20/07/2020 | NOAA https://www.star.nesdis.noaa.gov/smcd/emb/vci/VH/vh_ftp.php |
| Road or topography data | shp | - | https://download.geofabrik.de/russia.html |
| Soil data | shp | - | https://soilgrids.org/ |
| Socio-economic/ demographic data | shp | - | Official website of Tatarstan state (https://open.tatarstan.ru/reports/categories) |

## 2. Methodology

Figure 2 shows the methodological steps of this research work. PSR framework was used for an ecosystem health assessment as its support all required environmental management, decision making, clear causal relationship, reached the most extensive agreement, and is widely used in different ecosystems assessment and evaluation [9].

### 2.1. PSR framework

Under the PSR framework, all indicators interact at a single unique platform, make relationships with other indicators and generate EH. PSR framework is subdivided into three parts as presented in table 2. A pressure indicator pressurized the ecosystem and enhances the environmental problems due to the negative impact on the ecosystem, while state indicators try to balance the situation by reducing the effect of pressure indicators. 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 3.

$$\mathrm{RI} = \mathrm{PI} - \mathrm{SI}. \quad (3)$$

### 2.2. Ecosystem health assessment

As the soil, water, vegetation, biology, atmosphere economy, and demographics 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 [8]. Water is a basic requirement for a society so water utilization, land use/cover, the management, or water resources are the main factors in an ecosystem or its change [1]. Biological contents affect the 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]. Higher socio-economic activities disturb natural resources and degrade ecosystem health. Therefore any disturbance or change in any ecological indicator ultimately affects or disturbs the whole ecosystem's health, as all are directly or indirectly connected and relevant.

The ecosystem health (EH) can be calculated by following equation 4.

$$\mathrm{EH} = \sum_{i=1}^{n} Z_i \times W_i . \quad (4)$$

Where EH is the ecosystem health index, Z refers to the standardized indicator's value, w weight of the indicator by AHP method, and n number of indicators. The resulting EH was classified into five levels based on natural breaks in ArcGIS software as shown in Tab. 3.

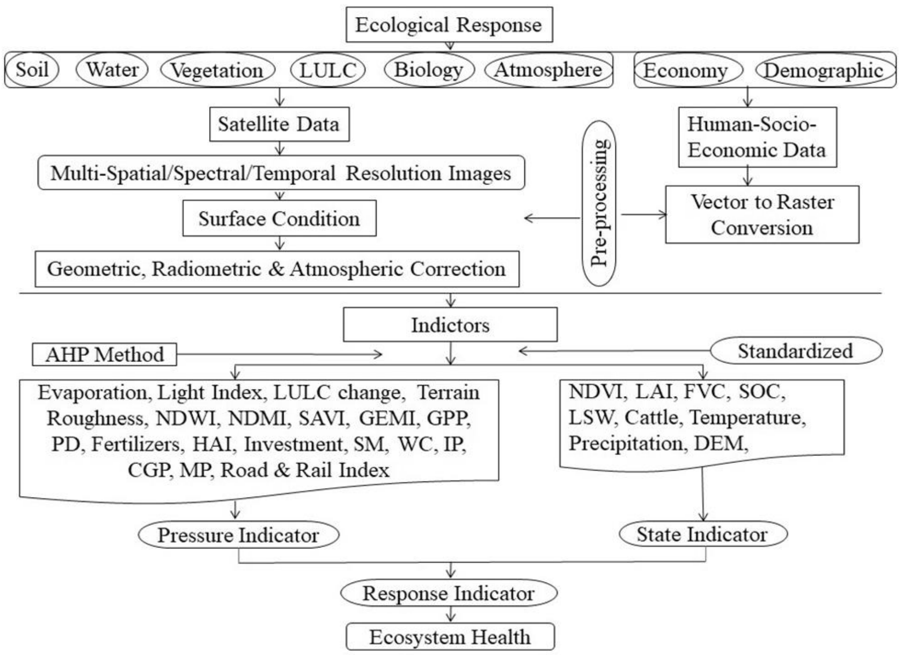


*Fig. 2. Methodological chart for ecosystem health assessment based on PSR framework*

## 3. Results and discussion

### 3.1. Assessment of PSR

Under the PSR framework ecosystem health was analyzed with individual factors contributing to further ecosystem preservation, protection, and sustainable development. Normally the analysis results of this research work are mainly based on the balance of pressure and state indicators from 2010 to 2020. For example, increasing gross primary production (GPP) and population density (PD), variables were start decreasing ecosystem health especially in settlements areas such as villages, towns and cities like Kazan and Samara city, etc. The increased pressure indicator associated with lower ecosystem health therefore in the north part of the study area shows lower ecosystem health levels due to higher pressure indicators such as HAI, investments, road density, etc., and shows higher human-socio-economic activities. The state indicators try to reduce pressure on ecology with greenness and moisture content and increase ecosystem health. Higher pressure affected areas illustrate higher response as well as lower ecosystem health thus lower ecosystem health areas show lower response areas. These responses first come from industrial production, livestock weight, or soil degradation. Generally, lower state indicator values have a higher response, and higher pressure indicator values, which represent a lot of changes in the ecosystem, means unstable ecosystem, or lower ecosystem health levels. In these areas, the government focused only on economic development, not sustainable development at the cost of ecosystem health. The lowest response values show stability in the ecosystem due to less pressure and a higher state value.

*Tab. 2. Indicators and their weight for ecological vulnerability index analysis*

| Level-1 | Level-2 | | Level-3 | | | |
|---|---|---|---|---|---|---|
| | Factor | Wn | Factors | Importance | GMn | Wn |
| EH | Pressure | 0.784 | Gross primary production (GPP) | 5.5 | 1.04 | 0.043 |
| | | | Population density (PD) | 8.5 | 1.61 | 0.066 |
| | | | Evapotranspiration (ET) | 8 | 1.52 | 0.062 |
| | | | Fertilizers | 4 | 0.76 | 0.031 |
| | | | Human activity index (HAI) | 7.5 | 1.42 | 0.058 |
| | | | Investment | 9 | 1.71 | 0.070 |
| | | | Land use land cover (LULC) | 7 | 1.33 | 0.054 |
| | | | Road density | 4.5 | 0.87 | 0.036 |
| | | | Soil moisture (SM) | 4 | 0.76 | 0.031 |
| | | | Water contamination (WC) | 2 | 0.38 | 0.015 |
| | | | Milk production (MP) | 4.5 | 0.85 | 0.035 |
| | | | Rail index (RI) | 3 | 0.57 | 0.023 |
| | | | Industrial production (IP) | 8 | 1.52 | 0.062 |
| | | | Crop grain production (CGP) | 6 | 1.14 | 0.047 |
| | | | Light index (LI) | 8.5 | 1.61 | 0.066 |
| | | | Terrain roughness (TR) | 4 | .76 | .031 |
| | | | Normalized difference water index (NDWI) | 2 | 0.38 | 0.015 |
| | | | Normalized difference moisture index (NDMI) | 3 | 0.57 | 0.023 |
| | | | Soil adjusted vegetation index (SAVI) | 4 | 0.76 | 0.031 |
| | | | Global environmental monitoring index (GEMI) | 7 | 1.33 | 0.054 |
| | State | 0.335 | Elevation | 5 | 0.95 | 0.039 |
| | | | Leaf area index (LAI) | 6.5 | 1.23 | 0.051 |
| | | | Normalized difference vegetation index (NDVI) | 6 | 1.14 | 0.047 |
| | | | Precipitation | 4 | 0.76 | 0.031 |
| | | | Temperature | 4 | 0.76 | 0.031 |
| | | | Fractional vegetation cover (FVC) | 6 | 1.14 | 0.047 |
| | | | Cattle | 7 | 1.33 | 0.054 |
| | | | Livestock weight (LSW) | 5 | 0.95 | 0.039 |
| | | | Soil organic carbon (SOC) | 3.5 | 0.66 | 0.027 |

*Tab. 3. Ecosystem health classification*

| Vulnerability | Level | EH | Description |
|---|---|---|---|
| Excellent | 1 | < 0.20 | Stable ecosystem |
| Good | 2 | 0.21 – 0.35 | Reasonably stable ecosystem |
| Moderate | 3 | 0.36 – 0.50 | Comparatively unstable ecosystem |
| Fair | 4 | 0.51 – 0.70 | Unstable ecosystem |
| Poor | 5 | > 0.71 | Extremely unstable ecosystem |

A high rate of pressure factor was presented in cities, some towns, and river basins. The central part shows the lowest pressure while sorrowing areas show midlevel. The pressure indicator was high in the northwest region of the study area, while the southeast region shows lower pressure. The pressure was slightly shifted in surrounding districts in patches format, which indicates high human-socio-economic and industrialization activities in the study area. The state indicator maps represent high stability in the east part of the study area, midlevel in the central part, while the west part has lower stability in 2010. In 2015 it was shifted anticlockwise and finally in 2020 north part comes under low stability and the south part has high stability, which indicates a high rate of development in the north part compared to the south part. All districts have different response indicators status based on their own general amenities facilities, services, income, capacity to face problems, etc. The river basin shows the lowest response while the central district shows the highest response.

### *3.2. Assessment of ecosystem health*

#### 3.2.1. The Republic of Tatarstan

Figure 3 represents 2010, 2015, and 2020 years of ecosystem health map of the republic of Tatarstan, which also allied with regional vulnerability events, hazards, and their impacts. Last decade huge investments in industry, development, modernization, urbanization, encroachment, and extreme weather conditions were the main cause of variation in ecosystem health in the study area. North parts of the study area, including the capital of Tatarstan, Kazan have a poor level of ecosystem health while the Volga, Kama River, and south-central part show excellent to a good level of ecosystem health. The central part is associated with moderate ecosystem health, while fair ecosystem health presents all over the study area in patches format.

The cross table 4 of ecosystem health indicates 1206, 1847, 1983, 2308 km$^2$ area of excellent, good, moderate, fair level ecosystem health converted in one lower level of ecosystem health from 2010 to 2015. In the second half 1853, 2969 km$^2$ area moderate, fair ecosystem health converted into fair and poor level respectively. In the net conversion of upper to the lower level of ecosystem health from 2010 to 2020 was as 1200, 1919, 2234, 2952 km$^2$ the area from excellent, good, moderate, fair to good, moderate, fair, and poor respectively which indicate a lower level of ecosystem health increased (table 4).

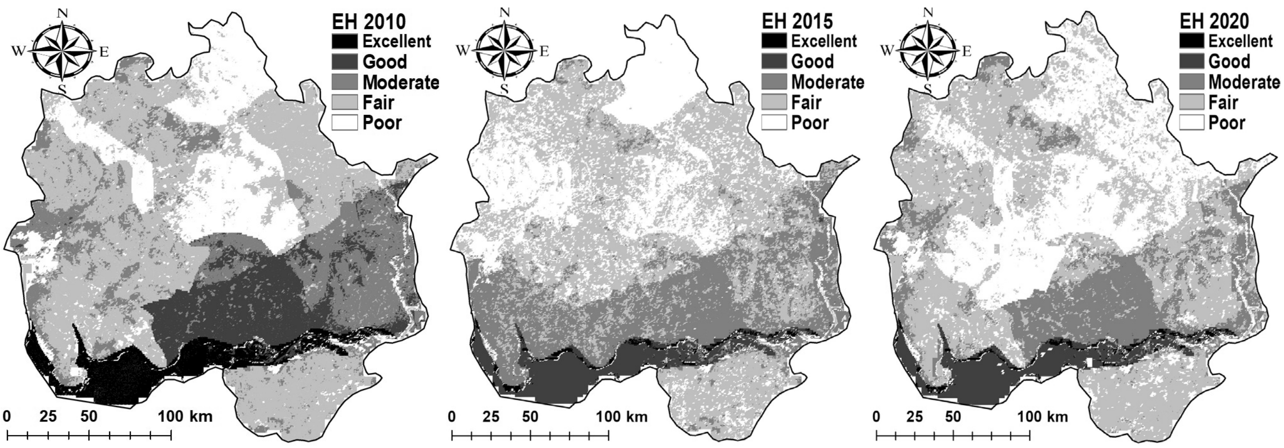


*Fig. 3. Ecosystem health (EH) distribution maps of the Republic of Tatarstan for the years 2010, 2015, and 2020*

*Tab. 4. Ecological vulnerability transformation matrix from 2010 to 2020*

| 2010 | 2015 | | | | |
|---|---|---|---|---|---|
| | Excellent | Good | Moderate | Fair | Poor |
| Excellent | 164.85 | 1206.75 | 24.80 | 0 | 0 |
| Good | 0.92 | 69.80 | 1847.77 | 452.30 | 6.43 |
| Moderate | 0 | 10.10 | 1554.35 | 1983.23 | 393.07 |
| Fair | 0 | 1.38 | 1039.60 | 4890.81 | 2308.34 |
| Poor | 0 | 0 | 100.56 | 955.11 | 2425.43 |
| 2015 | 2020 | | | | |
| Excellent | 151.58 | 28.65 | 0 | 0 | 0 |
| Good | 30.50 | 1241.73 | 33.27 | 0.46 | 0 |
| Moderate | 0.92 | 30.50 | 2481.15 | 1853.58 | 249.55 |
| Fair | 0 | 0.46 | 817.04 | 4476.60 | 2969.61 |
| Poor | 0 | 0 | 112.30 | 2096.20 | 2967.30 |
| 2010 | 2020 | | | | |
| Excellent | 162.55 | 1200.32 | 18.37 | 0 | 0 |
| Good | 0.92 | 85.41 | 1919.87 | 353.12 | 18.37 |
| Moderate | 0 | 0.46 | 1254.96 | 2234.87 | 450 |
| Fair | 0 | 0.46 | 197.45 | 5089.64 | 2952.58 |
| Poor | 0 | 0 | 7.35 | 722.30 | 2751 |

#### 3.2.2. Samara state

A higher ecosystem health value represents a favorable and stable ecological condition and vice versa. Fig. 4 shows the ecosystem health map of the Samara study area, where dark green color represents the good ecological condition and dark red shows the worst ecosystem condition (fig. 4). The resulting ecosystem health map was very much similar to vegetation maps as high NDVI value areas show good ecological condition and a lower NDVI, higher temperature, higher human pressure areas showed lower ecological conditions.

The spatial distribution of ecosystem health maps showed that forest area or natural resources have excellent ecosystem health condition and its neighboring area showed excellent to moderate ecosystem health condition. Some cultivation and industrial areas showed fair to poor ecological conditions. South part of the study area was showed fair and poor ecology, where the north part shows moderate to excellent ecological condition. Central part of the study area and Samara city comes under good to moderate ecological conditions which represent a mixed situation of governmental protection and awareness of the location population for ecology (fig. 4).

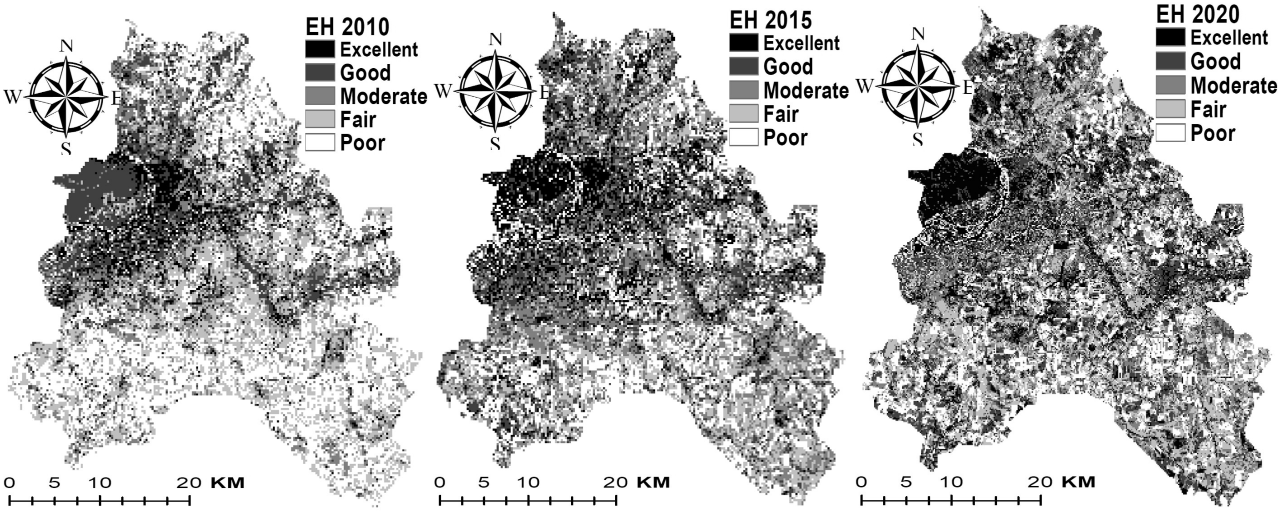

*Fig. 4. Ecosystem health (EH) maps for the year of 2010, 2015 and 2020, with five levels of EH*

Fig. 5 indicates that from 2010 to 2020 good and excellent ecological conditions gradually increased from 12.90 % to 24.94 % and 5.87 % to 12.90 % respectively, while poor EH class continuously reduced from 32.41 % to 18.77 % from 2010 to 2020 in Samara. The fair class first reduced and then increased but not reached till earlier years and moderate ecosystem health class first increased (17.82 to 25.04 %) and then decreased in 2020 at 18.66 %. In 2010 maximum area was covered by poor ecosystem health class, then fair, moderate, good and in the last excellent class but in 2020, all classes have very much similar areas or with a little bit different (fig. 5).

Figure 6 indicates that in this decade maximum area (4614.96 km$^2$, 31.84 %) was improved and 11.88 % (1721.62 km$^2$) degraded, while 10.68 % (1547.68 km$^2$) was unchanged from 2010 to 2020. The unchanged area was the lowest in all classes. The second highest class area was "first increase then decrease" class around 28.31 %. The first decreased and then increased class area was 17.29 % (25.0.47 km$^2$). The continuously increased area was distributed in forest and natural resources areas and continuously decreased area patches all over the study area, while the maximum unchanged area was distributed in the central part of the study area. The first increased then decreased class was present in the south and top north part while first decreased then increased class was present in the central part of the study area. The ecosystem health condition in agriculture and open field/areas were first increased from 2010 to 2015 and then decreased from 2015 to 2020 around 28.31 % (4104.11 km$^2$). Some patches close to the city and small towns/villages were first decreased and then increased as they were industrial sites and the government has special attention on them (17.29 %), while maximum part of Samara city and central part was unchanged.

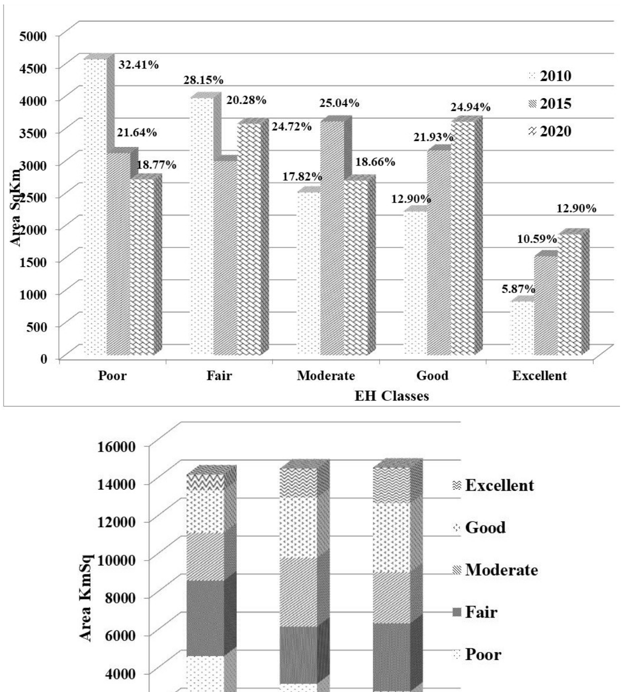

*Fig. 5. The area change in each ecosystem health (EH) level for the years 2010, 2015, and 2020*

### 3.3. Comparison of Tatarstan and Samara EH

In the Tatarstan state, ecosystem health was continuously decreased from 0.429, 0.425, and 0.419 from the years of 2010, 2015, and 2020 respectively, which indicate the year 2010 has the best while 2020 have the worst situation (tab. 5). Overall fair class was the most dominated class in all three years, higher level of ecosystem health covers less area as well reduced continuously while lower levels of ecosystem health increasing from 2010 to 2020.

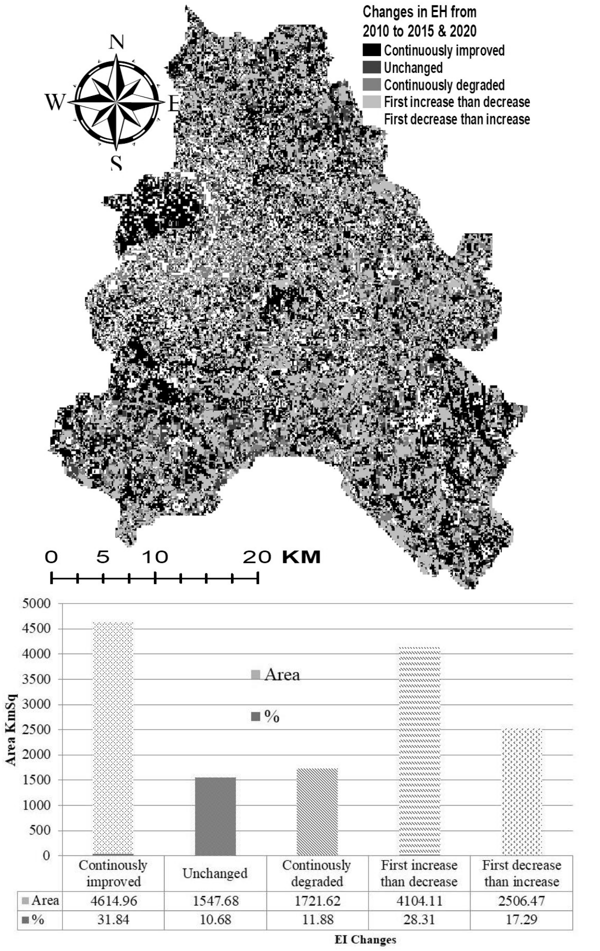


*Fig. 6. Changes in ecosystem health (EH) between 2010 to 2015 and then 2015 to 2020*

Samara state EH values increased 0.334 to 0.434 from 2010 to 2020 (tab. 5), which means better ecosystem health. In comparison to the first half (2010 to 2015) and the second half (2015 to 2020), the ecosystem health was really improved in the first half from 0.34 to 0.43, and in the second half, it was negligibly improved from 0.430 to 0.434 (tab. 5).

*Tab. 5. Statistics of ecosystem health*

| | 2010 | 2015 | 2020 |
|---|---|---|---|
| Tatarstan | 0.429 | 0.425 | 0.419 |
| Samara | 0.334 | 0.430 | 0.434 |

There were a lot of changes in ecosystem health from 2010 to 2020 in both states especially in the north part including the Samara and, Kazan cities. Due to the FIFA world cup 2018, hues amount of money comes to the state from Russian Federation for modernization, advancement, infrastructure, and facilities therefore it was a big challenge to the state government to one side protect the fragile environment and the other side sustainable development. This research work was based on the most suitable and available 29 indicators under the PSR framework thus this type of study is good for real-time accurate mapping and monitoring as well as can use for live telecast and applied in other areas as any scale but also have some limitations in terms of accurate weight calculations.

As this research work was done for the years 2010, 2015, and 2020, so we identify the changes only in these specific years. Therefore, to identify exact changing point or change tendency and main influence parameters, next time will study continuous years' time-series databases even monthly basis study for key change identification.

### 3.4. General assessment for sustainable development

Under the PSR framework response indicator easily identifies any change in any ecosystem under different types of pressure. Thus an effective method was developed in this research work with the help of RS/GIS to map, monitoring and management of ecological issues from regional to a global level. In ecosystem health analysis state index was very important because SI neutralized the pressure. Therefore forest and natural vegetation play a major role in reducing environmental degradation and making a stable ecological condition in the study area. During this decade forest, mangroves, and wetland areas were increased to protect the ecology. Results maps also showed shifting of SI index from non-vegetation area to natural vegetation area from 2010 to 2020 to give more stability to regional ecology.

During this ecosystem health assessment, tried to calculate maximum possible parameters, which were relevant to topographic features, complex climate, and natural conditions, and the main focus was given to the vegetation ecosystem as reducing pressure index and protecting the ecology. We noticed that during the ecological monitoring period, the vegetation ecosystem was improved. Surrounding the Samara city and central part of the study area, where the land exploration was relatively high due to specific socio-economic activities such as cultivation activities, urban development, therefore in this part of study area human pressure was increased and its bad effect on surrounding vegetation ecosystems health and natural environment. Therefore these areas show high human pressure, bad ecological condition and a higher response, should draw more attention and regular ecological monitoring for its protection. In ecosystem health assessment, also identify specific locations, which were covered by governmental protection to protect ecology have less effect from human pressure than unprotected areas. Therefore need to make special policies for healthy and stable ecology and implement them properly in required areas. Thus the development of all factors in this research work is important for NGOs and governmental decision and policy making and support to sustainable development as all factors/parameters/indicators have broad aspects.

Therefore this research work shows a true replica of the study area, the actual situation of the study area, before governmental development plans, and after investments/advancements, which also verified by statistical analysis. The year 2010 was a normal time period when governments just start their plans, invest money, start development, infrastructure and modernization. Later on in 2015, when hues money was spent as well as a large number of human migrations was happened and development and modernization work were almost on its top speed. Therefore the year 2015 shows maximum disturbance but still has a good ecological condition in comparison to other years. It shows good governmental decision-making and well management. In last after 2018 FIFA world cup things were with less speed, therefore, the year 2020 has not shown any extraordinary results. Thus this is a good research work that covers maximum possible indicators and provides true replica results of the study area at any scale and area.

## *Conclusions*

This study was a new and innovative approach to understanding and comparison of ecosystem health of Tatarstan and Samara states. Ecosystem health was generated through remote sensing and GIS technology under the PSR framework with the AHP weight method. 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 conditions, even at inaccessible locations, very quickly and cheaper with less manpower and effort and providing real-time information. Samara state ecosystem health is improving continuously, while Tatarstan state ecosystem health decreasing. Overall ecosystem health assessment is critical to regional environment protection and sustainable development, as a new research topic, combining traditional ecology principles with remote sensing, GIS technology, landscape ecology, and ecosystem service evaluation; would have great sustainable development.

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