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Urban Green Space Site Suitability Analysis of Angul City, Odisha – A Geospatial Approach

Tejaswini Mallick[1], Jajnaseni Rout[2], Dibya Jyoti Mohanty[2,*]

Abstract

The urban ecological system is crucial for human survival in cities. Residents receive various services directly or indirectly from the functions of ecosystems, known as ecosystem services. Heat stress in urban areas can be particularly harmful, as the negative effects of increasing urbanization lead to significant temperature changes that impact both vulnerable species and human health. While there are several methods, such as modifying roof materials and using lighter colors, to mitigate the Urban Heat Island (UHI) phenomenon, none have been significantly effective in addressing this issue. The Angul District is in the central region of Odisha. The district finds its circumferential limits within 20° 31′ N – 21° 41′ N latitude and 84° 15′ E – 85° 23′ E longitude. The main objective is to find out about the environmental problems of the city community and propose suitable sites for green spaces in the city area. The analysis of the various parameters – like NDVI, NDWI, LST, LULC, and slope of the area – gave an overview of many different aspects of the city. The major findings are there has been a considerable loss in vegetation cover in the city area over the decade, the temperature of the city has drastically increased over the years owing to the presence of industries and mines around the city, the loss in vegetation is adding up to the heating effect of the region, the NDWI in the city region is low in 2024 as compared to 2014.

Keywords: LST, LULC, NDVI, NDWI, UHI

INTRODUCTION

Cities and urban centers of developing countries grow to a scale with no precedent. This situation is very worrying, and it creates negative effects among which the following stand out; population density excess, environmental damage and pollution, bad urban regulation and traffic congestion; all in all, a tendency to a worse life quality. This situation highlights the importance of examining the urban environment [1]. The urban ecological system is a vital component for human existence in cities. People receive various services, both directly and indirectly, through ecosystem functions known as ecosystem services. Environmental changes in urban areas have been the subject of numerous research studies over the past few decades. Recent studies concerning urban environments indicate that city areas tend to be warmer than their rural surroundings [2]. This phenomenon leads to the creation of heat islands due to nearby land use and human activities. Heat stress in urban areas tends to be more detrimental; subsequently, due to the adverse effects of increasing urbanization, significant temperature changes occur, impacting various vulnerable species and human health. Although there are various methods, such as changing roofing materials and using lighter colors, to mitigate the Urban Heat Island (UHI) effect, none have proven to be significantly effective in addressing the issue. Nonetheless, a viable solution to this challenge could be the implementation of urban green infrastructure (UGI) [3–5].

***Author for Correspondence**
Dibya Jyoti Mohanty
E-mail: dibyagis29@gmail.com

[1]Student, P.G., Department of Geography, Ravenshaw University, Cuttack, Odisha, India.
[2]Assistant Professor, Department of Geography, Ravenshaw University, Cuttack, Odisha, India.
[3]Ph.D. Scholar, Department of Geography, Ravenshaw University, Cuttack, Odisha, India.

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Urban Green Infrastructure (UGI) plays a crucial role in city planning, and its importance is particularly recognized for maintaining the environmental quality and sustainability of urban areas. Urban Green Spaces (UGS) in a city include bio-parks, parks, gardens, recreational areas, informal green zones such as waterfronts, green areas around historical locations, along railway and road corridors, as well as native plant types. These UGS offer multiple benefits to city residents. They function as the lungs of the urban area, filtering pollutants and releasing oxygen. In addition to providing clean air, they also aid in soil and water conservation and maintain the natural urban environment of the city. Numerous studies show that UGS improves human behavior and characteristics and aids in recovery from stress and anxiety, both mental and physical. In addition to their socio-psychological advantages, urban green spaces are known to reduce the strain on air conditioner and air cooler energy use. Therefore, to build green spaces that can improve city life, appropriate sites are required [6–9].

STUDY AREA

The central region of Odisha is home to the District of Angul. The district's perimeter lies between latitudes 20° 31′ N – 21° 41′ N and longitudes 84° 15′ E – 85° 23′ E. Keonjhar and Sundargarh border it on the north, Cuttack, and Dhenkanal to the east, Boudh to the south, and Sambalpur and Deogarh district to the west. The district has a total land area of 6375 square kilometers. In terms of area, the district ranks eleventh out of all the districts in Odisha. A chain of hills that spans Athamallik and Angul stretches along the southwest border. The Brahmani River valley, which runs along Talcher's border through Kaniha and ends at Pallahara, is the third natural division from Figure 1.

The district can be separated into three natural tracks based on topography. The first is a series of hills that stretch along the district's northeastern border, encompassing Pallahara. Along the southwest border, there is another set of hills that encompass Athamallik and Angul. The Brahmani River valley, which runs along Talcher's border through Kaniha and ends at Pallahara, is the third natural division. Varieties of economic mineral areas are occurring in the district which includes coal, chromites, graphite, manganese, mica, kyanite, granite, laterite, sand (stow), quartz, etc. [10–11].

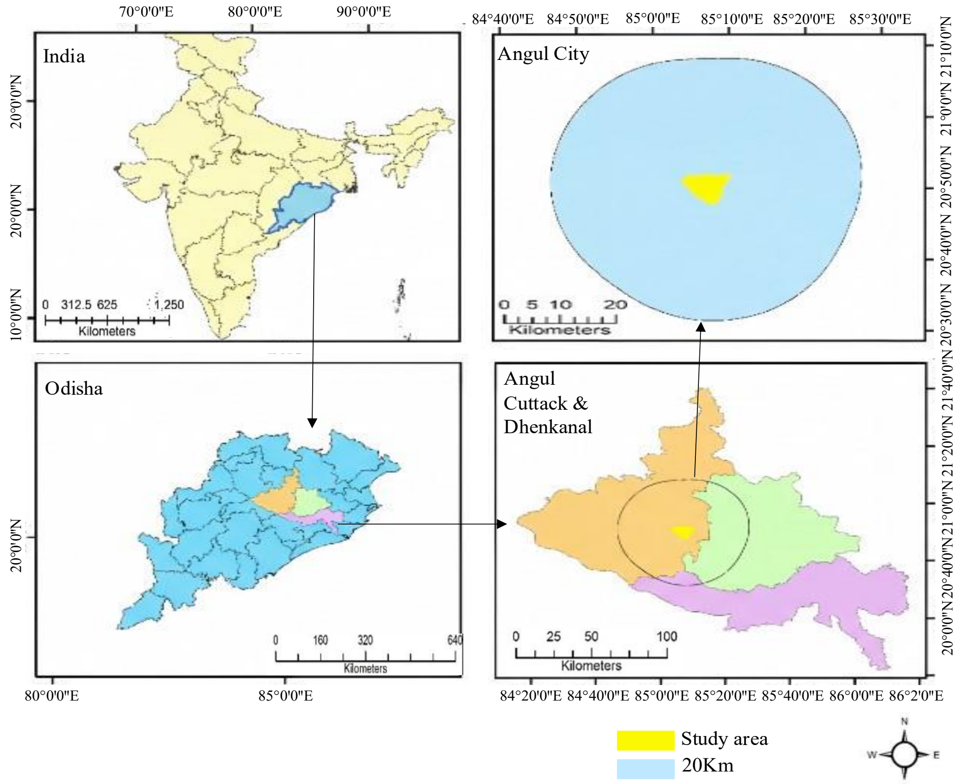

Figure 1. Location map of the study area.

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OBJECTIVE

- To analysis the Environmental problems of the city community.
- To propose suitable sites for green spaces in the city area.

DATABASE & METHODOLOGY

United States Geological Survey (USGS) was used for obtaining the datasets of Landsat 8 and 9; covering the study area to be processed. The images were masked to the area of interest and saved in the shapefile format, and a buffer of 20 km was applied from the boundaries of the study area from Figure 2. For processing the datasets ArcGIS 10.8 is used to obtain elevation, slope, and an aspect map using DEM data from USGS Earth Explorer. Indices – like NDVI and NDWI – are calculated to study the vegetation cover and presence of water in the study area (10).

NDVI is calculated as a ratio between the red (R) and near-infrared (NIR) values in traditional fashion:

NDVI = (NIR – R) / (NIR + R).

Formula for Landsat 8–9:

NDVI = (Band 5 – Band 4) / (Band 5 + Band 4).

Normalized Difference Water Index (NDWI) utilizes the green (Band 3) and near-infrared (Band 5) bands to highlight water bodies and their presence in satellite imagery.

Formula:

NDWI = (Band 3 – Band 5) / (Band 3 + Band 5).

For Landsat 8,

The formula for calculating LST is:

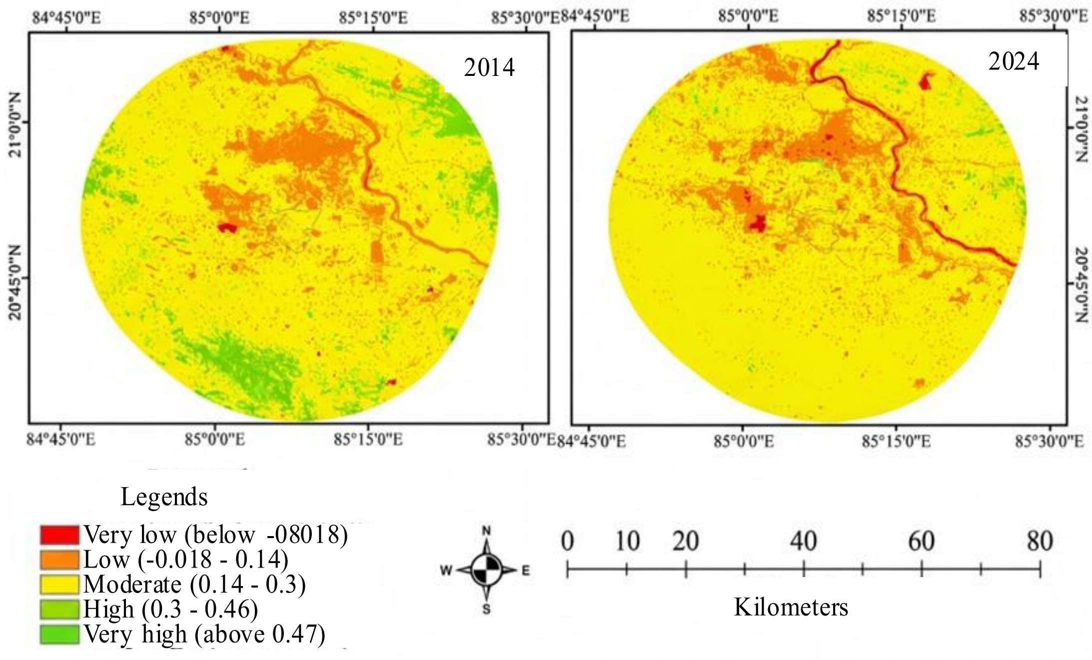

Figure 2. NDVI of the study area.

Calculation of TOA (Top of Atmospheric) Spectral Radiance

$$TOA\ (L) = ML * Qcal + AL$$

where:

ML = Band-specific multiplicative rescaling factor from the metadata (RADIANCE_MULT_BAND_x, where x is the band number).
Qcal = corresponds to band 10.
AL = Band-specific additive rescaling factor from the metadata. (RADIANCE_ADD_BAND_x, where x is the band number).

TOA to Brightness Temperature conversion

$$BT = (K2 / (\ln (K1 / L) + 1)) - 273.15$$

where:
K1 = Band-specific thermal conversion constant from the metadata (K1_CONSTANT_BAND_x, where x is the thermal band number).
K2 = Band-specific thermal conversion constant from the metadata (K2_CONSTANT_BAND_x, where x is the thermal band number).
L = TOA.

To obtain the results in Celsius, the radiant temperature is adjusted by adding absolute zero (approx. –273.15°C).

- The LULC map of the area is processed by doing an FCC and then classifying the area into five classes using the Isocluster visual interpretation technique.
- The slope map is prepared with the help of GIS of metadata by doing a FCC on the DEM data. Then using the Spatial Analyst tool, the elevation of the surface of the given area is classified into five classes
- After all the parameters of the both the year 2014 and 2024 are observed and analyzed; Analytic Hierarchy Process (AHP) is used to give hierarchy to the parameters of LULC, slope, NDVI, NDWI and LST and finally suitable sites are suggested for creating green spaces in the study area, i.e., Angul city from Figure 3.

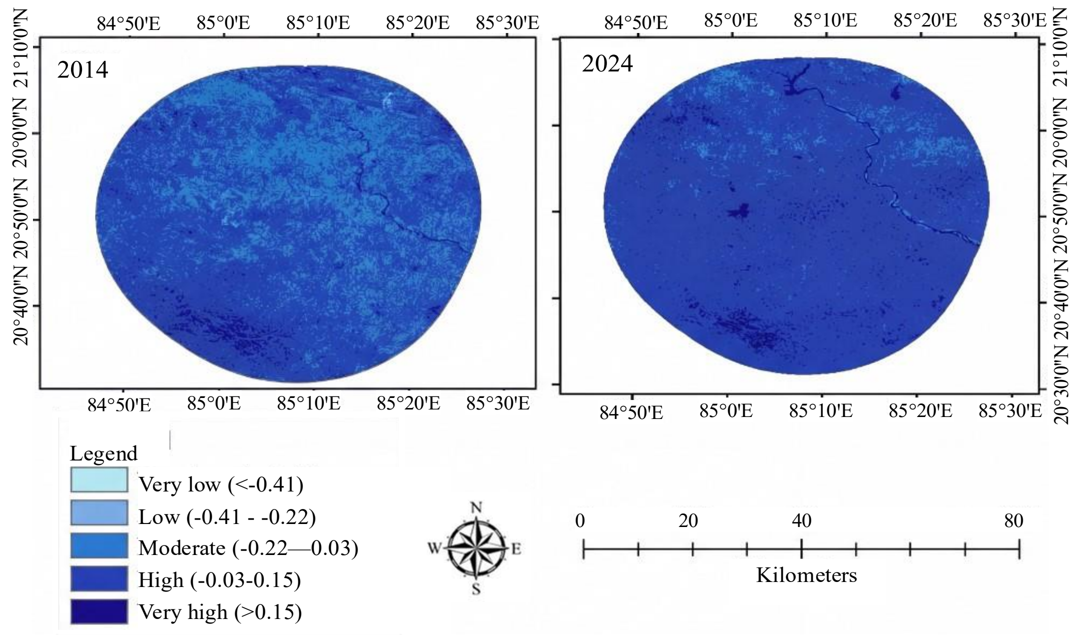

Figure 3. NDWI of the study area.

DISCUSSION

The study area along with its buffer area of 20 km is analyzed under various parameters like NDVI, NDWI, LST, LULC, and slope; to understand the decadal variation in various aspects of the city like its vegetation cover, water resource, temperature, elevation, and land use. Using ArcGIS 10.8, the above-mentioned indices are obtained using tools like Raster calculator, Image analysis. The derived results are classified into five classes to understand and compare their spatial variation. Further using Analytic Hierarchy Process (AHP) suitable sites are proposed in the city region for constructing green space.

NORMALIZED DIFFERENCE VEGETATION INDEX (NDVI)

Using NDVI, the study of 20 km buffer zone of Angul City is done using satellite imagery and GIS analysis tool. NDVI of two years, i.e., 2014 and 2024 are compared to see the vegetation cover and the areas that have the potential creating green spaces in the region.

In 2014, Angul City showed spatial variation in NDVI. The northern region of the study area has low vegetation cover with values ranging from 0.01 to 1.36. The Talcher mine area shows a very low NDVI with some areas having values, ranging from –0.017 to –0.019. As we move towards the northeast direction from the city towards Anantapur Reserve Forest and Kamakhya Forest Range, a positive trend in NDVI value is observed, ranging between 0.340 to 0.388. The industrial areas of NALCO and Tata Steel showed a low vegetation cover with values of –0.092 and 0.091, respectively. The southwestern part of the Angul City region has a good vegetation cover due to Kandhakoili forest, Tikarpara sanctuary and Hindol–Satkosia Forest Range where the NDVI ranges between 0.305 to 0.394. In the northwest direction from the Kanjara Forest region there is a positive trend in vegetation cover with value ranging between 0.307 to 0.330. The city has scattered vegetation in small patches along ponds, canals, and some roads with NDVI value ranging between 0.31 to 0.36. In 2024, Angul City has shown a considerable loss in vegetation cover a decade. The region in the north has almost same values of NDVI as compared to 2014. There are some patches in the central region with very low values ranging between –0.016 to 0.0176 are seen. The southern region and the central region have a very low NDVI with values ranging between –0.015 to 0.11. The regions that showed high vegetation cover in 2014 have now reduced to moderate vegetation with values between 0.172 to 0.255. The Talcher region shows very low values for the vegetation cover, with lowest at –0.021. NALCO and TATA Steel also show very low NDVI value. Thus, after comparing the decadal status of NDVI, we can conclude that the city has experienced a noticeable loss in vegetation cover. The areas that showed high NDVI in 2014 have reduced and overall moderate vegetation can be seen. The reduction in NDVI could be due to anthropogenic factors like large scale forest clearance for industries and mines.

NORMALIZED DIFFERENCE WATER INDEX (NDWI)

The NDWI values correspond to the following ranges:

- 0.2–1 – Water surface.
- 0.0–0.2 – Flooding, humidity.
- –0.3–0.0 – Moderate drought, non-aqueous surfaces.

The NDWI values are high for water bodies like ponds, reservoirs, and rivers. The Dehjang reservoir and river Brahmani show high values of NDWI showing water availability with values ranging between 0.330 to 0.594. In the southwest region the moisture in the vegetation cover shows values of NDWI. The Talcher region and the Rungta mining region shows a very low NDWI values ranging from –0.239 to –0.157 indicating the presence of non-aqueous surface and dry land. The area has small patches with very low water content, around –0.25 and moderate to low NDWI in areas with settlement and degraded land with values ranging between –0.091 to 0.142. Ponds, canals, and areas with vegetation in the city show a higher value as compared to its surrounding area. The value of NDWI has decreased in many areas like the NALCO region with values ranging between –0.042 to –0.091 and the Talcher region with lowest being –0.077 to –0.044. The built-up in the area has increased with values ranging between 0.0120 to 0.116. The river Brahmani shows a high NDWI with a value of 0.191. Thus, we can conclude that over the period of ten years the NDWI has decreased from 2014 to 2024.

LAND SURFACE TEMPERATURE (LST)

The LST of Angul region is very low in Kandhakoili forest, Tikarpara sanctuary and Hindol–Satkosia Forest Range due to the vegetation cover with values ranging from 25.88 to 28.56. The Anantpur Reserve Forest area and the Talcher forest in the northeast also show low LST values in the range of 26.68 to 28.64. The area to the west of the Derjang reservoir shows low surface temperature owing to the vegetation cover with values ranging between 26.16 to 28.09. Meanwhile areas with industries and mines show very high land surface temperature. For example, NALCO, which is situated near Angul City, shows a high LST value ranging between 32.84 to 33.08. The TATA Steel Limited and Jindal Steel and Power plant (JSPL) show high land surface temperature as compared to the surrounding region with values ranging between 30.47 to 35.60.

Rungta Mines to the south of TATA Steel also has shown high LST values, i.e., more than 31.09. In the north the Talcher coal mining area shows very high around values of LST ranging between 31.14 to 35.43 due to low vegetation cover and the heat produced by the open cast mines. Thus, it is clearly visible that water bodies and areas with high vegetation cover have low LST as compared to other areas. The forest areas show a similar result to LST after a decade with values ranging between 27.37 to 28.64.

However, in the other areas the LST has increased over the ten years. The values of the surface temperature have increased. Industrial sites – like JSPL, NALCO, and TATA Steel – show high values ranging between 35.37 to 41.33.

The Talcher region shows very high LST with values ranging between 36.63 to 44.94. As compared to 2014, the city region has more areas with values ranging between 31.02 to 35.08. Some central areas also show values around 40.08 to 42.03. This could be due to low vegetation cover and surrounding factors – like industries and mines – that are adding up to the heating effect of the city from Figure 4.

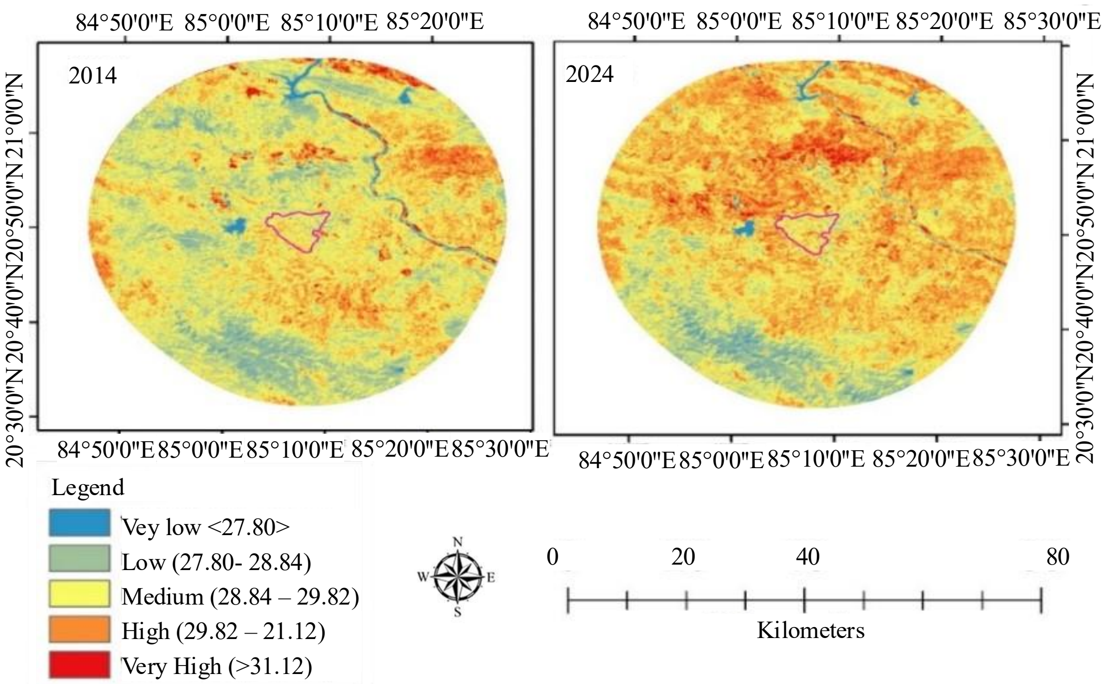

Figure 4. LST of the study area.

SLOPE

Slope The northeastern region has higher elevation compared to the central region. The areas with low slope areas are suitable for agriculture and settlements, i.e., below 5 degrees. The chains of hills running in the southwest region of Angul covering Athamallik shows a high degree of slope with values ranging between 18.26 to 23.42 degrees. The flat plain area in the city is ideal for green space creation and development from Figure 5.

ANALYTICAL HIERARCHY PROCESS (AHP)

AHP is a method for making decisions based on multiple factors. One of the most suitable methods for site suitability analysis. Using AHP; the criteria of LULC, slope, NDWI, NDVI, and LST are given priority, respectively. Five areas are identified with suitable characteristics for creating green space. Top priority is given to degraded lands near water bodies. A layout map is prepared showing the most suitable sites for Urban Green Space creation from Figure 6.

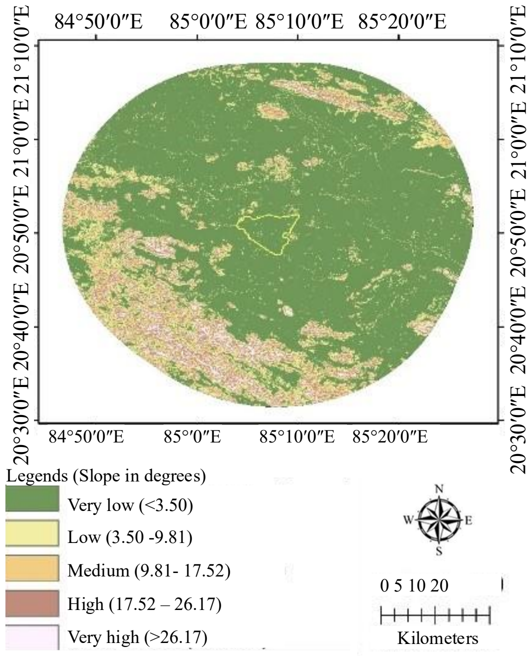

Figure 5. Slope map of the study area.

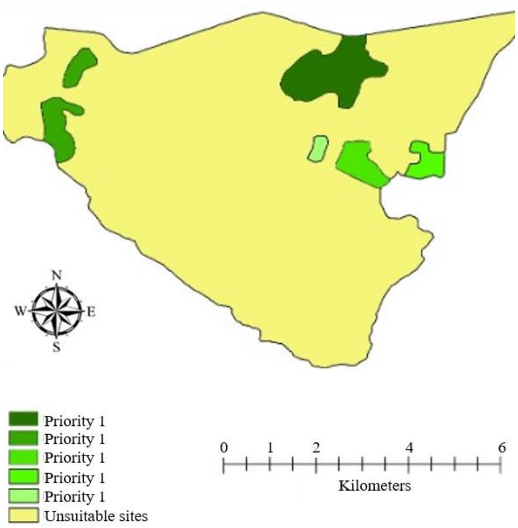

Figure 6. Green space suitability map of Angul city.

CONCLUSION

The analysis of the various parameters – like NDVI, NDWI, LST, LULC, and slope of the area – gave an overview of many different aspects of the city. The major findings are there has been a considerable loss in vegetation cover in the city area over the decade, the temperature of the city has drastically increased over the years owing to the presence of industries and mines around the city, the loss in vegetation is adding up to the heating effect of the region, the NDWI in the city region is low in 2024 as compared to 2014. Except for a few ponds and canals, there are no other means to recharge the ground water. The city areas closer to industries, roads, and built-up areas show high surface temperatures, the city requires more green space to sustain its environment and community. The city of Angul is a rapidly developing industrial town. With its large mineral reserves, and booming industries, Angul growth is unprecedented. Although industries – like TATA Steel, JSPL, NALCO, and mining corporations like RUNGTA – have significantly led to the development of the people and area, they are the major cause of rising temperature around the city area. It is rightly said "with progress comes challenges". The analysis and the review of literature have given us enough evidence for the degrading environmental condition, loss of vegetation and how it can affect the city and its community in longer run. Finally, development is an ongoing process, however, to ensure that development is sustainable we need to take measures that can reduce the adverse effects of development on humans and their lives. One such measure is by increasing green spaces. By increasing vegetation cover, we can not only reduce the effect of heat but also improve the health and mental wellbeing of the community.

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