Alexandria Engineering Journal (2023) 62, 269–277

HOSTED BY

Alexandria University

Alexandria Engineering Journal

www.elsevier.com/locate/aej
www.sciencedirect.com

GIS-based assessment of land use for predicting increase in settlements in Al Ahsa Metropolitan Area, Saudi Arabia for the year 2032

Ali Alqahtany

Department of Urban and Regional Planning, College of Architecture & Planning, Imam Abdulrahman Bin Faisal University, P.O. Box 1982, Dammam 31441, Saudi Arabia

Received 15 March 2022; revised 23 May 2022; accepted 16 July 2022
Available online 29 July 2022

KEYWORDS

Land use map;
LandSat;
LULC;
Geographical Information System (GIS);
Al Ahsa

Abstract Al Ahsa Metropolitan Area (AMA), located in the Eastern Region of Saudi Arabia, has witnessed rapid population growth with remarkable urban expansion during the past few decades due to the discovery of oil. Because of this rapid growth, AMA is currently exposed to many short and long-term social, economic, and environmental challenges that need to be studied and assessed to provide solutions for the betterment of the population. This study examines the historical growth of AMA by using Geographical Information System data and satellite image classification techniques for the last 30 years. The results show that the total urban area of AMA has significantly increased from 199 sq. km. to 276 sq. km. during the past 30 years from 1992 to 2022 with a sharp increase of 25.5 % in the last 10 years only. Statistical analysis of the historical data predicted an increase of 26.8 % in the area of settlements during the next decade up to the Year 2032. After a study of land use maps it was also observed that the increase in settlements caused a decrease in vegetation to 18 % in the last decade. The research presents beneficial statistics which shall help the decision-makers and related authorities in managing the development process in the area in a better and more sustainable manner.

1. Introduction

Land is a major source of human growth and sustainable development [1,2]. In recent years, much research has focused on the topic of land use and land cover changes worldwide and it has become an essential part of research and studies on global change and sustainable development [2–8]. The first time the term land use land cover (LULC) was used was in a study supported by the United Nations Educational, Scientific and Cultural Organization (UNESCO) and carried out jointly by the International Geosphere-Biosphere Program (IGBP) and the International Human Dimensions Program (IHDP) in 1987 [8]. The central objective of that study was to improve knowledge of the dynamics of LULC changes and to understand their relationships with global environmental change [2]. Subsequently, observations of LULC changes became

E-mail address: amalqahtany@iau.edu.sa

Peer review under responsibility of Faculty of Engineering, Alexandria University.

https://doi.org/10.1016/j.aej.2022.07.020

most vital for several planning and management strategies [9]. According to Cegielska et al. [10], the notion of land use refers to human and economic activities related to certain parts of any spatial area, whereas land cover refers to the kind of phenomenon represented on the earth's surface. LULC change detection analysis consists of a wide range of methods that identify, describe, and evaluate differences between images of the same scene under different conditions and at different times [11].

Change detection can be defined as a process of studying a specific phenomenon for evaluating and identifying the differences resulting from different factors at different times [12]. There are several applications in which the utility of the detection of LULC changes can be demonstrated, including shifts in cultivation and landscape, which are vital for natural resource management and environmental change monitoring as well as their potential contribution to global climate change [13,14]. Furthermore, the detection of LULC changes is important for studying land degradation resulting from different environmental processes by using the data of remote sensing satellites covering the Earth's surface [8]. Several researchers [15–20] have discussed that this is mainly because of several activities such as urbanization, socio-economic aspects, agricultural intensification, deforestation, and biophysical attributes.

The idea of LULC can be classified as intensely dynamic in terms of changes in both human activities and natural components that influence the environmental elements negatively including topography, soil, surface, and groundwater [3]. When selecting, planning, and implementing land-use schemes, it is very necessary to study the LULC pattern to meet the increasing human needs and welfare [4]. This also offers the information needed to meet the demands of a growing population and manage land use dynamics [21]. For instance, land surface temperature (LST) may increase due to the change in land cover especially from green areas to urban areas and particularly in semi-arid regions [22].

Currently, the change of LULC, especially in arid and semi-arid regions where land and water resources are insufficient, is considered a major factor affecting global environmental change [23]. Saudi Arabia was no exception, it has undergone extreme change over the past 30 years due to the rapid increase in the population of urban areas in addition to the accelerated economic growth resulting from the rise of the petroleum industry [24]. In 1975, the percentage of the population living in urban areas in Saudi Arabia was 58 % and increased significantly, reaching 87 % in 2001 and 91 % in 2016. This accelerated urban growth has led to an increase in the size of built-up areas and created a change in land use, particularly in pre-urban areas [25]. Urbanization can be described in its simplest terms as the process that rural people go through as they develop an urban lifestyle and expand the urban construction area and urban environment [26]. It involves the process of agricultural civilizations change into modern urban civilizations, focusing on modern services and industries, marked by modern public service facilities and urban infrastructure [27].

It is argued that the number of research that has previously been conducted on the issue of LULC in Saudi Arabia is low. For example, Khan et al. [2] identified and analyzed the dynamic transformation of LULC taxonomy in Riyadh by using remotely sensed LandSat-derived data. Abd El Aal et al. [8] utilized remote sensing and GIS for the detection of LULC changes in Najran and its potential environmental threats. Furthermore, to improve understanding of both causes and consequences, several change detection methods, including remote sensing, have been developed to monitor changes in land cover. For instance, Hereher et al. [28] used Shuttle Radar Topography Mission (SRTM) sensors and Moderate Resolution Imaging Spectroradiometer (MODIS) to analyze the topography and land cover of the Hail region. Some GIS-related studies have been found for Al Madina and Al Khobar regions focusing on the topography of the areas using ArcMap and Surfer [29–31]. Alqurashi and Kumar [3] used LandSat images to develop LULC maps and evaluated LULC change in Makkah and Al-Taif regions. Albalawi et al. [32] studied LULC changes in Tabuk City by using the Object-Based Classification technique (OBC) of LandSat images and the authors employed the GIS technique and Urban Growth Analysis Tool (UGAT) to measure the urban growth of the city. Many examples are found in the literature related to the studies on LULC all around the world. Sisodia et al. [33] performed a GIS-based study of urban sprawl in Jaipur, India. They used the satellite data for the previous 40 years.

The Eastern Region of Saudi Arabia has witnessed intense and accelerated changes since the 1970 s due to the oil boom and the rise in oil revenues, which in turn naturally led to great economic growth and a rapid increase in the urban population. The Eastern Region is considered one of the regions most affected by the issue of desertification and change of land cover compared to the other thirteen regions of the country [34]. The main driving factors of this issue are human activities e.g. urban development and food scarcity and natural factors e.g., wind erosion, however, other causes vary with the area [35,36]. Al Ahsa Metropolitan Area (AMA), one of the major cities of Eastern Province, has experienced a huge development during the last few decades. It is dominated by date palm farms that constitute the main source of income for local farmers and government where it forms 92 % of the land cover of the oasis [37] as shown in Fig. 1. The desertification has had a deep influence on the socio-economic and environmental development in the Al Ahsa Oasis [38], which occurred as a result of drastic urban activities [23,25], vegetation cover removal, and soil salinity [39], and sand encroachment [40]. Abdelatti et al. [25] highlighted the urban growth in Al Ahsa Oasis and pointed out that several factors have contributed to the current urban growth, the most important of which is the regional balanced development and the adoption of an oil-based economy. Aldakheel and Al-Hussaini [41] and Salih [42] indicated that the use of multi-temporal LandSat TM imagery to detect changes in LULC shows that the most prevalent types of land cover in the area are vegetation, soil salinization, and urban area.

The population of AMA has increased significantly from 500 thousand inhabitants in 1990 to 1.24 million in 2017. The urban growth tends mainly along the southern borders, due to the surrounding agricultural lands, as well as the presence of lands owned by the Saudi Arabian Oil Company (ARAMCO) and the National Guard in the East [44]. It is highlighted that urban growth in Al Ahsa Oasis without comprehensive planning in the future would have negative implications on the social life of the residents and the local environment as it has reduced the area under cultivation. Unfortunately, in addition to the fact that urban growth was at the expense of agricultural lands, it led to a quick increase in settlements, which caused many problems such as water sup-

Fig. 1 Al Ahsa Oasis with Date Palm Farms [43].

ply, sewage, and solid waste disposal, in addition to the industrial pollution, all of which led to a change in the morphological structure of the area [25]. Now there is a need for proper management and regulation system for allowing the settlement areas to increase such that all other amenities remain in control. But this can only be achieved if there is some study available that could predict the increase in the settlement areas. After an extensive literature review, although there is a good amount of study available on Al Ahsa Oasis, however, no studies have been found which assess the percentage of land use by settlements and predict the volume of settlement for the future years by using the LandSat data. This research focuses on the assessment of land-use changes in Al Ahsa Metropolitan Area (AMA) for a period of 30 years from 1992 to 2022. Moreover, it analyzes the trend of the increase in the settlements at AMA for the study duration and also predicts the expected increase in the settlements up to the year 2032. The research uses Geographical Information Systems (GIS) techniques by classifying LandSat data to assess the historical changes in the land use of AMA. In addition to the settlements, other types of land use are also critically analyzed in the research.

2. Materials and methods

2.1. Study area

Al Ahsa Metropolitan Area is located in Al Ahsa Oasis in the Eastern Province of Saudi Arabia at 25° 25′ N and 49° 35′ E as shown in Fig. 2(a). It is situated almost 300 km away in the East from the capital city Riyadh and also 50 km from the coast of the Arabian Gulf. Currently, Al Hofuf is the capital of Al Ahsa Governorate in the Eastern Province, which was initially known as Al Ahsa, and it was the capital of the Eastern Province until 1953. AMA is home to the largest oasis in the world which was declared a UNESCO World Heritage Site in 2018, with having more than 2,500,000 date palms, in addition to being one of the oldest settlements in the world [44]. The continuous vitality of the oasis is due to the availability of groundwater and the fertility of the soil in the area where the origin of the oasis can be traced back several millennia. AMA has a gradually varying topography ranging from 50 to 350 m above the Mean Sea Level (MSL) as shown by the contour plan in Fig. 2(b). The Eastern part of AMA, which is closer to the coastline, is lower whereas the elevation starts increasing while moving towards the West.

AMA consists of plains and moving dunes, which over many centuries expanded at the expense of the cultivated areas and which put the oasis at risk. For the population of Al Ahsa Oasis, agriculture is the main source of livelihood due to the availability of water from numerous springs and underground sources [23]. Water is transported to other areas of the region with the help of a well-developed system of canals and streams running under gravitational flow. The average climate of AMA is semi-arid which remains dry and cold in winter and becomes very dry and hot during summer.

2.2. Methodology and data collection

The methodology for the research has been adopted after a review of the related literature available on research platforms as well as the capabilities of GIS-based analysis tools were also explored to their extent for the best possible results. Li et al. [45] performed a comprehensive review of the image classification techniques used in remote sensing. They found pixel-based classification one of the most common strategies used for the purpose. A similar study was published by Escape et al. [46] and Soni [47] where they reviewed the image classification methods for various objectives. The procedure used for image classification and research analysis for this study is also adapted by a few other researchers as well [48–50].

Based on the above literature review, the process of preparation of land use maps for the current study has been divided into two main steps which are; Satellite Image Processing and the Image Classification Process. The detailed procedure is shown below in Fig. 3.

The historical satellite images were downloaded from the official website of The United States Geological Survey [51].

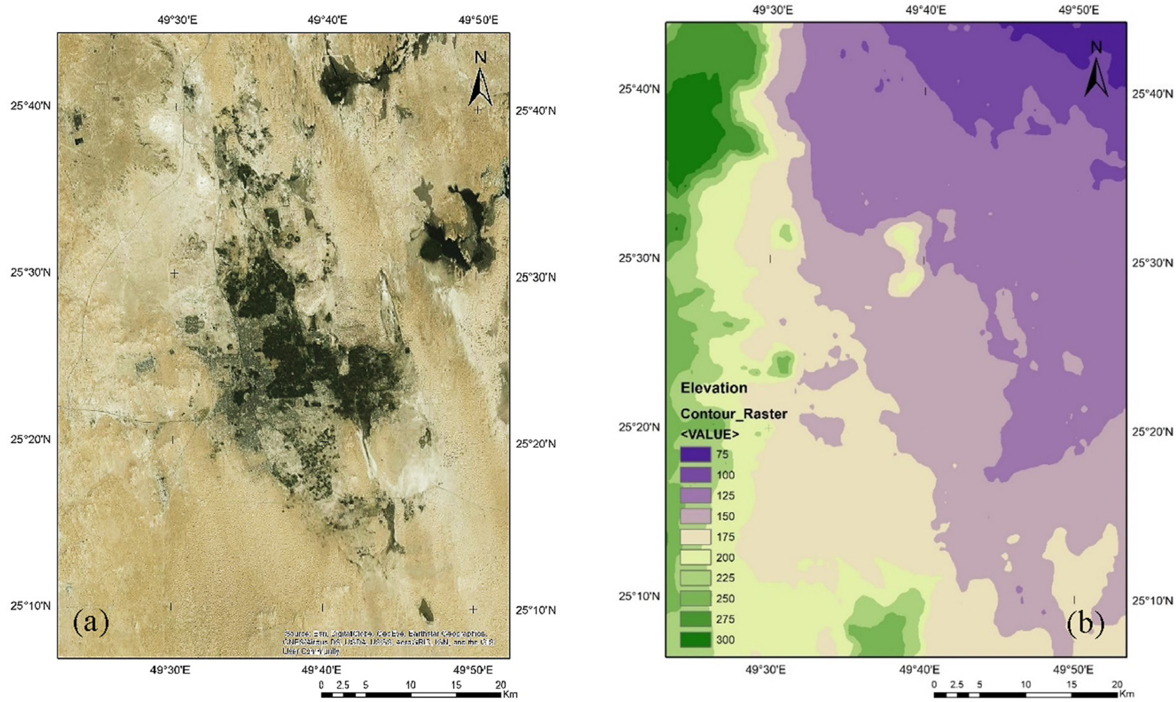

Fig. 2 (a) Satellite Image and (b) Contour Plan of Al Ahsa Metropolitan Area (AMA).

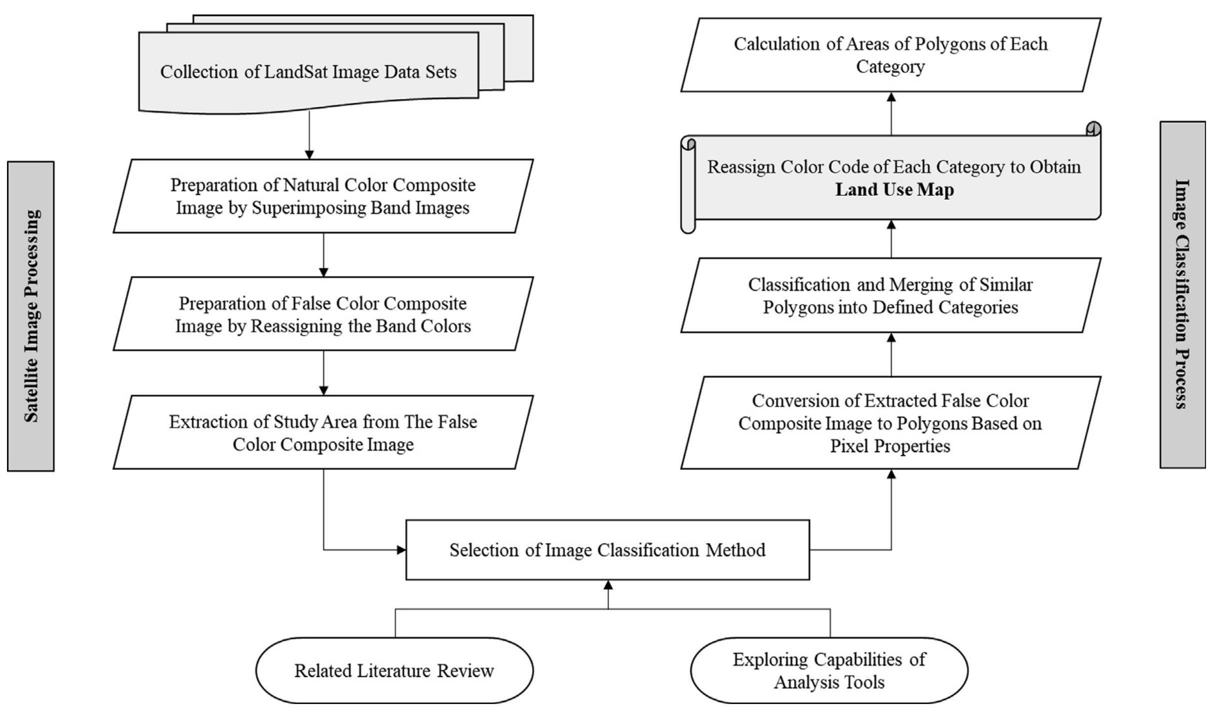

Fig. 3 Methodology of Developing Land Use Maps by using GIS and LandSat Data.

The images were downloaded for the span of 30 years from January 1992 to January 2022 with a duration of 10 years to study the change in the land use of the area. Specifically, the satellite data was collected for the years 1992, 2002, 2012, and 2022 with the following configuration as shown in Table 1 below. All the data was referenced to World Geodetic System 1984 (WGS84) for accurate latitudinal, longitudinal, and altitudinal values.

Table 1 LandSat image data configuration [50].

Year	LandSat No.	Sensor Type on Satellite	Datum
2022	8	Operational Land Imager (OLI) Thermal InfraRed Sensor (TIRS)	WGS84
2012	7	Enhanced Thematic Mapper Plus (ETM +)	WGS84
2002	7	Enhanced Thematic Mapper Plus (ETM +)	WGS84
1992	4–5	Thematic Mapper (TM)	WGS84

3. Results and discussion

A total of 11 images were obtained while downloading the LandSat data for each year representing different bands. Each band measures a specific wavelength of light that is reflected off of the surface of the Earth. Once all these bands are combined only then a natural-color satellite image is obtained.

The collected LandSat data was imported to ArcGIS to create the natural color composites by superimposing all the 11 satellite image bands for each of the years under study as shown in Fig. 4(a). Although a natural color composite is an image that appears natural to the human eye, due to low contrast and scattered blue color by the atmosphere, some land features are not recognized correctly during the image processing.

To remove this error, the false-color composites are produced which makes it easy to visualize even those wavelengths which are not visible to the human eye including infrared light. This process helps in recognizing all land features correctly. The false-color composite produced from a natural color composite for AMA for the Year 2022 is shown in Fig. 4(b).

After obtaining the false-color images for all the years, the image processing involved the classification of pixels that were classified into three different categories named vegetation, settlement, and barren land represented by green, blue, and fawn colors respectively. The image classification method by using ArcGIS is a proven technique and produces reliable results as mentioned by Rwanga and Ndambuki [5] and also tested by Sisodia et al. [52] who found it above 96 % accurate. The image classification of pixels resulted in the land use maps of the study area, as shown in Fig. 5.

As the main objective of the research is the calculation of areas occupied by settlements, the land use maps obtained through the above-mentioned process for the years 1992, 2002, 2012, and 2022, were converted into polygons by using ArcGIS, and later similar category polygons were merged to show the combined area of each category for a specific year as shown in Fig. 6.

By comparing the land use maps in Fig. 5 and the contour plan in Fig. 2(b), it can be observed that the settlements have spread towards the higher areas in elevation. Hence in the future also it is expected that the barren land area higher in elevation shall be occupied by the settlements which lie towards the west and south of the AMA. The future development plan of AMA developed by the Ministry of Municipal and Rural Affairs [43] shown in Fig. 7 also validates the results where it can be seen that the new settlements are already in the process of development in the west of the study area whereas the new future settlements are scheduled to be developed in the south of the area.

The areas occupied by settlements and vegetation as obtained from ArcGIS are shown in graphical form in Fig. 8. It can be seen that the settlement area has significantly increased over the years. The area occupied by settlements was 199 sq. km. which increased by 4 % to 207 in 2002 and then increased by 6.3 % to 220 in 2012. There is a sharp increase observed in the settlement area in the past decade when it increased by 25.5 % to 276 sq. km. On the other hand, there is a downward trend seen in the vegetation over the past decade, as shown in Fig. 8, which shows that the settlements are taking over even the vegetation area. The trees are being cut, the date palm fields are being reduced, and are covered by the paved areas and buildings. In comparison to an increase of 25.5 % in the area of settlements between the years 2012 and 2022, there is a decrease of 18 % in the area of vegetation during the same duration. Although vegetation area was on an

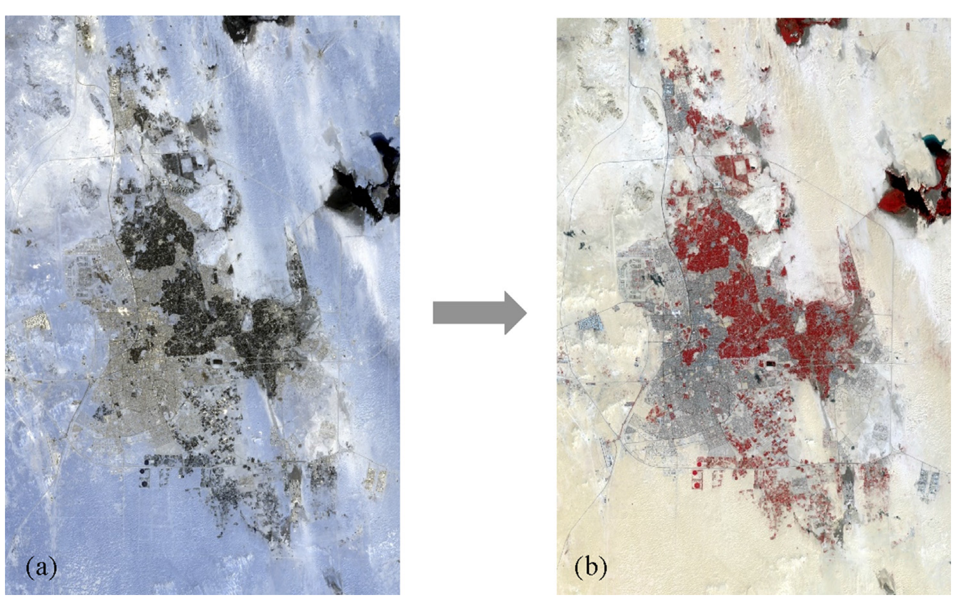

Fig. 4 Conversion of (a) Natural Color Composite Image to (b) False Color Composite Image of AMA for the Year 2022.

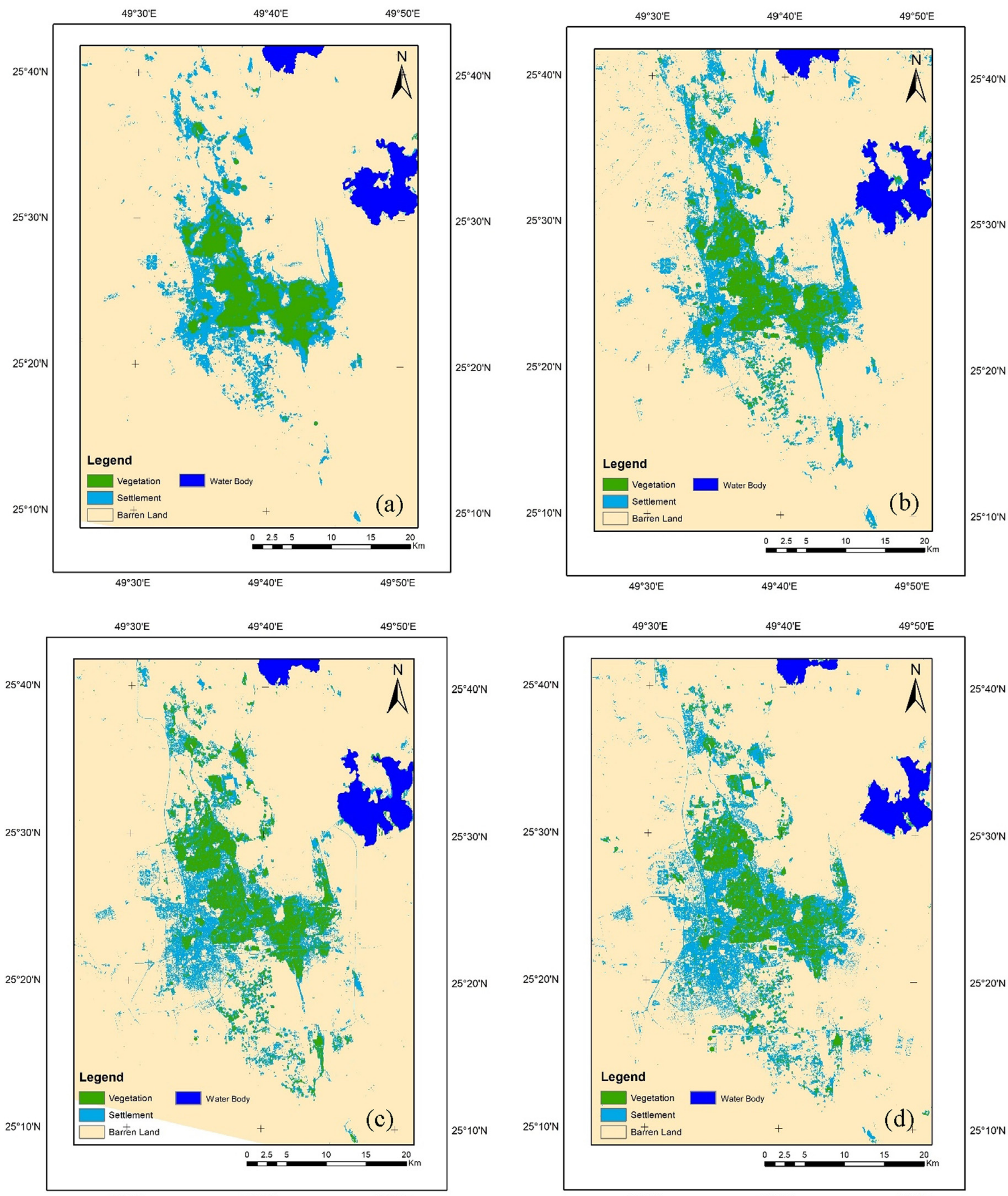

Fig. 5 Land Use Maps of AMA showing Variation in Settlement and Vegetation Areas for the Year (a) 1992, (b) 2002, (c) 2012, and (d) 2022.

increasing trend from 1992 to 2012, a sharp increase in settlement caused a sharp decrease in vegetation from 2012 to 2022. The area of the water body which is a natural lake is found to be varying based on the weather of the season during which the satellite image was captured. Although, it can be seen that the area of the lake has reduced slightly during the past decade, however, the amount of water shall be replenished naturally after the annual rainfall and the lake shall retain the average volume of water again.

The upward trend is clear as far as the settlements are concerned as shown in Fig. 9. This historical data was put to statistical analysis and a trend line was obtained which predicted that in the next 10 years the settlements would increase to almost 350 sq. km. by the year 2032 with an increase of 26.8 %. A trend line follows a regular increasing pattern having a coefficient of determination (r^2) value of 0.979 which shows that it is well fitted to the actual data and the predicted value is considered highly reliable.

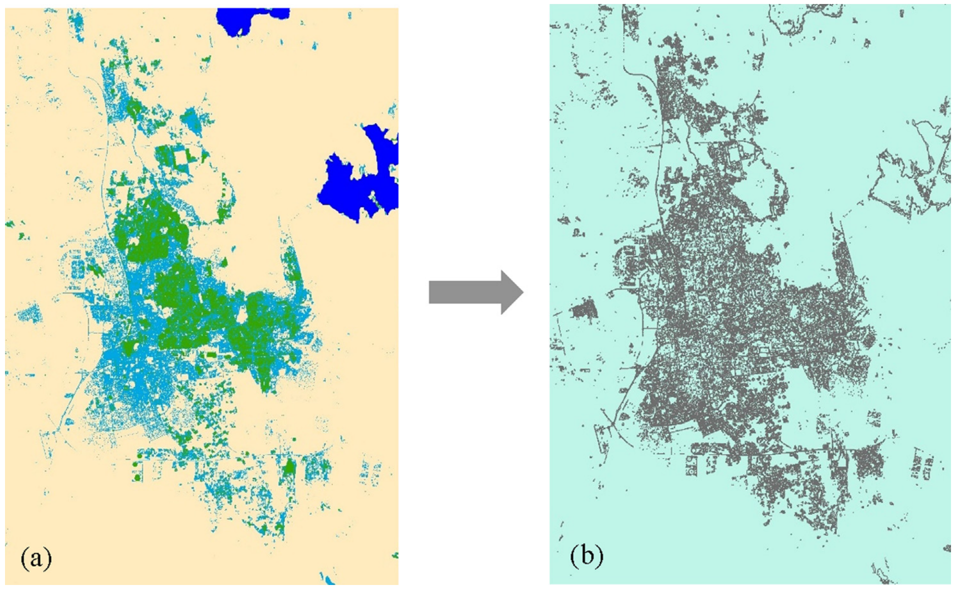

Fig. 6 Conversion of (a) Land Use Map to (b) Classified Polygon Image of AMA for the Year 2022.

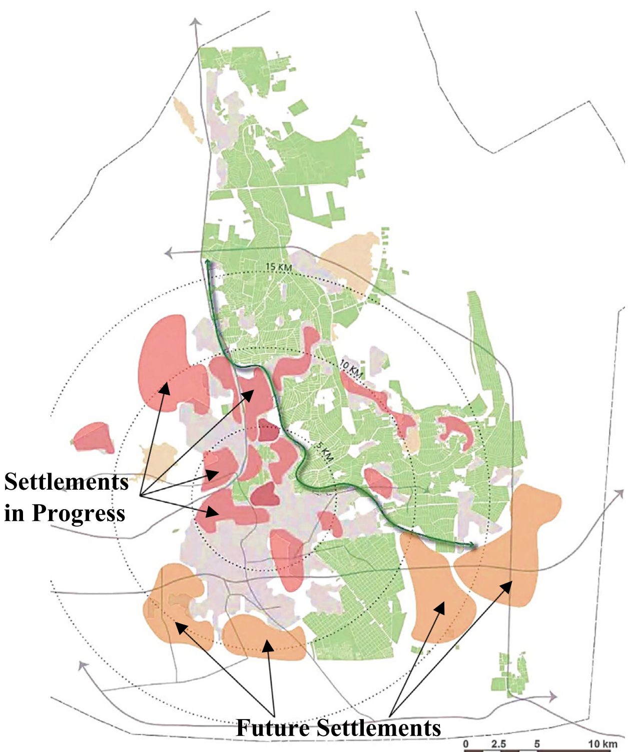

Fig. 7 Future Development Plan of AMA [43].

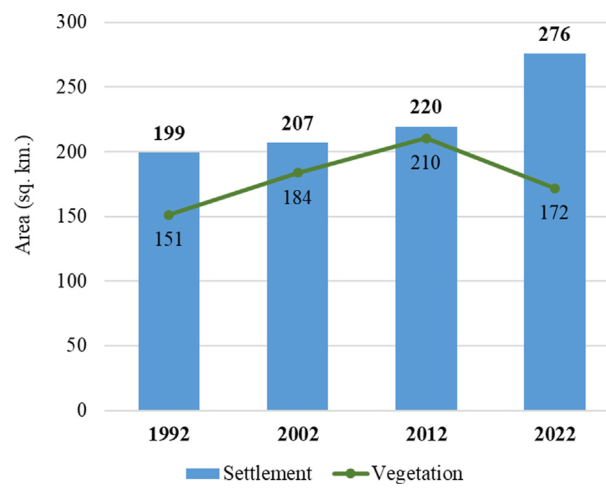

Fig. 8 Area Occupied by Settlements and Vegetation over the Years.

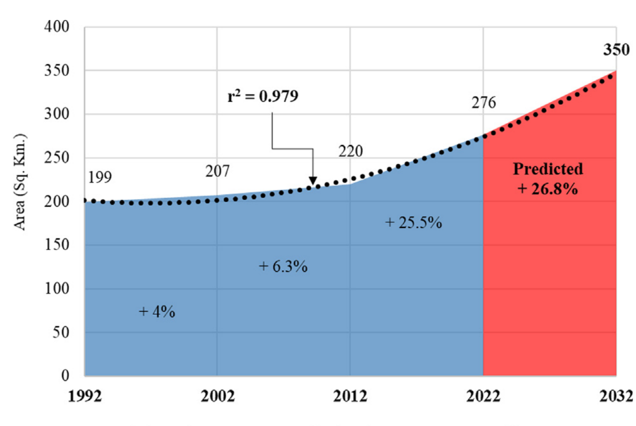

Fig. 9 Trend Analysis for Increase in the Settlement Area at AMA.

4. Effect of environmental factors on future settlements

A few environmental factors also affect the settlement in a region on land among which are the availability of water and the weather. As AMA lies in an oasis, there is plenty of water available for irrigation and domestic purpose. Although the environment temperature and air pollution remain within bearable limits, the future development plan of AMA includes such neighborhoods which can reduce the volume of traffic and there is a significant decrease in air pollution [43]. The increase in settlements in the last few decades is a sign that the people have sufficient basic needs available for their growth. According to the MMRA & UNHSP [43], the population of the AMA was 1.24 million in 2019 and it is expected to be 1.5 million by 2030 with an annual growth rate of 3 %. This increase in population is almost 20 % in a decade from 2019 to 2030. Whereas in this research the settlements are predicted to be increased by 26.8 % in the future decade which is well covered under the expected increase in the population. The growth in the industry is also expected to increase at the same rate as the population and the authorities shall be able to manage it as per their development plan.

5. Conclusion

This research was carried out to predict the increase in the settlements in Al Ahsa Metropolitan Area (AMA), Saudi Arabia citing the sharp increase in urban development during the past decade. The historical satellite images were collected from web resources for the past 30 years and image processing and image classification were performed to obtain the land use maps. The data was extracted from the land use maps categorizing it into vegetation, settlement, and barren land areas. It was found that during the past decade there was a sharp increase of 25.5 % in the settlements as compared to the previous decades. The statistical analysis predicted that the area of settlements in the region might reach 350 sq. km. in 2032 which stands at 276 sq. km. in 2022. Also, the increase in settlements over the past decade has caused a decrease in vegetation by up to 18 %. This is a bit of concern and if it continues for another decade, it might harm the environment of AMA. A well-regulated system is required to make this urban development process smooth and environment-friendly. The related government authorities must adopt such measures that should retain and improve the environment along with managing the sustainable development of the area in parallel for the next 10 years. This study aspires to contribute to helping decision-makers and various stakeholders reduce the potential negative effects of excessive growth and allow AMA to grow more sustainably.

Data availability statement

The datasets generated and analyzed during the research are available with the corresponding author and can be furnished upon request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] J. Maes, A. Barbosa, C. Baranzelli, G. Zulian, F. Batista e Silva, I. Vandecasteele, R. Hiederer, C. Liquete, M.L. Paracchini, S. Mubareka, C. Jacobs-Crisioni, C.P. Castillo, C. Lavalle, More green infrastructure is required to maintain ecosystem services under current trends in land-use change in Europe, Landscape Ecol. 30 (3) (2015) 517–534.

[2] M.S. Khan, M. Suhail, T. Alharbi, Evaluation of urban growth and land use transformation in Riyadh using LandSat satellite data, Arabian J. Geosci. 11 (2018) 1–13.

[3] A.F. Alqurashi, L. Kumar, Land use and land cover change detection in the Saudi Arabian desert cities of Makkah and Al-Taif using satellite data, Adv. Remote Sens. 03 (03) (2014) 106–119.

[4] A. Tilahun, B. Teferie, Accuracy assessment of land use land cover classification using Google Earth, Am. J. Environ. Prot. 4 (4) (2015) 193–198.

[5] S.S. Rwanga, J.M. Ndambuki, Accuracy assessment of land use/land cover classification using remote sensing and GIS, Int. J. Geosci. 08 (04) (2017) 611–622.

[6] C. Liping, S. Yujun, S. Saeed, A. Westergaard-Nielsen, Monitoring and predicting land use and land cover changes using remote sensing and GIS techniques-A case study of a hilly area, Jiangle, China. PLoS One 13 (7) (2018) e0200493.

[7] Y. Ren, Y. Lü, A. Comber, B. Fu, P. Harris, L. Wu, Spatially explicit simulation of land use/land cover changes: Current coverage and future prospects, Earth Sci. Rev. 190 (2019) 398–415.

[8] A.K. Abd El Aal, M. Kamel, S.H. Alyami, Environmental analysis of land use and land change of Najran city: GIS and remote sensing, Arab. J. Sci. Eng. 45 (10) (2020) 8803–8816.

[9] P.K. Srivastava, D. Han, M.A. Rico-Ramirez, M. Bray, T. Islam, Selection of classification techniques for land use/land cover change investigation, Adv. Space Res. 50 (9) (2012) 1250–1265.

[10] K. Cegielska, T. Noszczyk, A. Kukulska, M. Szylar, J. Hernik, R. Dixon-Gough, S. Jombach, I. Valánszki, K.F. Kovács, Land use and land cover changes in post-socialist countries: Some observations from Hungary and Poland, Land Use Policy 78 (2018) 1–18.

[11] D.X. Tran, F. Pla, P. Latorre-Carmona, S.W. Myint, M. Caetano, H.V. Kieu, Characterizing the relationship between land use land cover change and land surface temperature, ISPRS J. Photogramm. Remote Sens. 124 (2017) 119–132.

[12] A. Singh, Review article digital change detection techniques using remotely-sensed data, Int. J. Remote Sens. 10 (6) (1989) 989–1003.

[13] B. Turner II, G. Hyden, R. Kates, B. Riddell, Population Growth and Agricultural Change in Africa, J. Peasant Stud. 23 (4) (1996) 186–187.

[14] N.D. Rao, J. Min, R. DeFries, S. Ghosh-Jerath, H. Valin, J. Fanzo, Healthy, affordable and climate-friendly diets in India, Global Environ. Change 49 (2018) 154–165.

[15] E.F. Lambin, Modelling and monitoring land-cover change processes in tropical regions, Prog. Phys. Geography: Earth and Environ. 21 (3) (1997) 375–393.

[16] E.F. Lambin, B.L. Turner, H.J. Geist, S.B. Agbola, A. Angelsen, J.W. Bruce, O.T. Coomes, R. Dirzo, G. Fischer, C. Folke, P.S. George, K. Homewood, J. Imbernon, R. Leemans, X. Li, E.F. Moran, M. Mortimore, P.S. Ramakrishnan, J.F. Richards, H. Skånes, W. Steffen, G.D. Stone, U. Svedin, T.A. Veldkamp, C. Vogel, J. Xu, The causes of land-use and land-cover change: Moving beyond the myths, Global Environ. Change 11 (4) (2001) 261–269.

[17] A. Veldkamp, E.F. Lambin, Predicting land-use change, Agric. Ecosyst. Environ. 85 (1–3) (2001) 1–6.

[18] F. Zeng, Y. Mao, W. Cheng, F. Wu, G. Zhang, Genotypic and environmental variation in chromium, cadmium and lead concentrations in rice, Environ. Pollut. 153 (2) (2008) 309–314.

[19] C.J. Dash, P.P. Adhikary, M. Madhu, S. Mukhopadhyay, S.K. Singh, P.K. Mishra, Assessment of spatial changes in forest cover and deforestation rate in Eastern Ghats Highlands of Odisha, India, J. Environ. Biol. 39 (2) (2018) 196–203.

[20] V. Duraisamy, R. Bendapudi, A. Jadhav, Identifying hotspots in land use land cover change and the drivers in a semi-arid region of India, Environ. Monit. Assess. 190 (2018) 1–21.

[21] P.K. Yadav, M. Kapoor, K. Sarma, Land use land cover mapping, change detection and conflict analysis of Nagzira-Navegaon Corridor, Central India using geospatial technology, Int. J. Remote Sens. GIS 1 (2) (2012) 90–98.
[22] A. Al-Ali, H. Mubarak, The effect of land cover on the air and surface urban heat island of a desert Oasis, Durham Theses, Durham University, < http://etheses.dur.ac.uk/11290/ > (2015).
[23] A.M. Almadini, A.A. Hassaballa, A. Dewan, Depicting changes in land surface cover at Al-Hassa oasis of Saudi Arabia using remote sensing and GIS techniques, PLoS ONE 14 (11) (2019) e0221115.
[24] F.A. Mubarak, Urban growth boundary policy and residential suburbanization: Riyadh, Saudi Arabia, Habitat International 28 (4) (2004) 567–591.
[25] H. Abdelatti, Y. Elhadary, A.A. Babiker, Nature and trend of urban growth in Saudi Arabia: The case of Al-Ahsa province–eastern region, Resour. Environ. 7 (3) (2017) 69–80.
[26] C. Gu, Urbanization: Processes and driving forces, Sci. China Earth Sci. 62 (9) (2019) 1351–1360.
[27] A. Alqahtany, S. Aravindakshan, Urbanization in Saudi Arabia and sustainability challenges of cities and heritage sites: Heuristical insights, J. Cultural Heritage Manage. Sustain. Dev. (2021), In Press.
[28] M.E. Hereher, A.M. Al-Shammari, A.S. Abd, E.,, Land cover classification of Hail-Saudi Arabia using remote sensing, Int. J. Geosci. 3 (2012) 349–356.
[29] R. Jamil, Digital Elevation Modeling Analysis for Investigation of Gravity Hill Phenomena, Int. J. 3-D Inform. Modeling 7 (3) (2018) 25–38.
[30] R. Jamil, GIS-Based Watershed Analysis for Water Storage Facilities in Underdeveloped Areas: Case of a Gravity Hill in Saudi Arabia, Handbook of Research on Driving Transformational Change in the Digital Built Environment, IGI Global (2021) 164–178.
[31] A. Qasem, R. Jamil, GIS-Based Financial Analysis Model for Integrated Maintenance and Rehabilitation of Underground Pipe Networks, J. Perform. Constr. Facil 35 (5) (2021) 1–8.
[32] E. Albalawi, A. Dewan, R. Corner, Spatio-temporal analysis of land use and land cover changes in arid region of Saudi Arabia, Int. J. GEOMATE 14 (44) (2018) 73–81.
[33] P.S. Sisodia, V. Tiwari, K.A. Dahiya, Urban Sprawl Monitoring Using Remote Sensing and GIS Techniques of the City Jaipur, India, Int. J. Appl. Geospatial Res. 7 (3) (2016) 93–104.
[34] A. Amin, E.S.A. Seif, Environmental hazards of sand dunes, South Jeddah, Saudi Arabia: An assessment and mitigation geotechnical study, Earth Syst. Environ. 3 (2019) 173–188.
[35] H. Barth, Desertification in the eastern province of Saudi Arabia, J. Arid Environ. 43 (4) (1999) 399–410.
[36] A.A. Amin, The extent of desertification on Saudi Arabia, Environ. Geol. 46 (2004) 22–31.
[37] S.M. Jain, Date palm biotechnology: Current status and prospective - an overview, Emirates J. Food Agriculture 24 (5) (2012) 386–399.
[38] Y. Aldakheel, A. Al-Hussaini, The use of multi-temporal LandSat TM imagery to detect land cover/use changes in Al-Hassa, Saudi Arabia, Scientific J. King Faisal Univ. (Basic and Appl. Sci.) 6 (1) (2005) 111–126.
[39] A. Allbed, L. Kumar, P. Sinha, Mapping and modelling spatial variation in soil salinity in the Al Hassa Oasis based on remote sensing indicators and regression techniques, Remote Sens. 6 (2014) 1137–1157.
[40] S. Alqarni, A. Babiker, A. Salih, Detection, mapping and assessment change in urban and croplands area in Al-Hassa oasis, Eastern region in Saudi Arabia using remote sensing and Geographic Information System, J. Geographic Inform. Syst. 10 (6) (2018) 659–685.
[41] Y.Y. Aldakheel, Assessing NDVI spatial pattern as related to irrigation and soil salinity management in Al-Hassa Oasis, Saudi Arabia, J. Indian Soc. Remote Sens. 39 (2) (2011) 171–180.
[42] A. Salih, Classification and mapping of land cover types and attributes in Al-Ahsaa Oasis, Eastern Region, Saudi Arabia using LandSat-7 data, J. Remote Sens. GIS 7 (1) (2018) 228–234.
[43] MMRA & UNHSP, Al Ahsa City Profile: Future Saudi Cities Programme, Ministry of Municipal and Rural Affairs and United Nations Human Settlements Programme, ISBN: 978-603-8160-99-2, 2019.
[44] SPA, Guinness Registers Al-Ahsa as World Largest Oasis, Saudi Press Agency, < https://www.spa.gov.sa/viewfullstory.php?lang=en&newsid=2142837 > (2020).
[45] M. Li, S. Zang, B. Zhang, S. Li, C. Wu, A review of remote sensing image classification techniques: the role of spatio-contextual information, Eur. J. Remote Sens. 47 (2014) 389–411.
[46] C.M. Escape, M.K. Alemania, P.K. Luzon, R. Felix, S. Salvosa, D. Aquino, R.N. Eco, A.M.F. Lagmay, Comparison of Various Remote Sensing Classification Methods for Landslide Detection using ArcGIS, Project NOAH Open-File Reports 3 (2014) 22–27.
[47] A.N. Soni, Spatial Context Based Satellite Image Classification - Review, Int. J. Sci. Res. Eng. Dev. 2 (6) (2019) 861–868.
[48] C.B. Pande, K.N. Moharir, S.F.R. Khadri, S. Patil, Study of Land Use Classification in an Arid Region Using Multispectral Satellite Images, Appl. Water Sci. 8 (123) (2018) 1–11.
[49] M.A. Oyekola, G.K. Adewuyi, Unsupervised Classification in Land Cover Types using Remote Sensing and GIS Techniques, Int. J. Sci. Eng. Invest. 7 (72) (2018) 11–18.
[50] P. Lemenkova, ISO Cluster Classifier ArcGIS for Unsupervised Classification of the LandSat TM Image of Reyjavik, Bull. Natl. Sci. Res. 11 (1) (2021) 29–37.
[51] USGS, The United States Geological Survey, Official website, < https://earthexplorer.usgs.gov/ > (2022).
[52] P.S. Sisodia, V. Tiwari, A. Kumar, Analysis of Supervised Maximum Likelihood Classification for Remote Sensing Image, IEEE International Conference on Recent Advances and Innovations in Engineering - ICRAIE, May 9-11, Jaipur, India, 2014.