ORIGINAL PAPER

Assessing spatio-temporal changes of soil moisture: a case study at Karachi, Pakistan

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Abstract
The soil moisture is an important component in the plant's growth that decreases with time. Soil moisture content relies on climate change, urban heat island (UHI), and population. The purpose of the investigation is based on the soil moisture changes that are with different prospective in which soil moisture index (SMI) with normalized difference vegetation index (NDVI), SMI with land surface temperature (LST), and SMI with LST and NDVI involved. Similarly, the satellite images of Landsat 8 OLI/TIRS (Operational Land Imager/Thermal Infrared Sensor) and Landsat 4-5 TM (Thematic Mapper) were based on examination and co-operate the RS/GIS techniques. All satellite data images were downloaded from the website of earthexplorer. The ERDAS IMAGINE 9.2, Microsoft Excel, and ArcGIS 10.3.1 software from diverse techniques were adopted like LST, SMI with LST, SMI with LST and NDVI, NDVI, SMI with NDVI, and LST with NDVI and all of the graphs were developed except LST and LST with NDVI. The study concludes that the SMI with LST decreased reasons of LST increased plus SMI with NDVI and SMI with LST and NDVI both increased in the review area, and all changes were examined from the images (1992 and 2019) comparisons. Furthermore, all of the changes graphically observed the high values of the no-change classes.

Keywords Soil moisture · Temporal changes · GIS/remote sensing · Satellite images · Karachi district

Introduction

The soil moisture is the water or moisture quantity present in the space of the soil particles (Sharma et al. 2018; Wikipedia Water Content 2019; Umar et al. 2011; Schmitz 2019). On the different regions, the soil moisture varies and its distinct depths in soil particles. Infiltration is a natural process in soil that generates through rainwater or alternative kinds of storage water (Boersma et al. 1971). According to the soil moisture properties and limited scale on the drainage pattern changes, the variable of soil moisture is heterogeneous (Umar et al. 2016; Copernicus Global Land Service 2019). During the rainfall season, the quantity of moisture in the soil exceeds and looses evapotranspiration as well streams and groundwater to drainage. However, moisture content depleted and evapotranspiration rates are high in the summer season.

The soil in which infiltration capacity depends on the properties of soil as well as it can be changed according to the weather condition. During hot and dry weather, the infiltration of water limits to crust additional, extreme cold season in which infiltration decrease or stop causes of soil freeze (COSMOS-UK 2019). The soil moisture is an important component of the plant's growth, soil erosion, and soil stability (Khan et al. 2018). The soil moisture is affected through precipitation, temperature, characteristics, etc. (Ali et al. 2015). All these factors aid to develop a useful field for the flourishing vegetation (Zahid et al. 2014). The water amount on the surface soil is the upper 10 cm, while in the upper 200-cm zones of the plant's roots (Hunt et al. 2009; Soil Moisture 1999; Drought.gov 2019).

The soil in which water status disclosed the volumetric moisture amount and capillary potential in soil pores to held moisture (Taktikou et al. 2016). When the soil in a large quantity of moisture/water presences so, the soil is too wet and it has increased capillary potential. The soil is in which the flow water process dependent on the hydraulic gradient potential

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(sums of the potentials of capillary and elevation). The properties of soil physically are indicated in the terms of a parameter called the hydraulic conductivity; further, it is modified in a nonlinear way with the soil moisture. Hence, the soil moisture in which solutes temperature and chemical concentration differences are the movements of water in soil causes (Encyclopedia 2019).

The plant's health relies on the supply of soil moisture and soil nutrients (Zakir 2018). The availability of soil moisture declines with times and it is with disrupted vegetation growth (Younis and Iqbal 2015). Furthermore, crops yield decreased due to climate changes and it is with the moisture availability (Saha et al. 2018; Potić et al. 2017; Earth Science Week 2019). Further, the population is exacerbating with the passage of times, so it is with urban heat island (UHI) increases and it is the reason for climate change (Shah and Ghauri 2015; Lemonsu et al. 2015; Ningrum 2018). Similarly, UHI reduces the soil moisture because of this zone on the fewer vegetation covers that support less soil moisture (Chaudhry et al. 2015). Thus, day by day exceeding UHI, it is with high response on the soil moisture that is very dangerous for the vegetation growth of the future (Durrani et al. 2017).

The soil moisture is related commonly definition known that is the water content present in the soil that is the help to the growth of vegetation but we don't know it's degrading with the passage of times and in this review, we will find the factors in the study zone that's decrease the soil moisture. Hence, the soil moisture was monitored through the diverse ideas and its valuable research for the future of the researcher's causes of the study helped in the probable sites for the vegetation growth.

The research is based on the analysis of soil moisture changes with various prospective in which included soil moisture index (SMI) with normalized difference vegetation index (NDVI), SMI with land surface temperature (LST), and SMI with LST and NDVI. Further, the UHI is estimated through LST and it also has changing studies as well; vegetation covers and LST with vegetation cover changes are evaluated. Additionally, all changes examine through statistical graphs except to LST and LST with vegetation covers. However, all analyzation in which uses RS/GIS techniques through diverse perceptions.

The problem statement and research gap are that this review studies the problems of soil moisture with its different aspects and elaborates the changes as well various new techniques that are very less used while in other researches, they only studied soil moisture. Additionally, the main gap of this research through filled is that the further deeply study soil moisture as soil moisture with vegetation, soil moisture with LST, and soil moisture with LST and vegetation and these other researches less studied. Similarly, the main problem of soil moisture decrease that is the reason of UHI increase, plus it's the vegetation growth effected and it's also defined in the research.

The soil moisture in many researches was conducted in different ways, but most commonly, the soil moisture was found with the land surface temperature (LST). However, in this study, soil moisture is detected with LST but it is also measured with the vegetation cover and the land surface temperature with vegetation cover that is the new unique analysis. Furthermore, the soil moisture measurement diagnosed that is the moisture quality decreased reasons of where the LST high and it's help can be examine high probable locations for vegetation covers growth evaluates where it's for the high amount of soil moisture exist. The soil moisture about detailed comprehensive knowledge examine in this review and the ground reality of the study zone probe additional, it becomes easier to the soil moisture problem understand. Similarly, the information find in the research about the soil moisture resolves problems and it is the best probable treatments investigates.

The study area

Karachi district is the review study area, and Pakistan is the famous biggest urban civic (Fig. 1). Karachi district is located around the seas of Arabia, and it is known as the capital of Sindh province (Ghazal et al. 2016; World Population Review Karachi Population 2018). Hence, it is situated around the 24.8607° N latitude and 67.0011° E longitude (Mahboob et al. 2015). Karachi city is the sixth rank of the most populated cities in the world with 14.91 million population recorded in the 2017 census of civic, and Pakistan is of the first highest populated metropolitan (Wikipedia Demographics of Karachi 2018). Globally, the population of metropolitan is rapidly exceeding with times and its population dispersed unevenly on the divergent regions. The city population is growing exponentially with the passage of times as well; its total zones about 3780 km^2. All over the global cities, Karachi city is beta ranked and third well-known civic. Pakistan in which premier metropolitan is Karachi in commercial and industries core and it's most cosmopolitan (Wikipedia Karachi 2018). In the South zones of the Sindh, province city located and its surrounded regions the Arabian Sea of coastline meets (Khan and Omar 2014). Similarly, the civic sea support to transport hub, and it has seaports that are the biggest and engaged (Sajjad et al. 2015). Karachi and Bin Qasim ports are two famous seaports in the city. Karachi is also known as the economic hub of Pakistan that shares 70% of the country's revenue. Furthermore, the civic is commonly recognized with the name as "city of lights" (Qureshi 2010; Population of 2018 Karachi Population 2018 2017).

There are three main river basins in the Karachi district as Hub, Lyari, and Malir rivers as well as the Hub river of the location which from it runs the Hub dam and it lies the city of the northwestern side (Fig. 2a). Hence, the Lyari river is the seasonal stream and this is in the city center from flows whereas, is also the Malir river known as the seasonal stream and it is
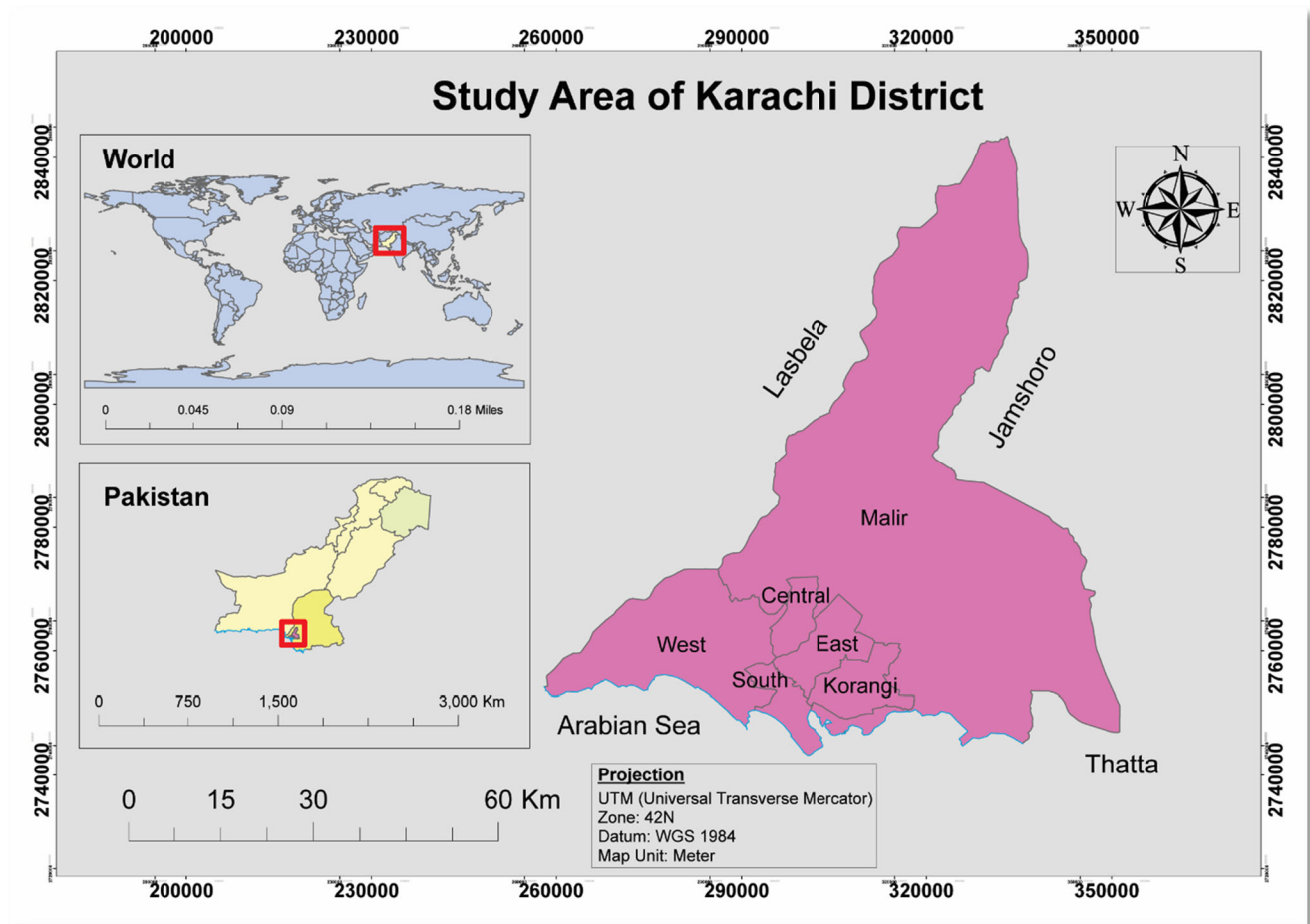
Fig. 1 Study area location of Karachi district

passes from the eastern side of the city, plus these all rivers drains into the Arabian Sea (in the south situated). Further, the Karachi city of the coastal region is located in the hills, scattered rocks outcroppings, and coastal marshlands and the various islands situated in the coastal zone. The civic of the coastline harbor surrounded lies the dense mangroves forests creeks which is the natural barrier and its brackish water in grows as well as its spreads towards the Indus River Delta of the southeast. In the west zone of the city lies Cape Monze which has a locally popular name Ras Muari and its areas of characterization are sea cliffs, beaches undeveloped, and rocky sandstones promontories. There are two small mountain ranges in the city like the Khasa hills and the Mulri hills, and these northwest sides are located, whereas these hills are the barrier between the North Nazimabad town and the Orangi town. Furthermore, these hills are barren and it is the Kirthar range parts that is the larger range and it has a maximum elevation of about 528 m (1732 ft). Similarly, the city of various rivers, geography, biogeomorphology, and geology is all important in the soil moisture scale level that has helped to its increase and decrease. The sedimentary rock type is most commonly located in Karachi city, and its geological ages of rocks are tertiary periods.

The sub-tropical zones on situated Karachi district and its region and climate are commonly known as arid. The long summer season is dominated in the city and mostly climate effects related to the Arabian Sea (in south lies). The metropolis climate that is mild and mostly in July to September months is common in the monsoon seasons. Hence, less annual average level recorded about 250 mm of precipitation while its highest monthly rainfall around 429.3 mm. In the metropolitan, summer weather months are April to October, and November to March months dominate winter seasons. The highest temperature in the city is estimated at approximately 48 °C and a minimum of about 0 °C (Wikitravel Karachi 2018) (Fig. 2b).

Materials and methods

In the direction of exploration, the divergent types of data are collected in the "Materials and methods" section. The data inquired through satellite images were downloaded from the source of the earthexplorer website (Table 1). Similarly, research is in which different kinds
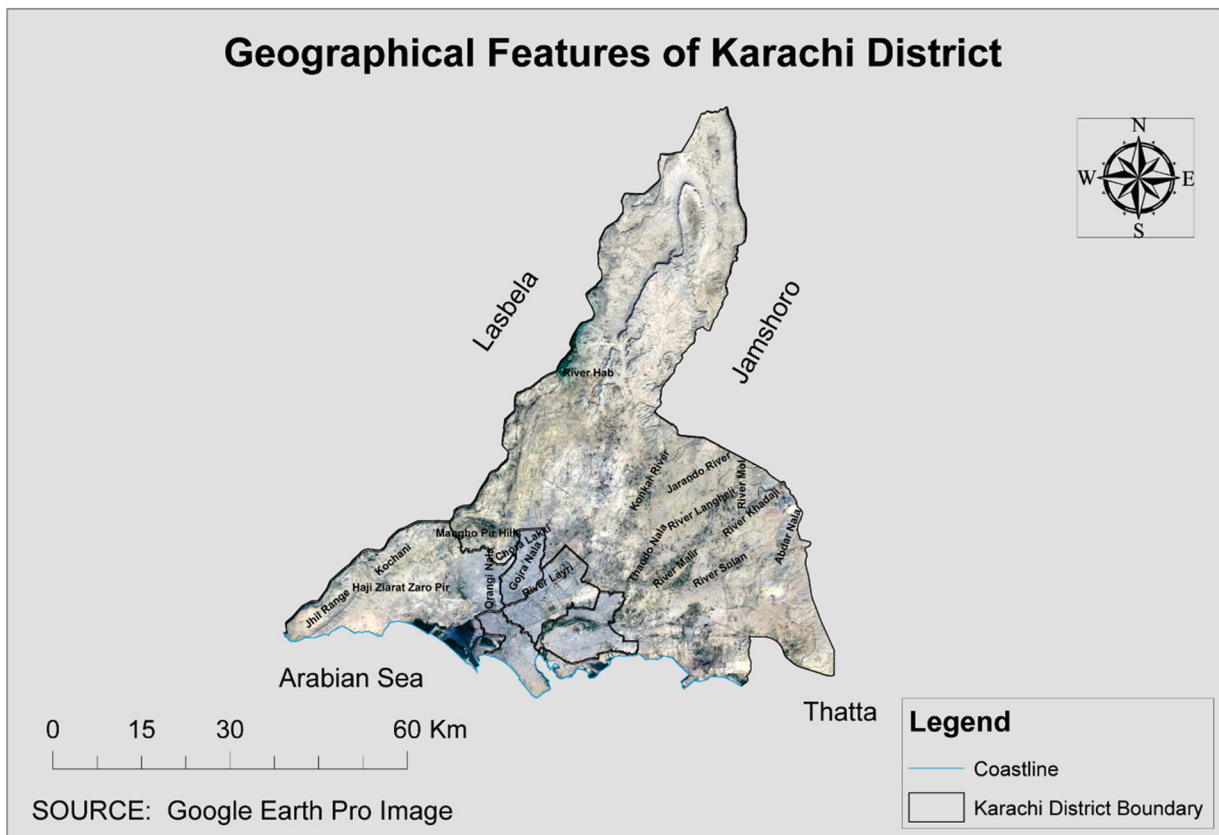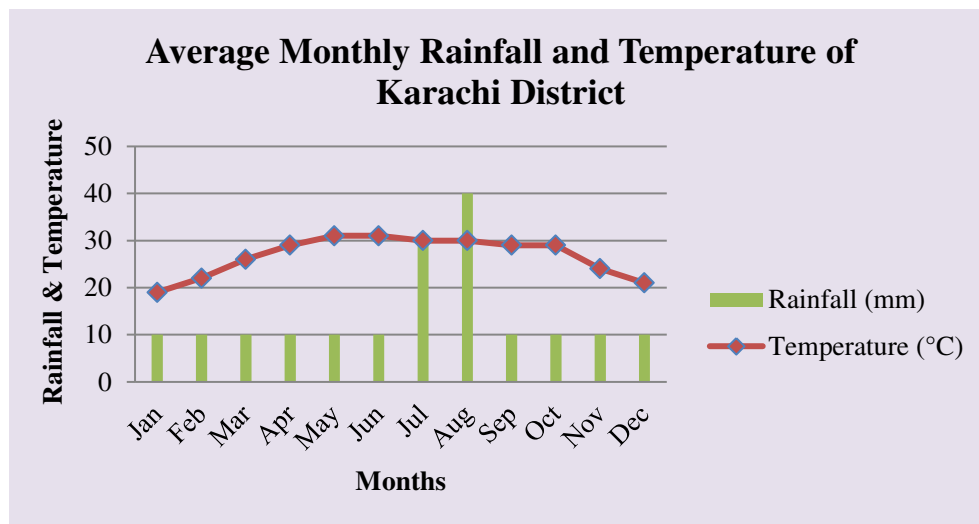
Fig. 2 a, **b** Geographical features and average monthly rainfall and temperature of study zone Karachi district graph

of data are used (Table 2). The methodological frame-
work is interpreted in Fig. 3. Furthermore, the research
methods processes in which various normes are using as

qualitative and quantitative and these are expresse in dif-
ferent aspects such as diverse techniques and distinct
formulas.

Table 1 Diverse parameters types of satellite data with its distinct properties and years of data gets

Parameter	Spatial resolution	Temporal resolution	Spectral resolution	Areal swath	Availability	Years	Pixel size	Thermal band
Landsat 8 OLI/TIRS	30 m (band 8 = 15 m) (bands 10 and 11 = 100 m)	16 days	10 bands	185 km	16 days	2019	30 m	100 m
Landsat 4-5 TM	30 m (band 6 = 120 m) (band 8 = 15 m)	16 days	7 bands	185 km	16 days	1992	30 m	120 m

Software

In the research of result examination, the various software are ERDAS IMAGINE 9.2, Microsoft Excel, and ArcGIS 10.3.1. Similarly, these software were used for the distinct purposes and various techniques of software adopted for the enhancement of results (Table 3). Further, the satellite data of Landsat 8 OLI/TIRS and Landsat 4-5 TM images on both the same techniques of software were used.

Processing of images

The best result improvement of images used various processes, and these processes included the following: layer stacking, subset development, LST with interpolation (IDW) and contour methods, supervised classification, matrix through change detection, and mosaicking. Furthermore, other processes illustrated are below:

Distinct indexes

The distinct kinds of indexes explained below were used in the study area:

NDVI The formula of NDVI in which adopted the layers or bands of Landsat 8 OLI/TIRS image as 4 and 5 represents red and NIR (near-infrared) bands. However, the NDVI formula can be expressed is:

$$NDVI = (NIR{-}Red)/(NIR + Red) \tag{1}$$

Thus, identical above formula follows on Landsat 4-5 TM image but layers change as 3 and 4 expresses red and NIR (near-infrared) bands.

Table 2 Data collection kinds in different formats as raster and vector formats on the satellite and shapefile data

Raster	Vector
Landsat 8 OLI/TIRS C1 Level-1 image 2019	Karachi district shapefile
Landsat 4-5 TM C1 Level-1 image 1992	

The ranges are − 1 to + 1 of the index values.

SMI The image of Landsat 8 OLI/TIRS from progressed LST for the SMI formula is given below:

$$SMI = (LSTmax{-}LST)/(LSTmax{-}LSTmin) \tag{2}$$

The same above formula applies to the Landsat 4-5 TM image of SMI.

Similarly, NDVI and LST with NDVI image layers (Landsat 8 OLI/TIRS and Landsat 4-5 TM images) on the same above formula were used. The ranges are 0 to 1 of the index values.

LST LST process in which the first step to the convert digital numbers into the radiance that's for using the constant values from the metadata file of the Landsat 8 OLI/TIRS image. So, radiance formula in which adopted layers 10 and 11 (thermal bands) of image and formula is given by:

$$Radiance = Radiance\ multiplicative\ layer \times LayerX$$
$$+ Radiance\ additive\ layer \tag{3}$$

Hence, convert radiance into SBT (satellite brightness temperature) for used the same above image of layers 10 and 11 and the metadata file from constant values adopted. The SBT or LST formula can be expressed as:

$$SBT = Thermal\ conversion\ constant(K2)/ln \tag{4}$$
$$\{Thermal\ conversion\ constant(K1)$$
$$/LayerXradiance + 1\}{-}272.15$$

Furthermore, both 10 and 11 layers from the SBT average were obtained.
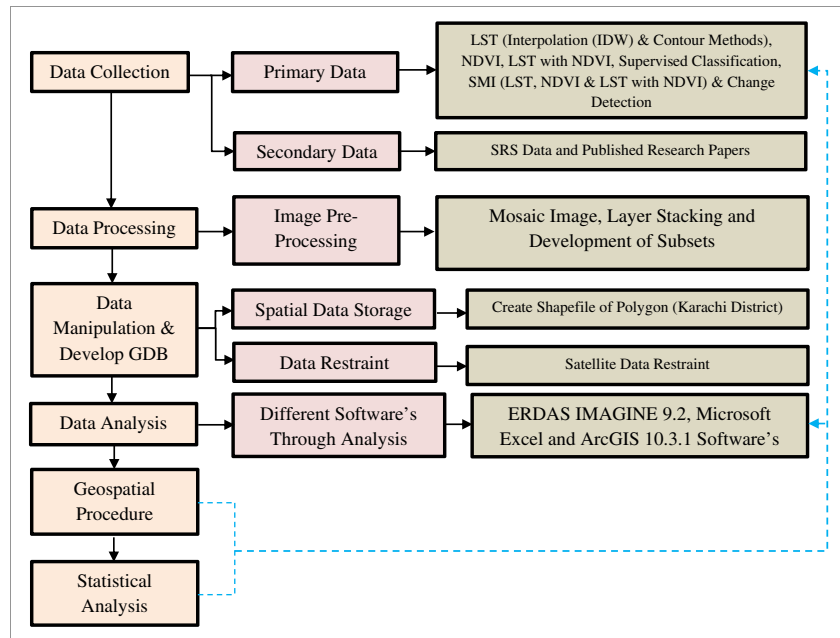
The identical above all formulas follows on the Landsat 4-5 TM image but band 6 used and its metadata file from constant values adopted.

LST with NDVI First NDVI layer of Landsat 8 OLI/TIRS image through extracted values of Pv (proportion of vegetation) and its formula is:

$$Pv = (NDVI{-}NDVImin/NDVImax{-}NDVImin)^2 \tag{5}$$

Fig. 3 Methodological framework of the study

Similarly, calculated e (land surface emissivity) and its formula are given below:

$$e = 0.004 \times Pv + 0.986 \qquad (6)$$

The LST with NDVI formula adopted average layer of LST or SBT of the Landsat 8 OLI/TIRS image. Further, both 10 and 11 layers of average used in formula and formula are as follows:

$$LST\,with\,NDVI = SBT/1 + Layers$$
$$\times (SBT/14380)x\ln(e) \qquad (7)$$

Further, the same above formulas apply to the Landsat 4-5 TM image and its NDVI, layer 6, and LST raster layers used in formulas.
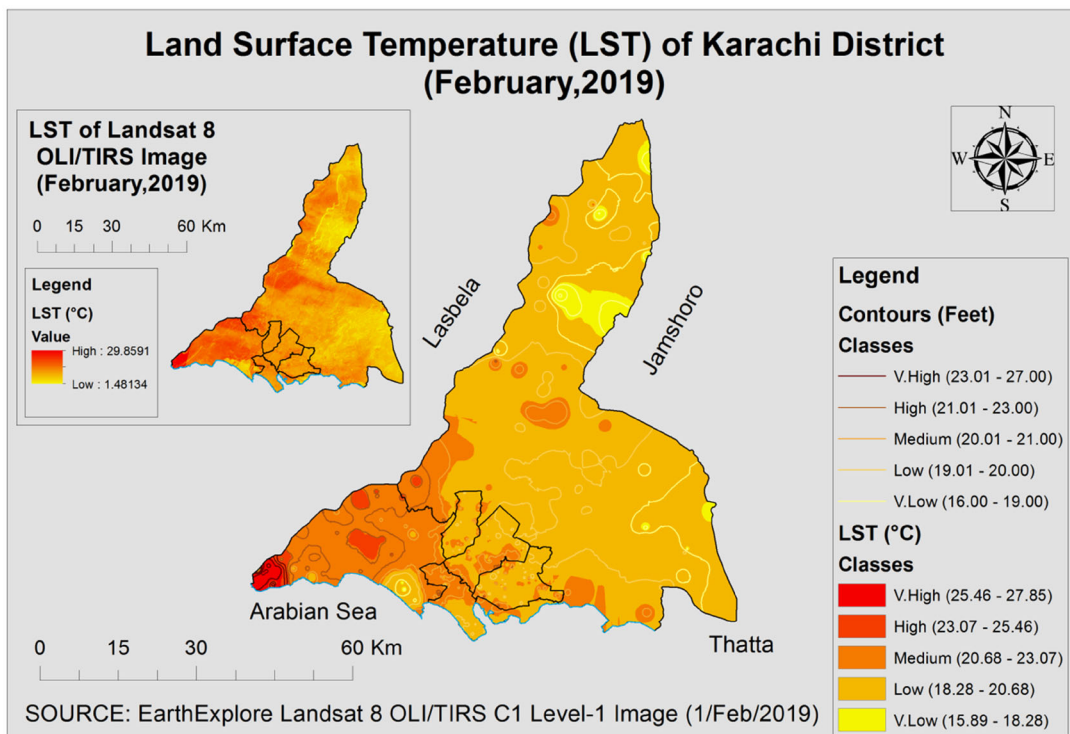
Results and discussions

The analysis of the study region based on the spatio-temporal changes of soil moisture with various aspects as well, these all changes elaborated on 27 years of differences. Further, review of all investigations in which used divergent techniques, and these techniques involved LST. LST defined the temperature of ground surface areas; it is used in the population settlement fields for the temperature detection of these zones (Figs. 4a and b). Hence, LST flourished from the sensor of thermal, and it illustrated the UHI as well as it is established with GIS tools. In LST changes, it was found that the LST decreased with the passage of times such as 1992 in the very high value of 30.64 °C and 2019 in very high value of 27.85 °C. However, the LST maps with small layouts expressed the LST without IDW (inverse distance weighted) and contour methods, while the

Table 3 Various software methods described that has helped in result enhancement

| S. no.	ERDAS IMAGINE 9.2 software	ArcGIS 10.3.1 software	Microsoft Excel software
1	Mosaic	Layer stacking	Graphs developed (NDVI, SMI with NDVI, SMI with LST, and SMI with LST and NDVI)
2	Supervised classification (NDVI, SMI with NDVI, SMI with LST and SMI with LST and NDVI)	Subset development	
3	Matrix through change detection	Land Surface Temperature (LST)	
4		Normalized difference vegetation index (NDVI)	
5		LST with NDVI	
6		Soil moisture index (SMI) with LST	
7		SMI with NDVI	
8		SMI with LST and NDVI	
9		All raster images of map layouts progressed	
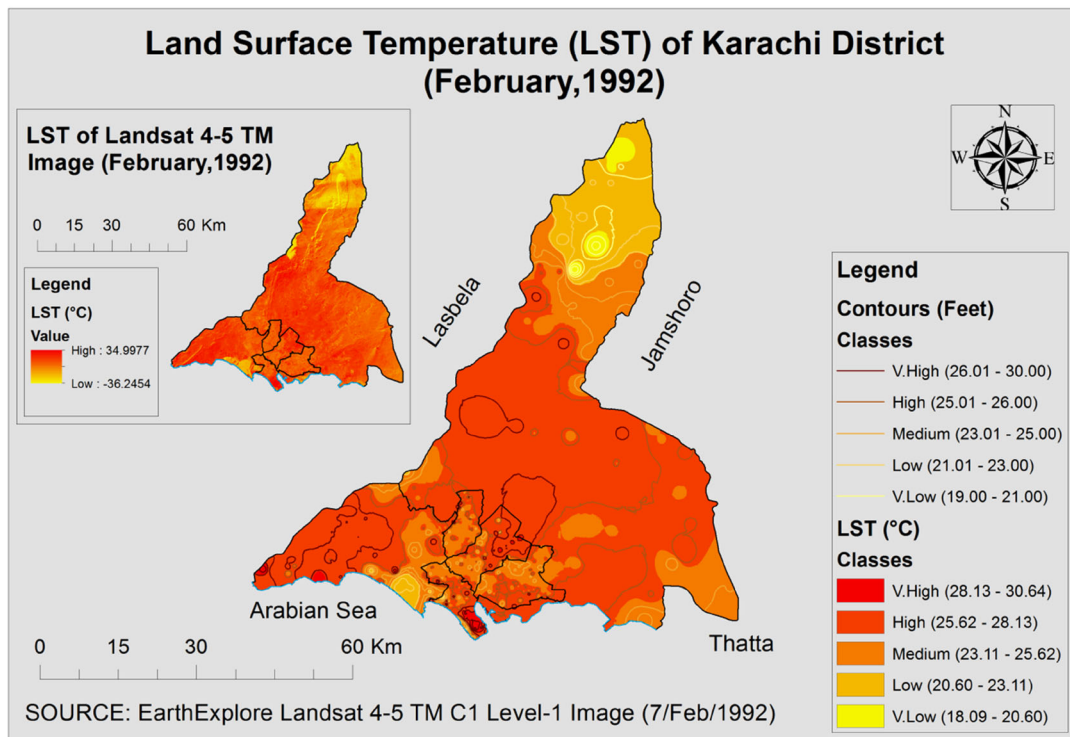
a

b

Fig. 4 **a**, **b** Land surface temperature (LST) of Karachi district (1992 and 2019) maps represents distinct classes names and values

a

b

c

d
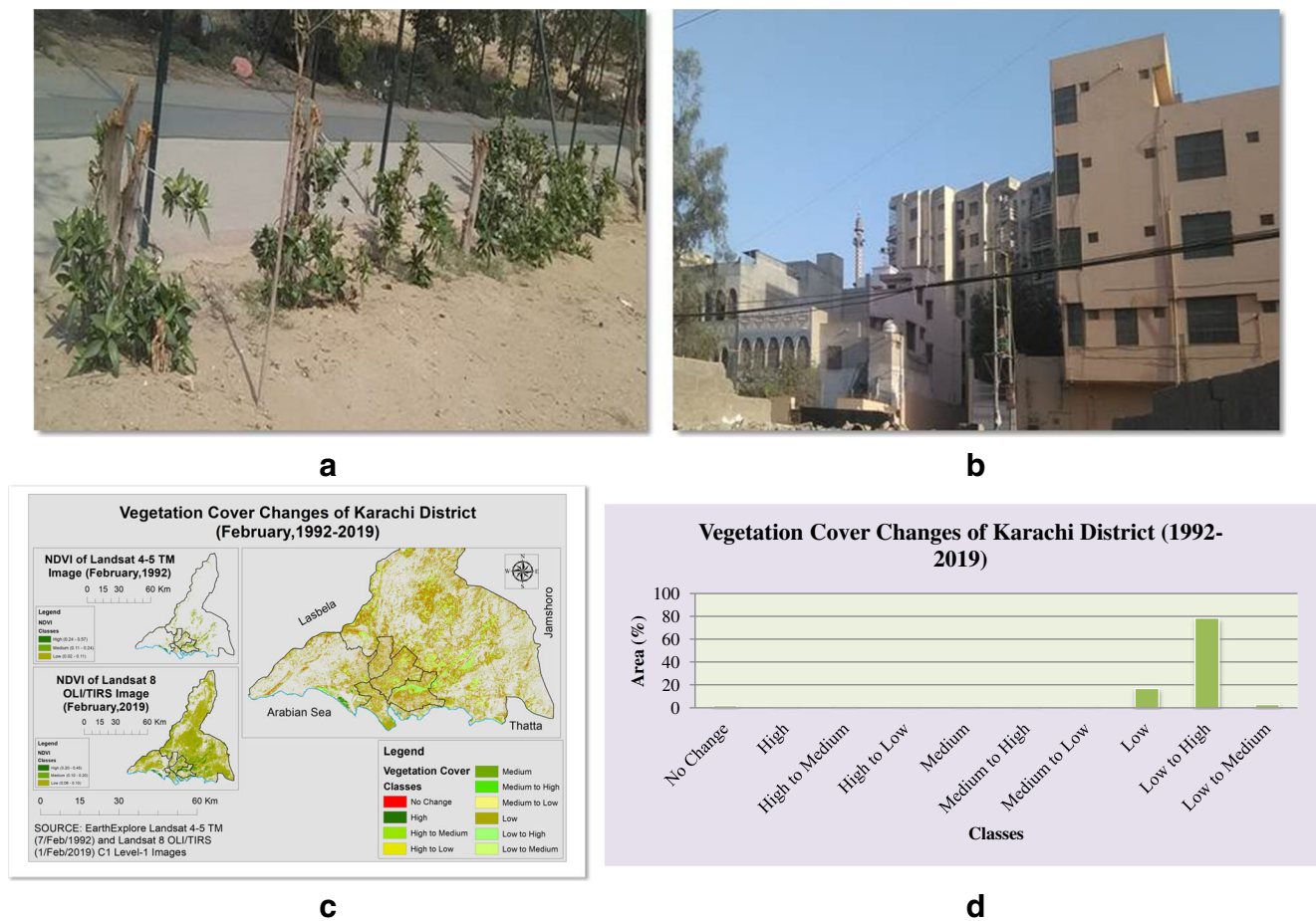
Fig. 5 **a**, **b** Deforestation trees and urban settlement of Karachi district. **c** Vegetation cover changes of Karachi district (1992–2019) map show various class names and small layouts in original NDVI images as they are referred with class names and values. **d** Vegetation cover changes (1992–2019) graph-based on different class names and its area (%)

main part maps showed that the LST with interpolation process (IDW) and also contours developed with the data usage of the LST with IDW. The LST was without IDW and contour methods as well as with processes both in the small changes in the values, whereas both have the same results. Similarly, LST (without IDW and contour methods) also described that the LST decreased with times like in 1992 high value of 34.9977 °C and 2019 in high value of 29.8591 °C. On January 21, 2019, the rainfall occurred approximately 33 mm on the study zones that are the reasons for LST decreased while, the image data have February 1, 2019 acquired and the atmospheric temperature was recorded 22 °C (AccuWeather Karachi weather 2019).

The vegetation cover explained the natural floras zones on the distinct fields of the Earth's surface as well, natural and human planted crops or greeneries both included in vegetation covers (Fig. 5c). The map developed with the support of geospatial techniques. The NDVI raster images of Landsat 8 OLI/TIRS and Landsat 4-5 TM on both the supervised classification processes proceeded then inquired changes. The vegetation cover changes were

determined on the study zones, and they were for adopted the change detection process from the ERDAS IMAGINE 9.2 software. Further, the vegetation cover changes observed from the two small layouts maps that are it has decreased with times as in 1992 high (0.24–0.57) and in 2019 high (0.20–0.45) because of deforestation and more population settlement regions exceeds (Fig. 5a and b).

Similarly, the vegetation cover changes of the graph progressed and this graph examined that the high changes have the low to high class (Fig. 5d), while the fewer changes have high to low, medium to high, and high to medium classes.

The difference between the LST and land surface temperature with vegetation cover (LST with NDVI) is that the LST detects the temperature of population zone surface, while its opposite LST with NDVI calculates the vegetation areas of temperature (Fig. 6a and b). The map was examined with the thermal sensor of LST and created through GIS modes. Furthermore, these maps were promoted from LST (without IDW and contour processes) and NDVI raster images. Hence, the LST with NDVI changes have elaborated that it declined as in 1992 high amount of 34.9946 °C and in 2019 high value
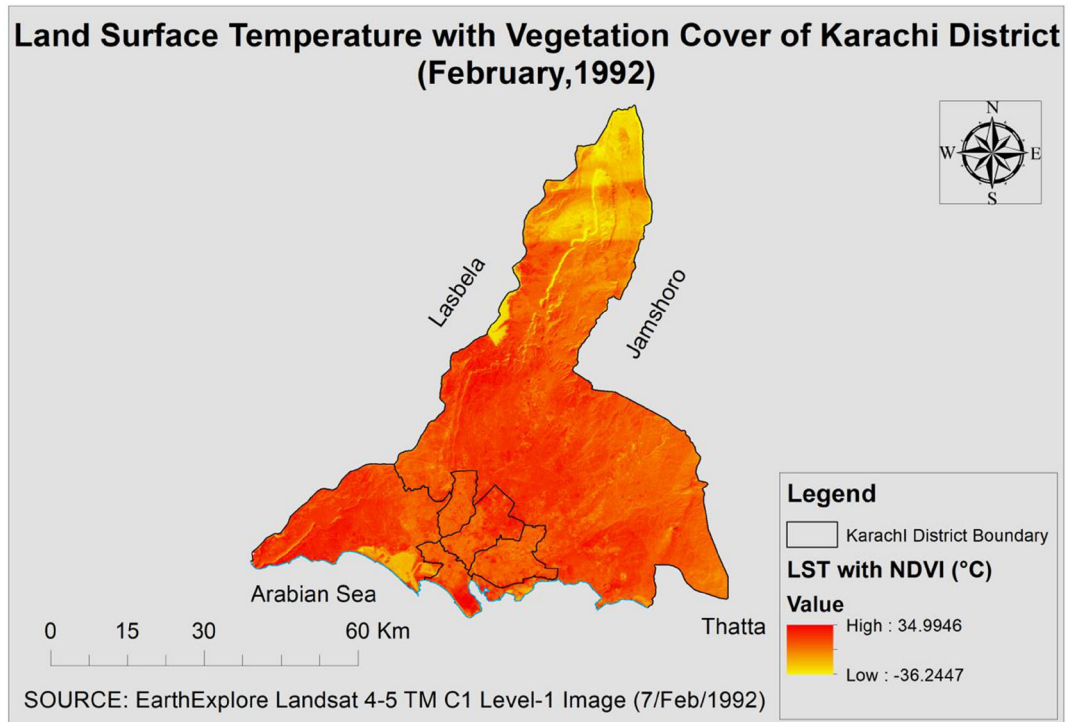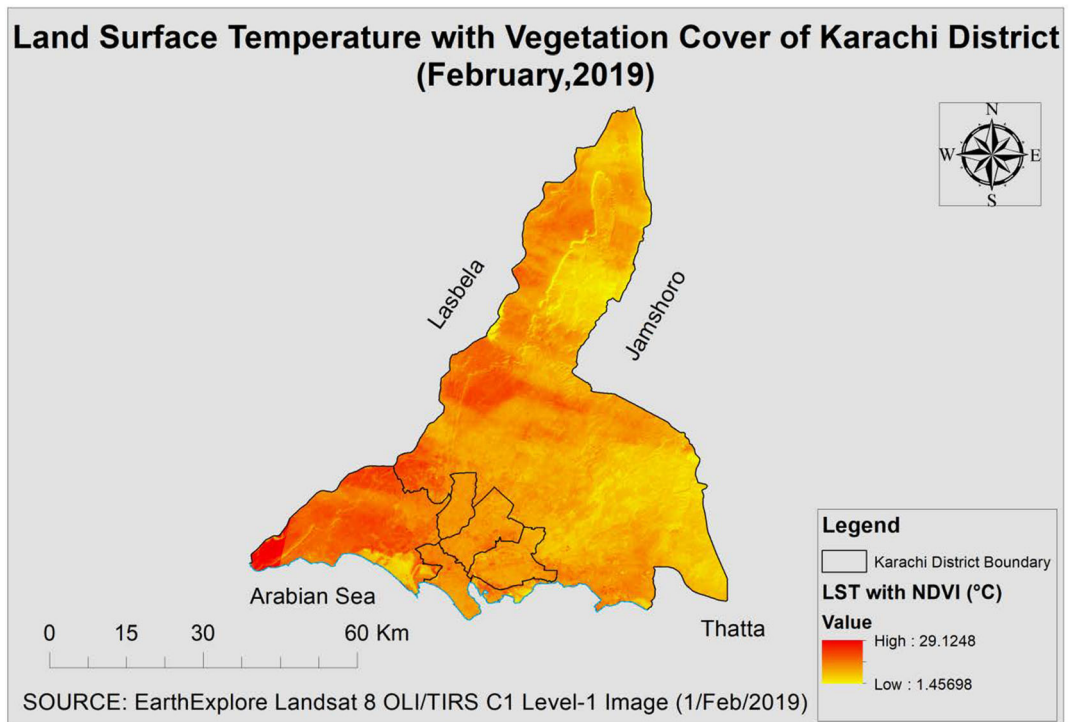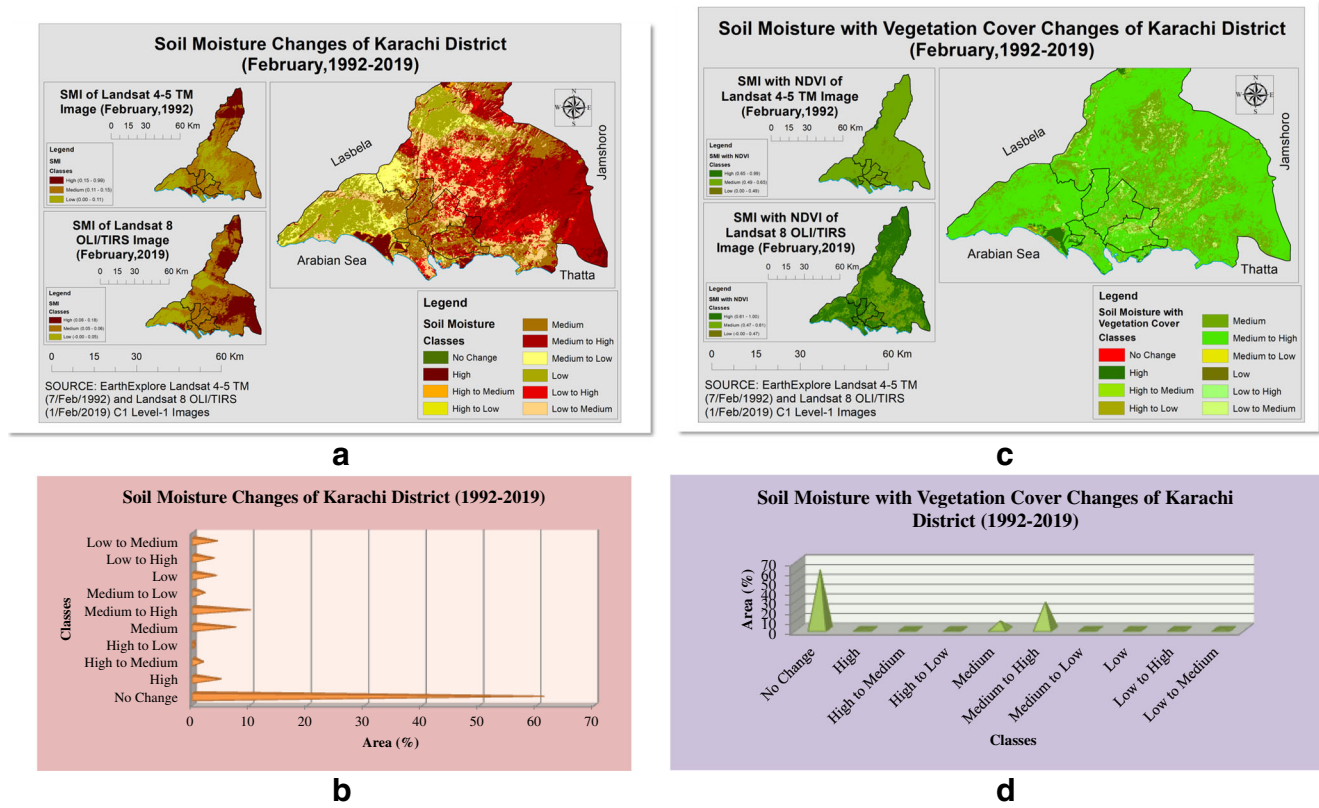
Fig. 6 a, **b** Land surface temperature with vegetation cover of Karachi district (1992) and (2019) maps

a

c

b

d

Fig. 7 **a** Soil moisture changes of Karachi district (1992–2019) map defined with distinct class names and small layouts in original SMI images with class names and its values. **b** Soil moisture change (1992–2019) graph and it is elaborated with various class names as well as its area in percentage measured. **c** Soil moisture with vegetation cover changes (1992–2019) map and its small layouts in original SMI with NDVI images are shown with class names and its values. **d** Soil moisture with vegetation cover change (1992–2019) graph

of 29.1248 °C; reasons of the vegetation cover decreased and the urban sprawl increased.

Similarly, the SMI illustrated the water or moisture amount in the soil particles. The SMI is measured with LST that described the soil temperature (Fig. 7a). Further, the SMI developed with the LST (without interpolation (IDW) and contour techniques) raster layers and the cooperation of the geoinformatics methods. The SMI raster layers images of Landsat 8 OLI/TIRS and Landsat 4-5 TM on both the supervised classification technique proceeded then examined changes. SMI changes inquired from the change detection mode and its two small maps of images differentiation through found that it is diminished such as in 1992 high range values (0.15–0.99) and in 2019 high range values (0.06–0.18) because of the population settlements zones increased with times.

The soil moisture changes of the graph elaborated the high value of the no-change class while fewer changes of the high to low class (Fig. 7b).

Hence, the soil moisture with vegetation cover is investigated in the review region and it is demonstrated the vegetation areas of the soil quality (Fig. 7c). SMI with NDVI progressed with the NDVI raster layers and with the help of the GIS procedures. The SMI with NDVI raster images of Landsat 8 OLI/

TIRS and Landsat 4-5 TM on both the supervised classification processes proceeded then investigated changes. SMI with NDVI changes was diagnosed through the technique of the change detection, whereas its two small layout image comparisons explained that it is increased as in 1992 high values (0.65–0.99) and 2019 high values (0.61–1.00).

SMI with NDVI changes of graph explained the high values of the no-change class while the fewer changes of the high to low class (Fig. 7d).

On the other side, the soil moisture with land surface temperature and vegetation cover is analyzed and measured the moisture amount of temperature of the vegetation zones of soil (Fig. 8a). SMI with LST and NDVI was promoted through LST with NDVI raster layers and the aids of GIS tools. Similarly, the SMI with LST and NDVI changes elaborated from the two tiny layout maps that are described is increased with times like in 1992 in high value ranges (0.15–0.99) and 2019 in high value ranges (0.35–1.00). The raster layers of SMI with LST and NDVI images of Landsat 8 OLI/TIRS and Landsat 4-5 TM on both the supervised classification method applied then investigated changes. Furthermore, the SMI with LST and NDVI changes probed through the change detection method which is practiced in the ERDAS IMAGINE 9.2 software.
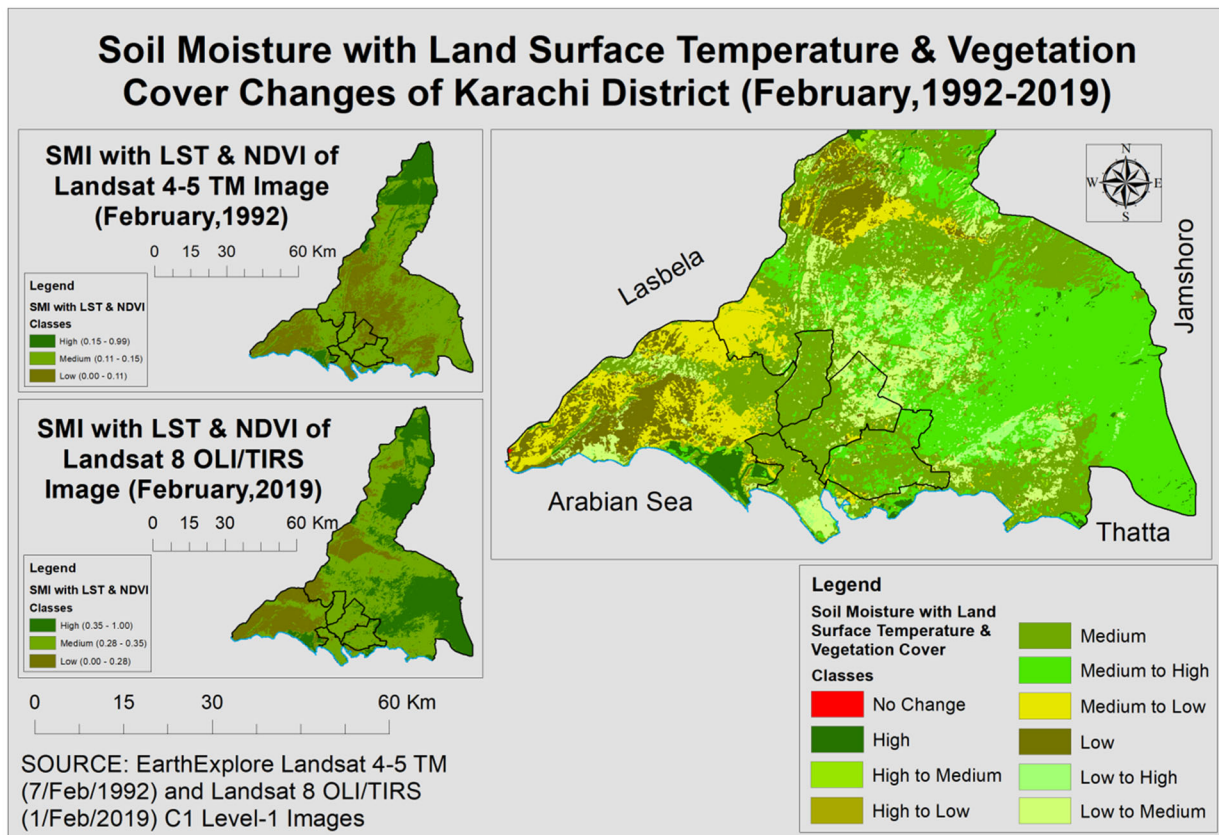
a
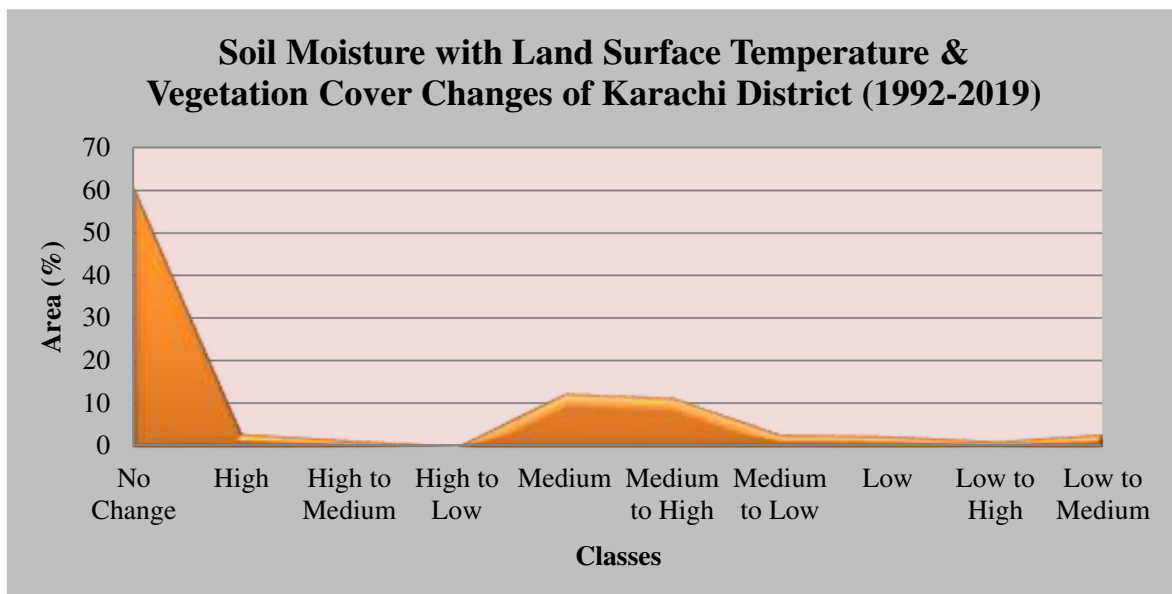
b

Fig. 8 **a** Soil moisture with land surface temperature and vegetation cover changes promoted on Karachi district location (1992–2019) and it is referred with diverse classes names and small layouts in original SMI with LST and NDVI images that are expressed with classes names and its values. **b** Soil moisture with land surface temperature and vegetation cover changes (1992–2019) graph and it is expressed with distinct class names as well as its area measured in percentage

Thus, the SMI with LST and NDVI changes of graph described the high values of the no-change class and the fewer changes of the high to low class (Fig. 8b).

Conclusions

The spatio-temporal changes of soil moisture with the different aspects have been observed in the review. All the observation of changes based on the Landsat 8 OLI/TIRS and Landsat 4-5 TM satellite images as well, various RS/GIS techniques supports in the analysis. Hence, the soil moisture inquired with the LST as well, SMI with NDVI, and SMI with LST and NDVI. The change image result was explored through the statistical graphs in which the SMI with NDVI, NDVI, SMI with LST, and SMI with LST and NDVI were involved plus it is all on the change detection process applied. However, the results of the LST and LST with NDVI were studied through the raster data images (1992 and 2019) as well it is based on the various classes examined.

Further, the LST investigated with the interpolation (IDW) and contours techniques as well as without interpolation (IDW) and contours methods and both processes in the small changes in values but both have the same results noticed in the research area that it is decreased. However, it increased with the passage of times that the causes of the rainfall on January 21, 2019 take place at about 33 mm precipitation while the image data of the review on February 1, 2019 have been acquired and the atmospheric temperature recorded 22 °C (AccuWeather Karachi weather 2019).

The NDVI data image (1992 and 2019) comparison found that its diminished reasons of population settlement regions and deforestation increased. Similarly, the NDVI changes investigated through the change detection method (ERDAS IMAGINE 9.2 software through used) and it is graphically explored which from examined that is the low to high class values of the high changes.

LST with NDVI from analyzed that it's decreased because of the vegetation is decreased and the study area of the urban sprawl exacerbating. The soil moisture with LST reduced with the passage of times causes of population settlement exceeds and its differentiation of raster images (1992 and 2019) results through observed. On the other hand, the soil moisture with LST changes probed through the technique of change detection as well as it is graphically analyzed the no-change class of the high values.

Additional, the SMI with NDVI increased as well as the SMI with LST and NDVI have also increased and its analyzation based on the results data images (1992 and 2019) whereas, it's change detection process through both graphically inquired that's from the same results studied as the high changes amount noticed in the no-change classes.

The research studied in which the soil moisture analyzed with NDVI and LST with NDVI which is the novelty of the review that's have the very less or nobody researched while the many studies in the soil moisture examined with LST. Furthermore, this review is based on the change detection technique of ERDAS IMAGINE 9.2 software which from the soil moisture changes progressed, and this technique is also very less used in researches. The new uniqueness of the research is the LST investigated with the interpolation (IDW) and contour techniques as well without its and this method very less used in the literatures or researches. The review explored the high and low soil moisture regions with the prospective of LST, NDVI, and LST with NDVI that are useful information for the future researcher in the monitor of the suitable sites for the vegetation or agriculture cultivation.

The findings of the study are that the soil moisture with LST decreases, the reasons of LST increased, and it is dangerous for the future growth of vegetation plus it is important to control the urban sprawl that is the main factor to increase the LST and tree cutting (deforestation) needs to be stopped. The present study used satellite data image (2019) of the nearest rainfall days data; therefore, the LST results are not accurately examined that need to be improved which for the satellite image without rainfall days data are adopted.

The review of the investigation is connected with the 2030 Agenda for Sustainable Development Goals, SDG Indicator 6.6.1, that is about the change in the extent of water-related ecosystems over time addition, restoration, and protection of the water-related ecosystems such as lakes, rivers, wetlands, mountains, aquifers, and forests.

Compliance with ethical standards

Conflict of interest The declaration of the interest is in the geography subject, and it is related to the various Earth-related changes as well as soil moisture and urban settlement, while the research is in which all of these disclosures are described.

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