A STUDY OF MODIFYING OF URBANIZATION FROM IMPERVIOUS SURFACES INDICES OF KARACHI USING A LANDSAT 8 OLI/TIRS SATELLITE IMAGERY

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ABSTRACT

Urbanization is the people's migration to the urban zones from rural for better living standard, and its growth causes natural landscape changes. In Karachi district urbanization is growing uncontrollably day by day. Extraction of the impervious surface is essential in assessing the expansion of urban regions and human activities. This study aims to focus on urbanization modified with impervious surface indices of Karachi. Landsat 8 OLI/TIRS satellite images are used to acquire Normalized Differentiated Built-up Index (NDBI), Normalized Difference Impervious Index (NDII) and Normalized Difference Impervious Surface Index (NDISI) for impervious surface estimation. Moreover, indices of accuracy assessment for spearman rank correlation were utilized. The results revealed the high impervious area in the NDISI with the blue band about 27.16% and a low impervious zone in the built-up land represented 4.93%. The spearman rank correlation in impervious surface indices is a perfect positive correlation between ranks analyzed. The study concluded that the accurate impervious surface distribution monitoring is easy through remote sensing technology otherwise its difficult, and GIS techniques helps more in Ground Truth collection.

KEYWORDS: Urbanization, Impervious Surface Indices, Landsat 8 OLI/TIRS, Remote Sensing, GIS Techniques, Karachi

1. INTRODUCTION

Urbanization is known as the people's migration from rural to urban places and its population growth increases gradually in urban zones, further, its pressure leads to rapid changes in natural landscape (Ghosh, 2020; Qiaoetal, 2014; Ritchie & Roser et al., 2020; Science Daily, 2020; Science Direct, 2020; Wikipedia. Urbanization, 2020). The main towns and cities undergoing the development process become the high population regions leading to an increase in living and working zones (Wikipedia. Urbanization, 2020). Urban growth through identified urbanization increases day by day, as well as its pressure increases on natural resources (Bhalli et al., 2012; Science Daily, 2020; Shah and Ghauri, 2015; Wikipedia. Urbanization, 2020). Urbanization is related to various ranges of disciplines such as geography, urban planning, economics, sociology, architecture, and public health (Science Direct, 2020; Wikipedia. Urbanization, 2020). Moreover, its phenomenon is closely linked to modernization, industrialization, and the sociological rationalization process (Encyclopaedia Britannica, 2020; Science Daily, 2020; Wikipedia. Urbanization, 2020).

The rapid development transforms the natural landscape into an artificial and manmade landscape. Its results in microclimatic changes, water quality deterioration, heat island effects, biodiversity reduction, disease patterns changes, greenhouse gas emissions, atmospheric pollution, and other such effects. The urban regions in population growth causes deterioration of the ecological, economic, and social conditions, and exponential urbanization spiral (Garg et al., 2016). The urbanization phenomenon is not affected by tiny zones rather it develops changes on global level. More than half of the population, lives in urban areas throughout the world and highly dense megacities are places that are extending with time (Ghazal et al., 2016; Milner et al., 2017; Mohsin &Bhalli., 2015).

The techniques are used to analyze the urban expansion and evaluate the impacts of urban-human activities on the environment, so the main purpose of estimation of impervious surface zones is to accurately monitor urbanization. The impervious surfaces are the surfaces of such material that does not allow water to infiltrate and it’s primarily associated with highways, sidewalks, transportation, building-rooftops, streets, and parking lots. One of the major land cover types are impervious surfaces in the urban and sub-urban environment. The increase of impervious surface regions in landscapes is directly related to the conversion of rural to urban land use. The imperviousness in turn affects water quality, degradation of surrounding lakes and streams, pollution, and hinders the amount of runoff to lakes and streams. The impervious surface percentage within a watershed has been diagnosed, and it’s a key indicator of the non-point runoff effects, future ecosystem and water quality (Garg et al., 2016).

The technology of remote sensing has been one of the primary processes for getting data on impervious surface regions, mapping watersheds for tax assessment and modeling applications (Garg et al., 2016). For impervious surface regions assessment several remote sensing indices are used such as Normalized Difference Built-Up Index (NDBI), used to delineate urban areas generally showed a higher reflectance in the shortwave-infrared (SWIR) region, as compared to the near-infrared (NIR) region (Zha et al., 2003). The Normalized Difference Impervious Index (NDII) rapidly delineates urban impervious surface areas with promising accuracy (Lu et al., 2006; Wang et al., 2015). Normalized Difference Impervious Surface Index (NDISI) can efficiently determine the consequences of land, bare rock, water, and bare soil on impervious surface extraction. The NDISI, incorporates the sharpened thermal band with reflective bands of Landsat imagery. A threshold choice automatic method was created to desirable sections of impervious surfaces from other land covers in the NDISI image (Sun et al., 2017; Xu, 2010). This paper aims extraction of impervious surface area distribution in the Karachi district and results acquired through Landsat 8 OLI/TIRS satellite image with the help of remote sensing and GIS techniques. Additionally, impervious surface indices statistically analyzed through spearman rank correlation for acquiring more accurate results.

The purpose of the study is to investigate the urbanization of Karachi city, which is growing with the passage of time. Therefore, various indices are used to monitor urban growth and analyze accurate results regarding the urban growth area in these indices. Furthermore, the different results of the indices are analyzed using Spearman rank correlation. The correlation reveals the best and most accurate relationship among the various indices. The research results are novel due to the scientific substantiation of the applicability of GIS technology in managing urbanization processes and promptly identifying land developments. The originality of the research lies in demonstrating a new approach to urban planning and urbanization management, with the goal of maintaining acceptable ecological parameters for human life. Furthermore, the research identifies a significant gap in previous studies, as there have been limited investigations regarding the accurate assessment of different impervious surface indices using Spearman rank correlation.

The main objectives of the study are to analyze urbanization using impervious surface indices in Karachi district. Furthermore, the study has the following sub-objectives:

- To extract the distribution of impervious surface areas across Karachi district using NDBI, NDII (VIS), and NDISI (VIS & WI).
- To identify the most accurate results of the indices in relation to urban growth areas.
- To investigate the impact of urbanization on ecological parameters and the environment.
- To statistically analyze the impervious surface indices using Spearman rank correlation to obtain more accurate results.

By achieving these sub-objectives, the study aims to provide valuable insights into the urbanization process in Karachi district, particularly focusing on the impervious surface indexes. These findings will contribute to a better understanding of urban growth patterns and support informed decision-making for urban planning and management.

1.1. Study Area

Karachi is a megacity of Pakistan and the capital of the southern Sindh province. Karachi is located geographically between 24° 45’ N to 25° 37’ N and 66° 42’ E to 67° 34’ E. The total zone of the city is about 3,780 Km^2, as well first highest populated city in Pakistan and sixth in the global (Wareing et al., 2010). According to the 2017 census, the metropolitan population reached around 14.91 million (STATISTICS, 2007) and exacerbating rapidly with time (Wazir & Goujon, 2019). The metropolitan constituted of six districts as Karachi East, Karachi South, Karachi Central, Malir, Korangi and Karachi West (Figure 1).

Physiographically, the megacity is divided into three general types: coastal regions, hilly zones, and an undulating plain. The Layari and Malir, are two main drainages, seasonal streams drained into the Arabian Sea which mark as the city of physical features (Pithawalla et al., 1946). The city of the coastal region is based on the scattered rocks outcrops, marshlands, hills, and various kinds of islands situated in the coastal area. The coastline surrounded located dense mangrove forests. The metropolitan is also constituted of small hill ranges as such the Mulri Hills and the Khasa Hills.

The megacity is represented as a zone that usually has high humidity and temperate climatic conditions as compared to other inland urban centres(Roth, 2007). The city’s climate is mainly affected by the Arabian Sea. According to climate-data.org, the monsoon seasons months are from July to September, where the rainfall annual recorded about 194mm. The summer and winter represented months from April to October and November to March, respectively. The temperature annual average is mostly about 25.9°C (Figure 2).

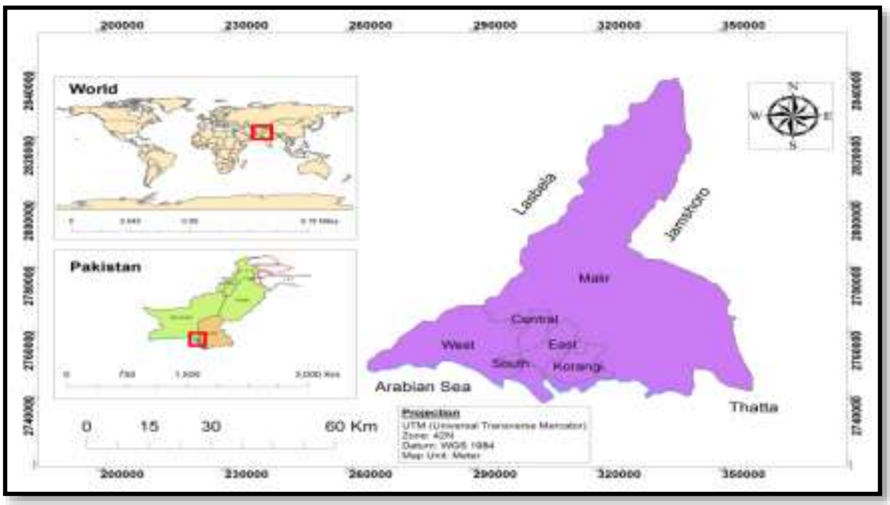

Fig. 1 Study Area of Karachi District

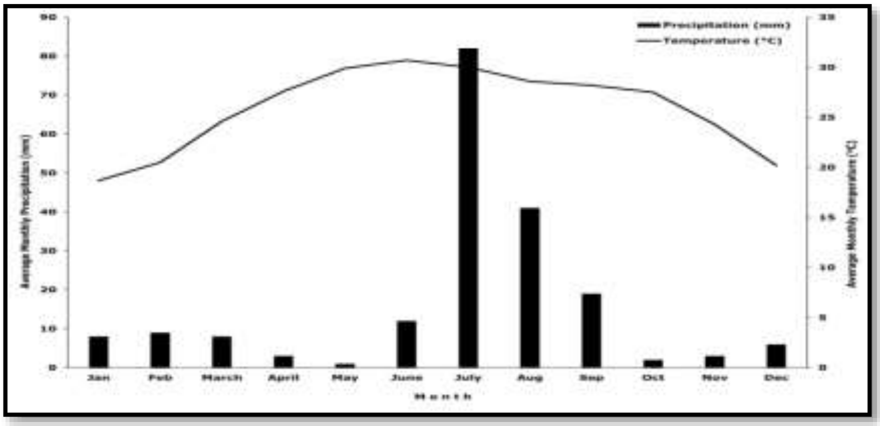

Fig. 2 Average Monthly Rainfall and Temperature

Karachi is now premier in the financial and industrial centre hub and the seaport of Pakistan. Consequently, the city receives people migrating from various parts of Pakistan to enhance their standard of living.

1.2. Population of Karachi district

The Karachi city's population is unevenly extended and diversified by area and rapidly increasing with time. In 1947, the city population was recorded at about 0.5 million. The population in the year 1950 was (1.0 million), increased to (9.3million) in the year 1998 about 17.2% per year, increased upto 8.3 million, and from the year 2011 it was (12.9 million) increased to (15.0 million) in the year 2017 about 35% per year and increased by 2.1 million. In the year 2018, the metropolitan population was recorded as around 15.4 million (Figure 3), while density reached approximately >6,000 persons per square kilometer (Safarik et al., 2016). Moreover, the city population is increasing daily.

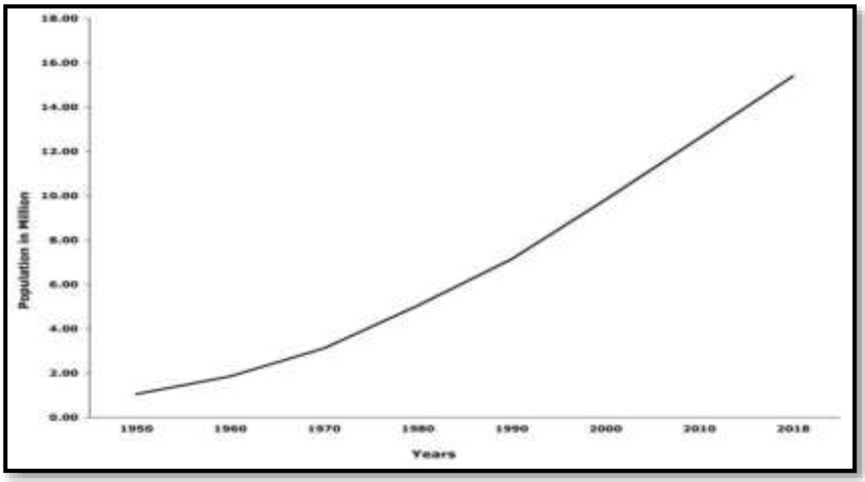

Fig. 3 Karachi District Population (1950-2018)

2. MATERIAL AND MEATHODS

2.1. Satellite Images and Ancillary Data

The Landsat 8 OLI/TIRS satellite data image was acquired through the USGS portal. The study area of administrative boundaries was acquired from the concerned authorities (Table 1). In the research, various types of data formats were used (Table 2). The study also discusses the properties of Landsat 8 OLI/TIRS satellite data from 2019 (Table 3).The methodological framework of this research is illustrated in (Figure 4).

Table 1: Diverse datasets of data sources

Dataset	Source
Landsat 8 OLI/TIRS C1 Level-1 image 2019	https://earthexplorer.usgs.gov/
Karachi District boundary	https://data.humdata.org/dataset/pakistan-administrative-level-0-1-2-and-3-boundary-polygons-lines-and-central-places

Table 2: Different Kind of Formats Data Utilize

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

Table 3: Properties of Satellite Data

Parameter	Spatial Resolution	Temporal Resolution	Spectral Resolution	Areal Swath	Availability	Dates	Pixel Size	Thermal Band
Landsat 8 OLI/TIRS	30 meters (band 8 = 15 meter) (band 10 & 11 = 100 meters)	16 days	10 bands	185 km	16 days	2019	30 m	100 m

2.2. Software's

In this study, various software applications were used for the investigation and analysis of the results. These include ERDAS IMAGINE 9.2, Microsoft Excel, and ArcGIS 10.3.1 software.

2.3. Processing of Satellite Images and Ancillary Data

The satellite image processing methods involve mosaicing, subset creation; layer stacking, area calculation, classification accuracy and Spearman rank correlation. Further, the image processing in various indices used for the detection of impervious surface zones is discussed below:

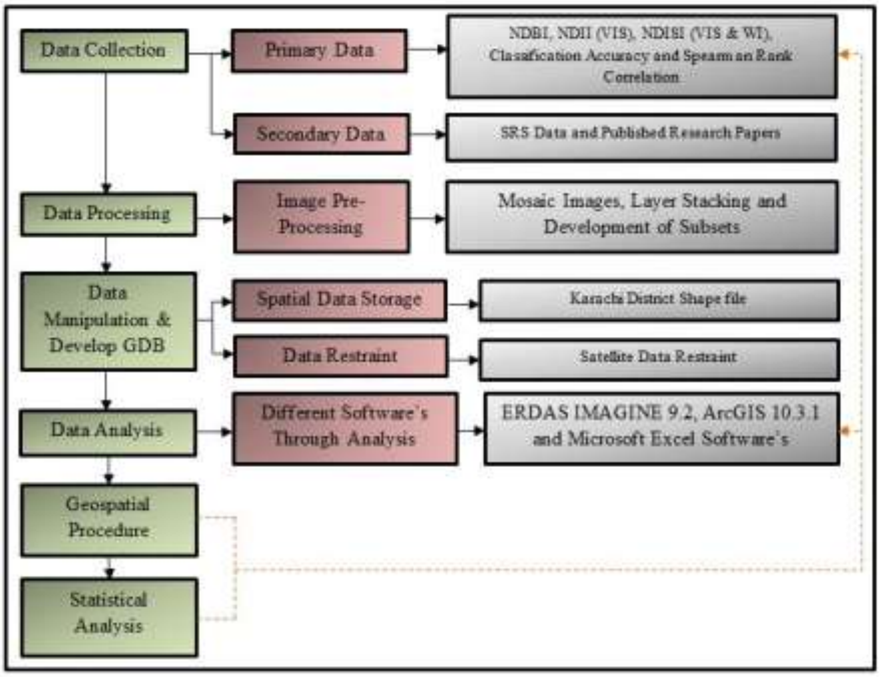

Fig. 4 Methodological Framework of the Study

2.4. Normalized Difference Built-Up Index (NDBI)

Land cover changes can be detected in urban areas as a consequence of urbanization. Therefore, the NDBI is the index for mapping built-up area automation (Zha et al., 2003). Consequently, the NDBI is derived from the Landsat 8 OLI/TIRS bands 5, 6 and 7, which are referred to as near-infrared (NIR), short-wave infrared 1 (SWIR 1), and short-wave infrared 2 (SWIR 2).The short-wave infrared bands (SWIR 1&SWIR 2) both of average used in NDBI formula. The NDBI is calculated from ArcGIS10.3.1 software using raster calculator.The NDBI formula is measured from the following equation 1 adopted from Xu (2008):

$$NDBI = \frac{(SWIR - NIR)}{(SWIR + NIR)} 1$$

The value ranges from -1 to +1.

2.5. Normalized Difference Impervious Index (NDII)

Urban land conditions have been deteriorating day by day due to the growth of population and area expansion. Impervious surface area is a significant indicator of changes in urban environment. Consequently, Landsat 8 OLI/TIRS visible bands (VIS) bands as 2 (blue band), 3 (green band) and 4 (red band)(used one by one band in NDII formula), and thermal infrared bands 10 and 11 (TIRS 1 and TIRS 2) both average of TIRS is used in NDII formulas. The NDII is calculated from ArcGIS10.3.1 software using raster calculator.The NDII is measured from the following formula adopted by Wang et al. (2015).

$$NDII = \frac{(VIS-TIRS)}{(VIS+TIRS)} \quad 2$$

The value ranges from -1 to +1.

2.6. Normalized Difference Impervious Surface Index (NDISI)

The impervious surface features extraction technique is normalized difference impervious surface index (NDISI). The NDISI is derived from the Landsat 8 OLI/TIRS bands as thermal infrared bands 10 and 11 (TIRS 1 and TIRS 2) both average of TIRS is used in NDISI formulas. Further, Landsat 8 OLI/TIRS bands 5, 6 and 7, which are referred to as near-infrared (NIR), short-wave infrared 1 (SWIR 1), and short-wave infrared 2 (SWIR 2). The short-wave infrared bands (SWIR 1 & SWIR 2) both of average used in NDISI formulas. The NDISI is calculated from ArcGIS10.3.1 software using raster calculator. We adopted the Garg et al. (2016) methods.

*NDISI = TIRS-((MNDWI+NIR+SWIR)/3)/TIRS+((MNDWI+NIR+SWIR)/3)*3

MNDWI (modified of normalized difference water index) can separate the built-up land efficiently from water bodies. Therefore, we adopted a formula from Xu (2006), which used Landsat 8 OLI/TIRS image of bands as 3,6 and 7 which are referred to as green, short-wave infrared 1 (SWIR 1), and short-wave infrared 2 (SWIR 2). The short-wave infrared bands (SWIR 1 & SWIR 2) both of average used in MNDWI formula. The MNDWI is calculated from ArcGIS10.3.1 software using raster calculator.

MNDWI = (Green-SWIR)/ (Green+SWIR) 4

The range value of the index is from -1 to +1.

Furthermore, the NDISI formula was utilized using Landsat 8 OLI/TIRS visible bands (VIS), specifically bands 2 (blue band), 3 (green band), and 4 (red band) (used one by one band in NDISI formula instead of MNDWI), to achieve improved results for urban area assessment. The NDISI (VIS) Index has a range value between -1 and +1.

3. RESULTS AND DISCUSSION

The remote sensing/GIS techniques efficiently helped in the analysis of impervious surface distribution in the study area. Moreover, the impervious surface accuracy assessment extracts through Spearman rank correlation.

3.1 Impervious Surface Analysis

The result of built-up land represented an impervious class and a non-impervious class. The impervious class counted at 4.93% (i.e. percentage of urbanized area covered) and the non-impervious class at 95.06% (non-urbanized area) of the study area (Figure 5a). The population displayed through built-up land showed impervious areas. While, impervious areas explained here involve zones covered with various pavement materials like steel, cement, concrete, dark roofs, etc.

The impervious index calculated through NDII with Blue Band counted 82.47% (non-urbanized area) to non-impervious index and 17.52% (urbanized area) to impervious index (Figure 5b), with Green Band counted 90.77% (non-urbanized area) to non-impervious index and 9.22 % (urbanized area) to impervious index (Figure 5c), and with Red Band counted 77.68% (non-urbanized area) to non-impervious index and 22.31% (urbanized area) to impervious index (Figure 5d).

The impervious surface index is calculated through the Normalized Difference Impervious Surface Index (NDISI). The NDISI with Blue Band accounted for 72.83% (non-urbanized area) of non-impervious surface index and 27.16% (urbanized area) of impervious surface index (Figure 5e), with Green Band accounted 77.98 % (non-urbanized area) of non-impervious surface index and 22.01 % (urbanized area) of impervious surface index (Figure 5f), and with Red Band accounted 87.90 % (non-urbanized area) for non-impervious surface index and 12.09 % (urbanized area) for impervious surface index (Figure 5g). While NDISI with WI accounted 94% (non-urbanized area) of non-impervious surface index and 5.99 % (urbanized area) of impervious surface index (Figure 5h).

The analysis of the results reveals the extent of urbanization and the variations among different indices in relation to urban growth. The NDISI with the blue band exhibited a high impervious surface coverage of 27.16%, indicating that it provided the most accurate results among all the indices. This can be attributed to the high population density in Karachi, which is reflected in the ground reality. Other indices demonstrated comparatively lower levels of urbanization.

The trend of change reveals that urban growth is increasing in the Karachi district, and it poses an alarming condition for global warming, climate change, and many dangerous natural disasters. These directly impact the lives of human beings and other living organisms, as well as the Earth life sphere. Therefore, it is crucial to control the rapid urban sprawl and implement effective urban planning and management strategies in

Karachi. Additionally, efforts should be made to improve the environment, such as planting trees can play a significant role in temperature control.

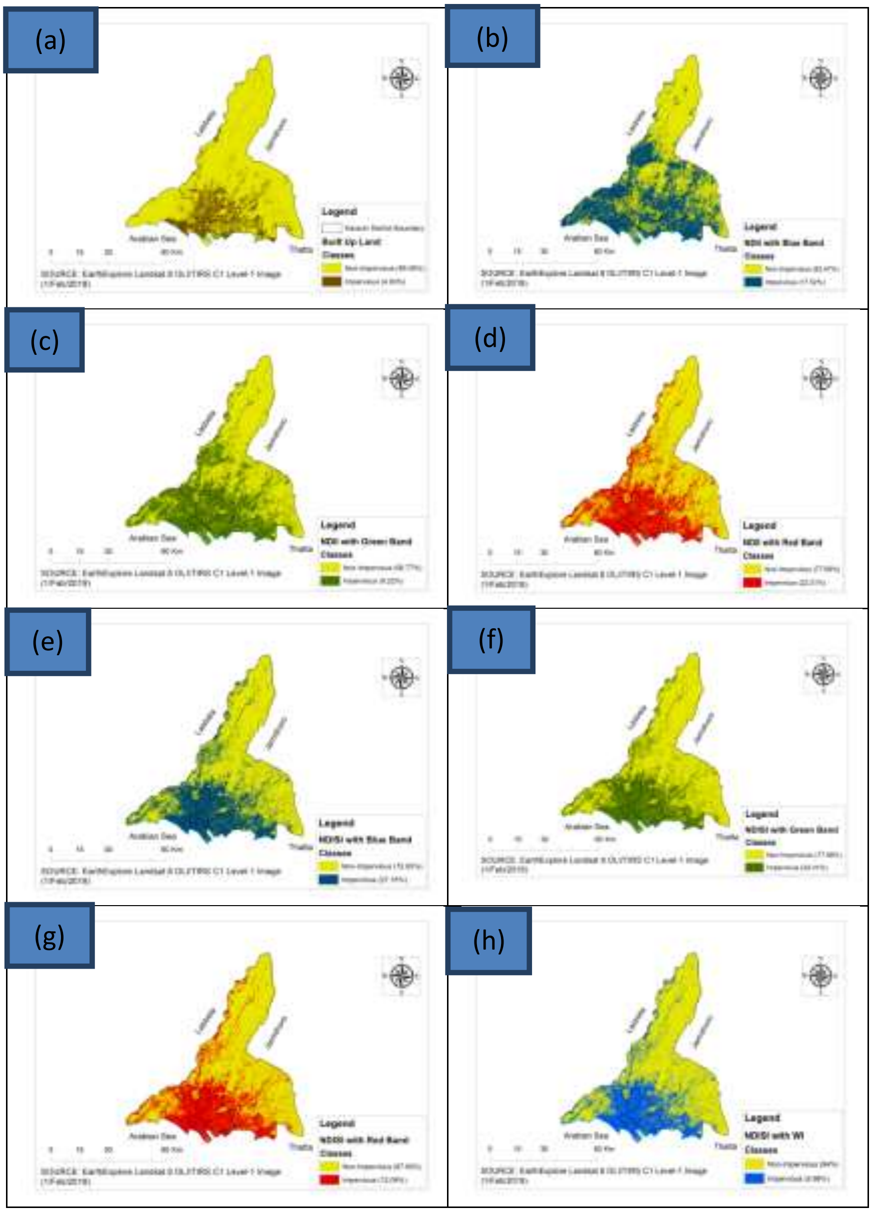

Fig. 5 (a) Built-up Land Distribution,Normalized Differences Impervious Index (NDII) with (b) Blue Band; (c) Green Band; (d) Red Band&Normalized Difference Impervious Surface Index (NDISI) with (e) Blue Band; (f) Green Band; (g) Red Band; (h) Water Index (WI) in Karachi District

3.2. Accuracy Assessment

Accuracy assessment is a basic challenge for impervious surface indices so; we are using the method of summary statistics for the accuracy assessment.

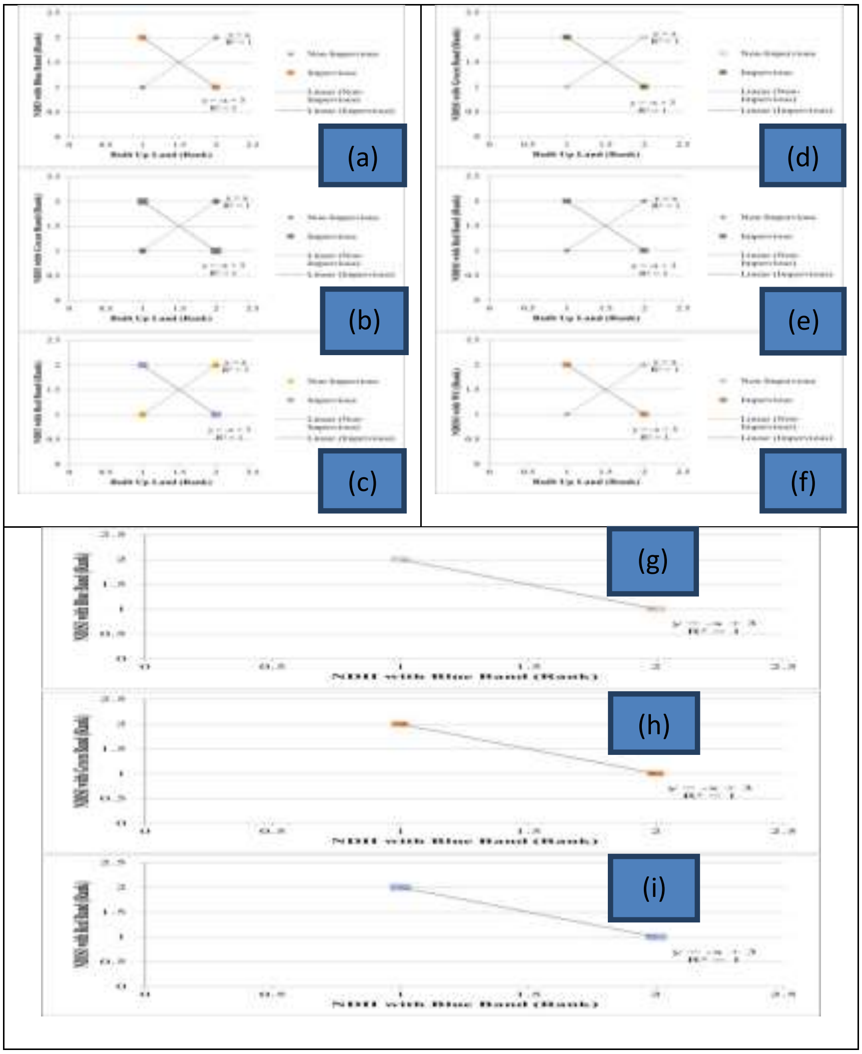

Fig. 6 Correlations between (a) Built-up Land and NDII with Blue Band; (b) Built-up Land and NDII with Green Band; (c) Built-up Land and NDII with Red Band; (d) Built-up Land and NDISI with Green Band; (e) Built-up Land and NDISI with Red Band; (f) Built-up Land and NDISI with Water Index (WI); (g) NDII and NDISI with Blue Band; (h) NDII and NDISI with Green Band; (i) NDII and NDISI with Red Band Statistical Graphs

This technique is generally adopted to assess the accuracy of impervious surface indices. For an impervious approach that's not volume preserving, target-level extracts can be collected to the level of area and matched to the true values utilizing the correlation coefficient. Therefore, the Spearman rank correlation was studied and observed on the built-up land and NDII with VIS (Figure 6 (a, b, c), built-up land and NDISI with green band, red band, and Water Index (Figure 6 (d, e, f), NDII and NDISI with blue, green and red band (Figure 6 (g, h, i). The results graphically illustrated the perfect positive correlation among the ranks respectively.

4. CONCLUSION

The review investigated the urbanization in terms of impervious surface indices of Karachi and analyzes the Landsat 8 OLI/TIRS satellite image data based. The precise results achieved from the built-up land, impervious index with VIS and impervious surface index with VIS, and WI were presented. The results in high impervious observed in the NDISI with blue band accounted for 27.16%. However, low imperviousness in the built-up land accounted for 4.93%. Moreover, the significant results showed through Spearman rank correlation between built-up land, impervious index with VIS, and impervious surface index with VIS and WI, as well as a perfect positive correlation between ranks analyzed. Remote sensing technology is an easy way to analyze impervious surface areas otherwise, it is difficult to estimate impervious surfaces through field surveys, because of the entire region in many locations is inaccessible or access is difficult due to the hilly, river and forested areas, etc. The GIS techniques applied through ArcGIS 10.3.1 software for the Ground Truth collection. The present study can also be expanded to monitor land surface temperature and correlate the data of impervious surface estimation with urban heat islands of the Karachi area.

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