Urban Development and Its Changes Using Hot Spot Analysis: A Case Study of Colombo Metropolitan Area, Sri Lanka

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***Abstract*—This study focuses on investigating the spatiotemporal changes of the built-up area and its change patterns in the Colombo metropolitan area, Sri Lanka. The same was achieved by employing the multi-temporal satellite data and geospatial techniques between 1988 and 2019. Remote sensing data were employed, and built-up areas were derived using spatial indices. Subsequently, the spatial calculation was performed by Grama Niladhari Divisions (GNDs) level using geospatial techniques. The results revealed that the study area had undergone a rapid urban expansion within the last three decades, while it has mainly focused on the western coastal belt. Hotspots analysis illustrated that very hotspot GNDs are gradually increased. There were 95 GNDs in 1988, and it increased up to 191 by 2019. The output of the study can be used as a proxy indicator for urban planning and development. Meanwhile, the constructed method can be applied in any city to study built-up dynamic changes and their patterns.**

***Keywords*— Hotspots, gradient analysis, built-up, urban patterns, Colombo, Sri Lanka**

I. INTRODUCTION

As a result of the high rate of socio-economic footprint, people are willing to lodge in the city [1]. In 2018, the world population in the city was 23%, and it is predicted that it will rise to 66% by 2050 [2].Population development in the city influences change in the city structure in various ways, including land use /land cover (LULC) change. City planners attempt to enhance the facilities (infrastructure, transport, job, etc.) for the benefit of residents by occupying a non-built-up area as built-up land[3,4]. However, this kind of drastic changes in LULC has been affected by the city's sustainability and life quality of the residence. Thus, studying the socio-economic influence of built-up expansion is becoming an interesting research topic among urban researchers. Other than this, precise information on LULC is essential for decision-making purposes.

Estimation and mapping of built-up areas in complex urban structures is not an easy task, and traditional data gathering methods are not continually effective. Thus, more sophisticated mapping applications, which is known as the Google Earth Engine (GEE) was popular among the researchers[5]. It is a remote sensing(RS) technology based application that spans over 30 years of Landsat historical data archives[6,7]. Furthermore, GEE helps to overcome the data mining obstacles such as could distortion, which is a very common issue in the tropical region[8]. GEE also facilities the generation of multiple time points Landsat data, which is important for time series analysis. Multiple time points Landsat data also provides a more accurate spatiotemporal comparison rather than a single snapshot of Landsat image as several past researchers noted[8].

A number of techniques are available for automatically mapping built-up areas using RS data, and those methods are popular among the urban researchers [9]even in Sri Lanka [10]. These techniques can be roughly grouped into two categories: (1) those based on the classification (pixel and object-based) [11]; and (2) those based on directly segmenting the indices, including normalized difference built-up index (NDBI) [11]. Some of the past research revealed that NDBI is an alternative for built-up areas[8,12]. The method takes advantage of the unique spectral responses of built-up areas and other land covers. Also, it creates binary images under the assumption that a positive value should indicate built-up areas, while negative numbers represent a surface water body. In contrast, a zero value usually belongs to vegetation [9,13].

Information on spatiotemporal changes of built-up structure and its pattern can enhance our understanding of current LULC changes and their future behaviours. According to evidences provided by literature[14], there are various methods and techniques to access the urban pattern. Among them, gradient analysis is a popular method to access the spatial changes along the gradient zones from the city centre[9]. At the same time, hotspots detection helps discover the active regions [15] with cluster analysis. It highlights regions sensitive to land-use change, which is of critical importance for administrative bodies for setting up future land-use strategies.

In view of the above aspect, the part of the Colombo metropolitan region (CMR) which encompassed the Colombo district was selected as the study area. It was promoted as a major port, trading, administrative, and service center from the early colonial period. Even after independence[16], it continues to experience an enormous economic agglomeration in Sri Lanka. Hence, conducting research on CMR about built-up changes and its pattern is a timely and important task. The purpose of this study was to compute the changes in built-up land and its spatiotemporal patterns over the last three decades.

II. Materials and Methods

Study Area

The Colombo Metropolitan Region (CMR) is the foremost administrative, commercial, and industrial area as well as the hub of the transport network of Sri Lanka [16]. From the socio-economic aspect, the administrative and economic capital of Sri Lanka, which is known as Colombo city, is located in the study area. Also, a highly complex urbanized system is seen, and it dominates the settlement system of Sri Lanka [16]. The CMR has a large manufacturing base and it is the main economic hub accounting for 65 percent of the region's gross domestic product (GDP), and this is against 58 percent nationally [17]. The CMR has seen its population climb from 3.9 million in 1981 to 5.8 million in 2012, and this is equivalent to 35 percent of the national increase. Mainly, built-up areas in the district are found along the coastal belt on its western side and along side the main transportation network

From the physical/environmental viewpoint, the selected area is situated in a lowland region. This is attributed by a typically hot and humid climate with two main monsoons and two inter-monsoon periods[10]. The southwest monsoon from late May to the end of September delivers much rainfall, while the northeast monsoon from the end of November to mid-February [18]brings relatively less rainfall.

CMR includes three districts: Colombo, Gampaha, and Kalutara. In this study, 434km^2 geographical area from Colombo district, which encompassed the CMR, was selected as a study area. It is bound by latitudes from 6.715793°N to 6.980561° N and longitudes from 79.869190° E to 80.080376° E (Fig. 1) Furthermore, the study area consistsof442GramaNiladhari Divisions (GND), which is characterized by various kinds of socio-economic attributes.

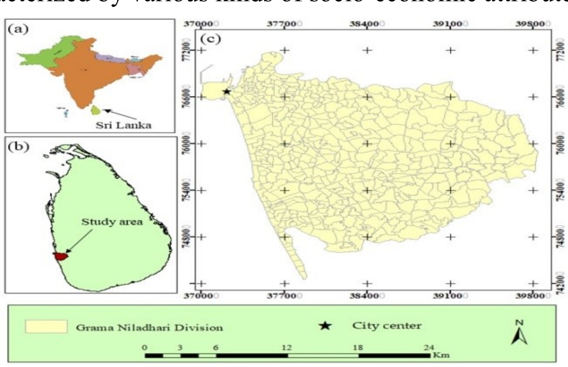

Figure1. Location map of the study area: (a) Map of South Asia, (b) Location of the study area, (c) the extent of the study area with Grama Niladhari Divisions

Data and Data Processing

Updated LULC data related to the current or past built-up areas were not available in the study area. This obstacle was managed by utilizing RS and geospatial techniques. This is because past researchers stated that atmospheric distortion, especially cloud, is a common issue in the tropical region[4][8].The study area was not an exceptional case. Cloud cover was the main obstacle to capture the image from RS sources. Hence, a more sophisticated, theoretical roughness and practical oriented data mining tool which is known as the Google earth engine (GEE) was chosen. GEE is an application programming interface that provides radiometric-calibrated and atmospheric-corrected Landsat level 2 data powered by United States Geological Survey (USGS) [19].In this study, four-time points were selected to cover approximately the last three decades. In the data acquisition process, the following steps were accomplished:

i. The median value of the Landsat data was selected by applying the study area as a geometry region.
ii. The masking method was applied to eliminate cloud disturbance in the available Landsat imageries.
iii. The image collection function in GEE was applied [20] to prepare the free imagery for the study area. Landsat-5 data covered three-time points and the number of images in each year are as follows; twenty, eighteen, and twenty-nine for 1988, 1997, and 2009, respectively. Meanwhile, twenty-two images for 2019 were selected from Landsat-8. Details of the Landsat images with date and time are summarized in Table A1.
iv. Multispectral bands (radiance values) of single data sets were produced for each year using GEE functions [20,21], and created data sets were downloaded as basic data sets.

NDBI Calculation

NDBI was carried out for each year using the above basic data sets, and it was derived by Equation 1[22].NDBI has been commonly used in previous studies to identify the built-up area that lacks ground survey or classification data [9,10]. NDBI represents the density of built-up in unit pixels, and its value range between −1 to 1. Its positive value means built-up areas, and its negative numbers represent a surface water body, while a zero value usually belongs to vegetation[13][9].

$$NDBI = \frac{(\mathrm{MIR} - \mathrm{NIR})}{(\mathrm{MIR} + \mathrm{NIR})} \quad (1)$$

where MIR = band 5 (Landsat-5) and band 6 (Landsat-8) and NIR = band 4 (Landsat-5) and band 5 (Landsat-8).

In addition, all water bodies have been masked by running a modified normalized difference water index (MNDWI). In the process, Otsu's optimal thresholding method was applied [23] in order to separate the water from the non-water area that has been applied successfully in other studies also [24,25]

Hot and Cold Spots Calculation

A hotspot analysis was carried out to determine the built-up hotspot by GNDs level. In an optimized hotspot analysis, a higher weight is given to spatial clustering, which further strengthens observations of built-up area for the same or nearby locations [26]. In this calculation, the following steps were completed;

i. 442 GNDs were selected, as explained in the study area, and the mean NDVI of each GNDs was extracted.
ii. Optimized hotspot analysis was carried out using ArcGIS optimized hotspot analysis (Getis-Ord Gi*) tool [10].
iii. Hot and cold spots were classified into seven categories based on their Gi Bin values: very hot spot (99% significant), hot spot (95% significant), warm spot (90% significant), not statistically significant, cool spot (90% significant), cold spot (95% significant), and very cold spot (99% significant) [27].

Spatial Distribution of NDBI

The Gradient analysis was applied to compute the spatial variation of NDBI from the city center, and it is one of the most commonly used methods in various kinds of research around the world[9,28]. In the process, the following steps were completed. Firstly, the sequence of buffer zones was created around the city center with a kilometre distance interval. As a result, 28 buffer zones were created. Secondly, the average values of the NDBI were extracted by each zone. Finally, the spatial distribution of NDBI was calculated.

III. Results

NDBI and its Spatial Distribution

Spatial and temporal distribution of NDBI for 1998, 1997, 2009, and 2019 is shown in Figure 2 (a)-(d), respectively. The mean values were -0.289, -0.164, -0.152, and -0.156for the same four-time points. High NDBI areas were mostly observed in the Colombo City area and along the western coastal belt. This is adjacent to the main transportation network, mainly in the west part of the study area. Around thirty years back (Figure 2 (a)), high dense NDBI area was mainly observed around the city center. This indicated that Colombo city was formed as a single core city in early time. Thereafter, it matured and shifted beyond the city along the coastal belt around 1997. Currently, it has dispersed towards the east side, but the higher portion is dominated by the western part as shown in Figure 2.

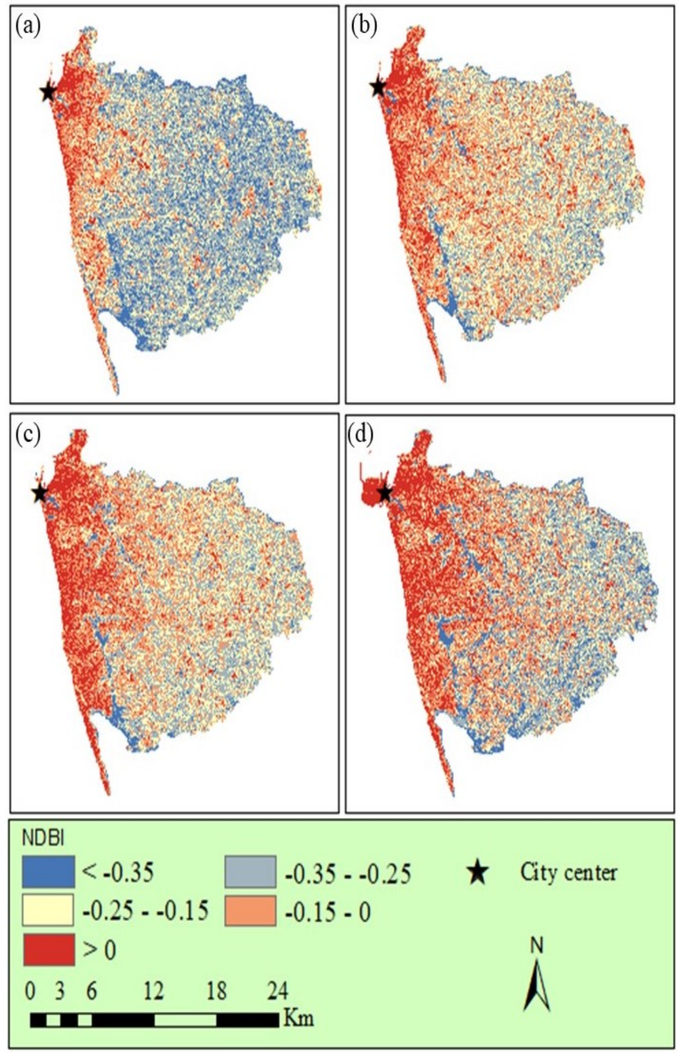

Figure2. Spatiotemporal distribution of NDBI: (a) 1988, (b) 1997, (c) 2009, and (d) 2019

The spatial and temporal distribution of mean NDBI is shown in Figure 3.As noted in the introduction section, NDBI is an alternative index to determine the built-up area. Furthermore, its positive values are mostly close to the built-up area. Hence, the gradient analysis illustrates that the built-up area has gradually increased from the city center to the western part of the study area. As evidenced by past researchers[9,25], the rapid urban development of the Colombo District was taken just after the conclusion of 30 years of civil war. Meanwhile, the newly reclaimed land (Figure 3 (d)) next to the Colombo harbor (Port City) has also made some influence on urban expansion. These socio-economic changes has influenced the improvement of built-uparea in the western part of the district [25].

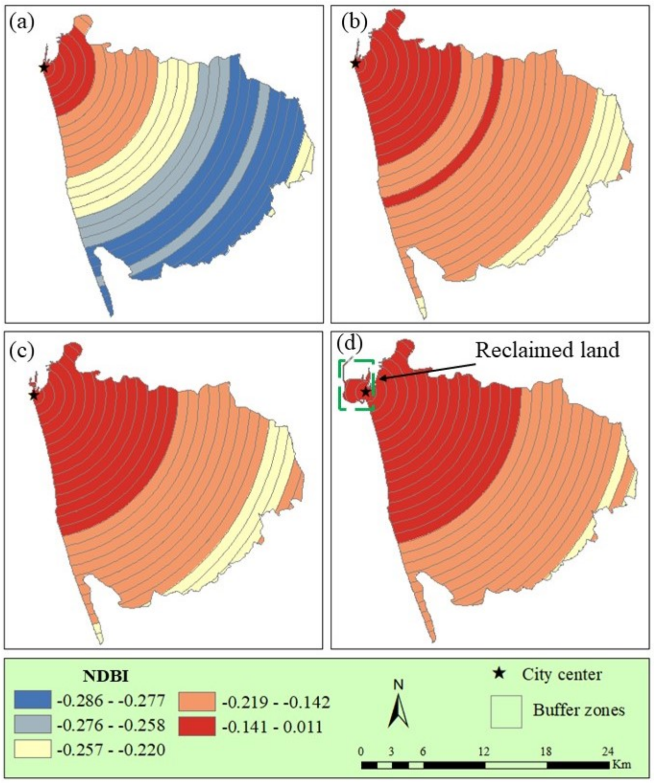

Figure3.Spatial distribution of NDBI from city centre: (a) 1988, (b) 1997, (c) 2009, and (d) 2019

Spatial Distribution of Hot and Cold Spots

The spatiotemporal clustering patterns of NDBI hot and cold spots are shown in Figure 4, while their descriptive statistics by GNDs are presented in Figure 5. Most of the very hot spots were observed in the western part along the coastal line in 1988 (Figure 4 (a)), and they developed along the coastal belt within the last two decades (Figure (b-c)). Finally, it has expanded into the country inrecent decades as shown in Figure 4 (d).As shown in Figure 5, very hot spots are gradually increased over the investigation period. It improved to95, 108,146, and 191 in1998, 1997, 2009 and 2019, respectively. The result showed that the area of built-up had increased, particularly towards the center of the district.

Very cold spots were mainly clustered in the eastern part which is notably highlighted. However, some of the very cold spot can be observed in northern part also as shown in Figure 4 (b). Furthermore, three classes (cold spot, cool spot, and hot spot) present declined trend over the study period as shown in Figure 5. The rest of the classes of the hot and cool spots present irregular patterns throughout the investigation period as illustrated in Figure 4 (spatially) and Figure 5 (statistically). Meanwhile, some of the hot and warm spots had changed to very hot spots when compared to the immediate past time points. This trend can be seen in 1997, 2009, and 2019.

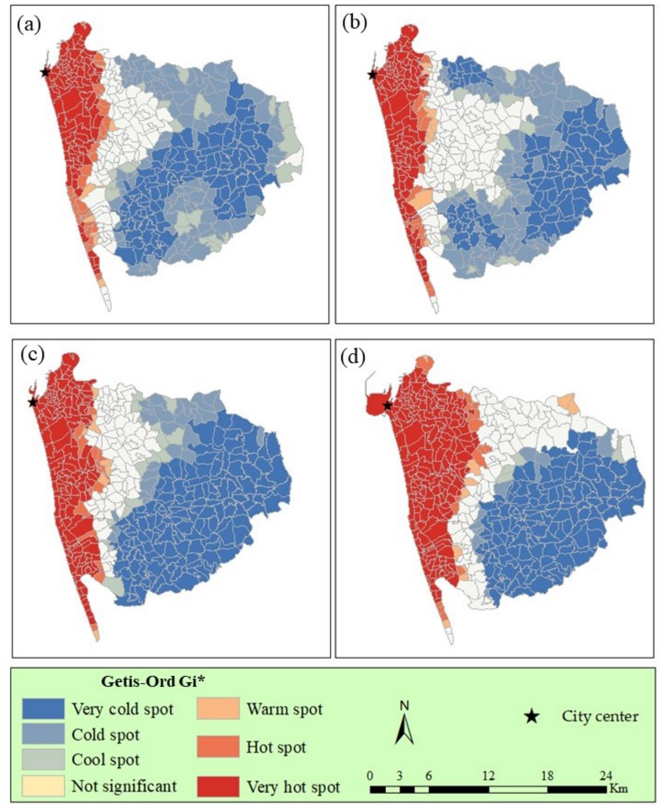

Figure4. Hot and Cold spots of NDBI: (a) 1988, (b) 1997, (c) 2009, and (d) 2019

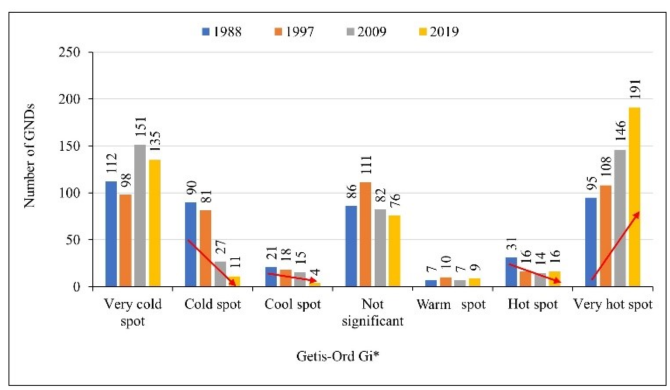

Figure5. Descriptive statistic of change of hot and cool spot by GNDs: (a) 1988, (b) 1997, (c) 2009, and (d) 2019

IV. DISCUSSION

NDBI was calculated using RS data for 1988, 1997, 2009, and 2019 in the Colombo metropolitan area, which encompassed the Colombo district. Gradient analysis was performed to access the spatial distribution of the built-up area. In contrast, hot and cool spot analysis helps to determine the clustering pattern of the built-up area in the study. Results of both gradient and hot spot analysis emphasized that high NBDI area improved over the last three decades. However, it has mainly concentrated on the western part along the coastal line. The reasons could be the influence of Colombo City, Colombo port, high dense transportation network [10], and industrial area which is located around the central capital of Colombo city. Warm and hot spots in 1988, 1997, and 2009 were transferred as very hot spots in 2019. This trend illustrated that there is a higher possibility of continuation of the process. Additionally, the results of Figure 5 show that there are increasing trends of very hot spot areas. This trend emphasizes our understanding of changes in built-up areas by administrative levels (GNDs).The results of the study can be used as supplementary for the policy formulation process regarding urban planning and infrastructure development. Administrative bodies will be able to determine urban development hot region by observing current trends, and their distance from the city center is also shown by gradient analysis.

Colombo, as the central economic and administrative hub of Sri Lanka, influences an increasing number of populations. Past researchers have stated that 11.4% of the country's population lodge in Colombo district with approximal 3438[10]population density (people per km^2), but with a total land area occupying only 1.01% of the country's area[10]. Increasing number of populations leads to several land use and land cover changes, especially increase in the built-up area around the main city and transportation line. This means that population expansion of the city and its periphery area has directly influenced the development of the built-up area. The study area has undergone a rapid urbanization expansion after 2009 as a result of the conclusion of the 30-year civil war. Most of the urban and transportation development projects were in the Colombo metropolitan area because the Colombo District is the capital and main commercial center of the country. The results of Figure 5 show that GNDs, which was reported as a very hot spot, had increased when compared to 1998 and 1997. In 2009, there were 146 GNDs, but it was improved to 191 by adding 45 GNDs within a decade.

Several urban studies have discussed the possibility of losing vegetation with urban expansion [29] even in Sri Lanka[21,30]. Thus, the selected study area is not an exceptional case, and there might be a loss of the vegetated area. Hence, city planners should pay more attention to conserve naturally vegetated land as much as possible for the benefit of urban residents. The mixture of land (green with built-up area) is a popular and modern urban concept which can apply to the study area [4].

V. Conclusions

The results of the analysis show that the study area has undergone a rapid built-up expansion over the last three decades. The built-up area mainly concentrated on Colombo City along the coastal belt in 1988.However, it developed and expanded beyond the city center as shown by gradient analysis. A very hot spot area in the western part along the coastal belt is remarkably highlighted and shows the spatial clustering pattern of urban expansion. In 1988, there were 95 very hot spots GNDs, but it increased to 191 in 2019. This means that there was a great improvement of the built-up area. Overall, the findings of this study can be used as a proxy reference in the context of a sustainable city and regional planning, while the constructed models can apply to any city by making necessary calibration on data.

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Table A1. Properties of the Landsat images (Level 2) used in this study

Sensor	Landsat ID	Date	Time
Landsat 5 (Thematic Mapper)	LT05_L1TP_141055_19880114_20170210_01_T1	1988-01-14	04:22:58
	LT05_L1TP_141055_19880130_20170209_01_T1	1988-01-30	04:23:16
	LT05_L1TP_141055_19880302_20170209_01_T1	1988-03-02	04:23:43
	LT05_L1TP_141055_19880403_20170209_01_T1	1988-04-03	04:23:59
	LT05_L1TP_141055_19880622_20170208_01_T1	1988-06-22	04:24:32
	LT05_L1TP_141055_19880708_20170208_01_T1	1988-07-08	04:24:35
	LT05_L1TP_141055_19880724_20170208_01_T1	1988-07-24	04:24:38
	LT05_L1TP_141055_19880809_20170207_01_T1	1988-08-09	04:24:37
	LT05_L1TP_141055_19880926_20170205_01_T1	1988-09-26	04:24:35
	LT05_L1TP_141055_19881129_20170205_01_T1	1988-11-29	04:24:30
	LT05_L1TP_141055_19881215_20170205_01_T1	1988-12-15	04:24:16
	LT05_L1TP_142055_19880105_20170210_01_T1	1988-01-05	04:28:59
	LT05_L1TP_142055_19880121_20170210_01_T1	1988-01-21	04:29:16
	LT05_L1TP_142055_19880206_20170209_01_T1	1988-02-06	04:29:34
	LT05_L1TP_142055_19880426_20170209_01_T1	1988-04-26	04:30:16
	LT05_L1TP_142055_19880715_20170208_01_T1	1988-07-15	04:30:48
	LT05_L1TP_142055_19880731_20170208_01_T1	1988-07-31	04:30:50
	LT05_L1TP_142055_19880816_20170206_01_T1	1988-08-16	04:30:49
	LT05_L1TP_142055_19881003_20170205_01_T1	1988-10-03	04:30:44
	LT05_L1TP_142055_19881206_20170205_01_T1	1988-12-06	04:30:35
Landsat 5 (Thematic Mapper)	LT05_L1TP_141055_19970122_20170101_01_T1	1997-01-22	04:17:55
	LT05_L1TP_141055_19970207_20170102_01_T1	1997-02-07	04:18:38
	LT05_L1TP_141055_19970223_20161231_01_T1	1997-02-23	04:19:18
	LT05_L1TP_141055_19970311_20170101_01_T1	1997-03-11	04:19:56
	LT05_L1TP_141055_19970327_20180620_01_T1	1997-03-27	04:20:33
	LT05_L1TP_141055_19970412_20170101_01_T1	1997-04-12	04:21:07
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	LT05_L1TP_142055_19970129_20170101_01_T1	1997-01-29	04:24:25
	LT05_L1TP_142055_19970318_20161231_01_T1	1997-03-18	04:26:23
	LT05_L1TP_142055_19970825_20161230_01_T1	1997-08-25	04:31:54
Landsat 5 (Thematic Mapper)	LT05_L1TP_141055_20090107_20161028_01_T1	2009-01-07	04:38:46
	LT05_L1TP_141055_20090123_20161028_01_T1	2009-01-23	04:39:12
	LT05_L1TP_141055_20090208_20161028_01_T1	2009-02-08	04:39:37
	LT05_L1TP_141055_20090224_20161029_01_T1	2009-02-24	04:40:01
	LT05_L1TP_141055_20090312_20161029_01_T1	2009-03-12	04:40:23
	LT05_L1TP_141055_20090328_20161027_01_T1	2009-03-28	04:40:45
	LT05_L1TP_141055_20090429_20161026_01_T1	2009-04-29	04:41:22
	LT05_L1TP_141055_20090515_20161026_01_T1	2009-05-15	04:41:40
	LT05_L1TP_141055_20090616_20161025_01_T1	2009-06-16	04:42:15
	LT05_L1TP_141055_20090702_20161024_01_T1	2009-07-02	04:42:32
	LT05_L1TP_141055_20090718_20161027_01_T1	2009-07-18	04:42:49
	LT05_L1TP_141055_20090803_20161022_01_T1	2009-08-03	04:43:03
	LT05_L1TP_141055_20090819_20161022_01_T1	2009-08-19	04:43:17
	LT05_L1TP_141055_20090904_20161021_01_T1	2009-09-04	04:43:32
	LT05_L1TP_141055_20090920_20161020_01_T1	2009-09-20	04:43:44
	LT05_L1TP_141055_20091006_20161024_01_T1	2009-10-06	04:43:55
	LT05_L1TP_141055_20091022_20161019_01_T1	2009-10-22	04:44:05
	LT05_L1TP_141055_20091123_20161018_01_T1	2009-11-23	04:44:19
	LT05_L1TP_142055_20090114_20161028_01_T1	2009-01-14	04:45:08
	LT05_L1TP_142055_20090130_20161028_01_T1	2009-01-30	04:45:34
	LT05_L1TP_142055_20090215_20161029_01_T1	2009-02-15	04:45:58
	LT05_L1TP_142055_20090404_20161027_01_T1	2009-04-04	04:47:04
	LT05_L1TP_142055_20090420_20161026_01_T1	2009-04-20	04:47:23

	LT05_L1TP_142055_20090506_20161026_01_T1	2009-05-06	04:47:41
	LT05_L1TP_142055_20090623_20161024_01_T1	2009-06-23	04:48:34
	LT05_L1TP_142055_20090810_20161022_01_T1	2009-08-10	04:49:20
	LT05_L1TP_142055_20090826_20161021_01_T1	2009-08-26	04:49:35
	LT05_L1TP_142055_20090911_20161020_01_T1	2009-09-11	04:49:48
	LT05_L1TP_142055_20090927_20161025_01_T1	2009-09-27	04:50:00
Landsat 8 (Operational Land Imager and Thermal Infrared Sensor)	LC08_L1TP_141055_20190103_20190130_01_T1	2019-01-03	04:53:47
	LC08_L1TP_141055_20190119_20190201_01_T1	2019-01-19	04:53:44
	LC08_L1TP_141055_20190220_20190220_01_T1	2019-02-20	04:53:38
	LC08_L1TP_141055_20190308_20190324_01_T1	2019-03-08	04:53:33
	LC08_L1TP_141055_20190324_20190403_01_T1	2019-03-24	04:53:29
	LC08_L1TP_141055_20190409_20190422_01_T1	2019-04-09	04:53:25
	LC08_L1TP_141055_20190425_20190508_01_T1	2019-04-25	04:53:18
	LC08_L1TP_141055_20190511_20190521_01_T1	2019-05-11	04:53:27
	LC08_L1TP_141055_20190527_20190605_01_T1	2019-05-27	04:53:36
	LC08_L1TP_141055_20190612_20190619_01_T1	2019-06-12	04:53:43
	LC08_L1TP_141055_20190628_20190706_01_T1	2019-06-28	04:53:49
	LC08_L1TP_141055_20190714_20190719_01_T1	2019-07-14	04:53:52
	LC08_L1TP_141055_20190730_20190801_01_T1	2019-07-30	04:53:57
	LC08_L1TP_141055_20190815_20190820_01_T1	2019-08-15	04:54:03
	LC08_L1TP_141055_20190831_20190916_01_T1	2019-08-31	04:54:07
	LC08_L1TP_141055_20191002_20191018_01_T1	2019-10-02	04:54:17
	LC08_L1TP_141055_20191018_20191029_01_T1	2019-10-18	04:54:19
	LC08_L1TP_141055_20191103_20191115_01_T1	2019-11-03	04:54:18
	LC08_L1TP_141055_20191119_20191202_01_T1	2019-11-19	04:54:15
	LC08_L1TP_142055_20191126_20191203_01_T1	2019-11-26	05:00:25
	LC08_L1TP_142055_20191212_20191217_01_T1	2019-12-12	05:00:24
	LC08_L1TP_142055_20191228_20200110_01_T1	2019-12-28	05:00:20