Assessment of Changes in Land Cover, Land Surface Temperature and Precipitation and Establishment of a Monitoring System

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***Abstract*—The urbanized have cost significant demand on the local and global natural environment. This demand rises beyond that which Earth can remain sustainability. Thus, evaluating the magnitude and pattern of land use is a need. This research investigated the relationships among land cover change, land surface temperatures, and precipitation in the Aichi Prefecture, Japan. Land cover and land surface temperatures were derived by using Landsat imagery. Then, the satellite-derived temperature algorithm was applied to land cover patterns to view the spatial and temporal changes.**

Precipitation data were collected from ground-based stations. Precipitation data could be obtained at a high frequency and on a virtually near-real-time basis. A meteorological database was then constructed. The information in this database can be communicated on a web-based system and may be valuable as an early warning system for flooding.

***Index Terms*—Flood, land surface temperature, meteorological database.**

I. Introduction

Climate change refers to global warming trends in which increases are occurring in terms of average global temperatures [1]. Human activities such as fossil fuel use are believed to be driving much of this change, and consequently, humans can have an influence on various natural disasters such as floods and wildfires, which may worsen with continued climate change. It is now common understanding that increasing temperatures can lead to decreases in soil moisture and increases in forest susceptibility to wildfires; likewise, increasing temperatures can lead to sea level rise, more rainfall, and increases in the severity of storms (hurricanes, typhoons), all of which may exacerbate flooding [2]. Disasters such as floods and wildfires pose risks to not only humans, but also wildlife, entire ecosystems, buildings, and other infrastructure. Temperature records from the Intergovernmental Panel on Climate Change (IPCC) were collected, and these data were put into a database and evaluated as shown in Fig. 1.

In regard to information sharing, there needs to be a balance between privacy and national security, and access to information is a fundamental human right that is important for ensuring people's safety and security. Japan is a country that provides abundant data to its citizens. Specially, information about disasters and related issues are available through various means (e.g., news outlets and the Internet). Information published by government agencies covers areas at the local level and is useful in terms of details and consistency. Data are available from the Internet; however, there is presently a lack of interactive maps. Thus, further information sharing formats should be developed.

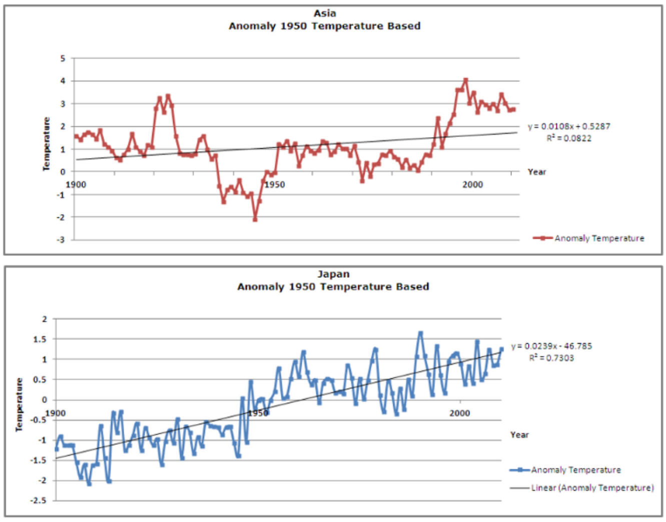

Fig. 1. Temperature normalization in Asia and Japan.

Flood consequences affect property and can multiply economic losses by impacting asset values and living conditions. Flooding over prolonged periods of time can also cause great suffering in afflicted communities. As human activities on land have increased at a high rate, the risks and severity of flooding have become more pronounced. While flooding will inevitably occur in many communities, effective emergency response plans can be used to quickly identify flooding areas and rapidly respond to the needs of people in the flood-affected areas. Several flood mapping approaches exist; however, the development of a system that can investigate flood disasters from satellite images and readily provide information over a web-based interface remains challenging.

There are several research studies that have identified a relationship between the land surface temperature (LST) and land use land cover (LULC). Patil *et al*., [3] focused on the impact of LULC on LST by using Landsat Thematic Mapper (TM) and Operational Land Imager (OLI) images. In their research land coverage indices (such as the normalized difference vegetation index (NDVI), the normalized difference built-up index (NDBI), the normalized difference bareness index (NDBAI), and the normalized difference water index (NDWI)) were calculated. The results showed that the NDVI and the NDWI presented a strong negative

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relationship, whereas NDBAI showed positive relationship with LST. Feng *et al*. [4] investigated the spatial patterns of LST and influencing factors by using Landsat images. They considered similar land coverage indices (NDBI, NDVI, and NDWI) and other factors (such as the proximity factor) as well.

Land use activities can alter the thermal environment, and LST have been used as an indicator to assess changes in climate patterns [5]. The LSTs are of high importance to many aspects of the geosciences, for example, the net radiation budget at the Earth's surface and the monitoring of crop stages as well as changes in regional environments due to the greenhouse effect [6]. Meanwhile, flooding disasters have become more frequent in recent years in association with irregularities in climate. This paper aims to evaluate changes in land cover, land surface temperature, and precipitation in the Aichi Prefecture, Japan, and a meteorological database was constructed. The development of a near-real-time web-based system may help to raise local awareness about the occurrence of natural disasters such as flooding

II. Framework of the Study

The research objectives were to elucidate the relevant relationships among land cover, surface temperatures, and precipitation in the study area, as well as to explore trends in these environmental and meteorological variables. A database was then constructed that can be used to assess rainfall and water levels in the local river basin. This information can be made available through a web-based application.

A. Satellite Imagery and Land Surface Temperatures

The Landsat optical remote sensing system provides the following four primary information types, which can be used for image interpretation research: radiometric (e.g., brightness, intensity, tone); spectral (e.g., color, hue); texture; and geometric and contextual [7]. With these optical image properties, multi-band combination (i.e., RGB) data, and 30-m spatial resolutions, Landsat imagery has been commonly used to detect water bodies and delineate areas of flooding. Various approaches have been utilized (e.g., Landsat, MODIS) to derive flood maps from the optical imagery. For example, Ireland et al. (2015) explored flooded areas by using the Landsat Thematic Mapper (TM) [8].

The Landsat dataset we used was downloaded from the U.S. Geological Survey (USGS) website, where all of the archived data are freely accessible [9]. The Landsat program was initiated in 1965 to gather land surface imagery from space. After intense discussions between supporters and the opposition, Landsat 1 was finally launched in July 1972, and the program has continued since then. More recently, Landsat 8 Operational Land Imager (OLI) with nine spectral bands launched in February 2013. This satellite has provided valuable data and imagery for education, government, and business applications [10]. In this study, top of atmosphere (TOA) spectral radiance data which measured in radiance units were converted from thermal infrared sensor (TIRS) band data by using the radiance rescaling factors, which are provided in the metadata file [11].

In order to calculate the brightness temperature, conversion of digital number (DN) values from Landsat thermal data to spectral radiance was performed. Both Landsat 5 and Landsat 8 were used in this study, and conversion from DN to radiance was performed in accordance with formula (2) for Landsat 8 data and formula (3) for Landsat 5 data, as shown below. Thermal infrared band sensor (TIRS) band data were converted from spectral radiance to brightness temperatures by using the thermal constants provided in the metadata file.

$$L_\lambda = M_L Q_{cal} + A_L \quad (1)$$

L_λ: Top of Atmosphere (TOA) spectral radiance (Watts/(m 2* srad * µm))

M_L: Band-specific multiplicative rescaling factor from the metadata(RADIANCE_MULT_BAND_x, where x is the band number)

A_L: Band-specific additive rescaling factor from the metadata) RADIANCE_ADD_BAND_x, where x is the band number)

Q_{cal}: Quantized and calibrated standard product pixel values (DN)

$$L_\lambda = ((LMAX_\lambda - LMIN_\lambda)/(QCALMAX-QCALMIN)) * (QCAL-QCALMIN) + LMIN_\lambda \quad (2)$$

L_λ: Spectral Radiance at the sensor's aperture in watts/(meter squared * ster * µm)

$LMIN_\lambda$: the spectral radiance that is scaled to QCALMIN in watts/(meter squared * ster * µm)

$LMAX_\lambda$: the spectral radiance that is scaled to QCALMAX in watts/(meter squared * ster * µm)

QCALMIN: the minimum quantized calibrated pixel value (corresponding to $LMIN_\lambda$) in DN

QCALMAX: the maximum quantized calibrated pixel value (corresponding to $LMAX_\lambda$) in DN

Q_{cal}: Quantized and calibrated standard product pixel values (DN)

Source: Landsat [12]

After the TOA spectral radiance was calculated, At-satellite brightness temperatures (T) with units in Kelvin (K) were derived in accordance with formula (3) and (4) applied to Landsat 5, and 8 data, respectively.

$$T = \frac{K2}{ln\left(\frac{K1}{L_\lambda} + 1\right)} \quad (3)$$

$$T = \frac{K2}{ln\left(\frac{K1 * e}{L_\lambda} + 1\right)} \quad (4)$$

T: At-satellite brightness temperature (*K*) L_λ

L_λ: TOA spectral radiance (Watts/(m2 * srad * µm))

$K1$: Band-specific thermal conversion constant from the metadata (K1_CONSTANT_BAND_x, where x is the thermal band number)

$K2$: Band-specific thermal conversion constant from the metadata (K2_CONSTANT_BAND_x, where x is the thermal band number)

e: Land Surface emissivity

For Landsat 8, emissivity needs to be considered in the formula, and it can be calculated from the proportion of vegetation (Pv) where Pv is derived from NDVI in formulas (5) and (6). Conclusively, LST was calculated from formula (7).

$$\text{Land Surface emissivity (e)} = 0.004\ \text{Pv} + 0.986 \quad (5)$$

$$\text{Proportion of Vegetation (Pv)} = [(\text{NDVI-NDVImin}) / (\text{NDVImax} - \text{NDVImin})]^2 \quad (6)$$

$$LST = BT / 1 + w * (BT / p) * \ln(e)) \quad (7)$$

BT: At Satellite Temperature

M_L: Wavelength of emitted radiance (11.5 µm) (Band 11 Landsat 8)

p: p = h * c/s (1.438 *10 -2 m K)

p = 14,380

h = Planck’s constant (6.626 * 10-34 JS)

s = Boltzmann constant (1.38 * 10-23 J/K)

c = velocity of light (2.998 * 108 m/s)

e: Land surface emissivity (e)

B. Database and Visualization

An effective database distribution information system will ensure that locals can receive indispensable information in a timely manner. The script is written to communicate within the database. Information for the two main factors (rainfall and water-level stations) is collected for various locations and attributes. The end product includes a well-visualized map, a chart, a self-identifying function, and a warning alert (Fig. 2)

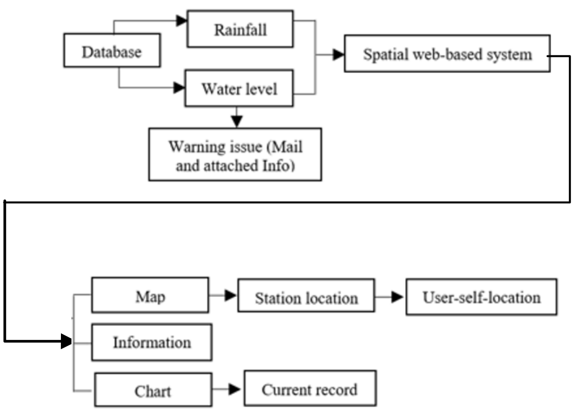

Fig. 2. Meteorological database workflow.

III. RESULTS

Land cover changes and corresponding increase in land surface temperatures

$$L_\lambda = M_L Q_{cal} + A_L \quad (8)$$

$$0.0003342 * [band11] + 0.1$$

The LST results derived from using the formulas listed above, for example, formula (8), are now discussed.

The satellite imagery were applied to study the changes in temperature. As shown in Figs. 3, 4, and 5, the land cover pattern changed mainly from forest to urban in the western part of the Aichi Prefecture, Japan. Following these changes, higher temperatures became apparent and increases were observed in different seasons.

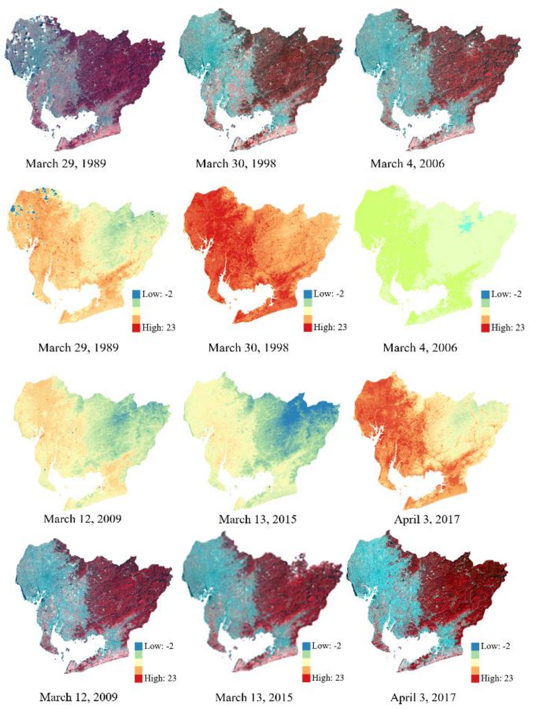

Fig. 3. Comparison during the spring season (March-May).

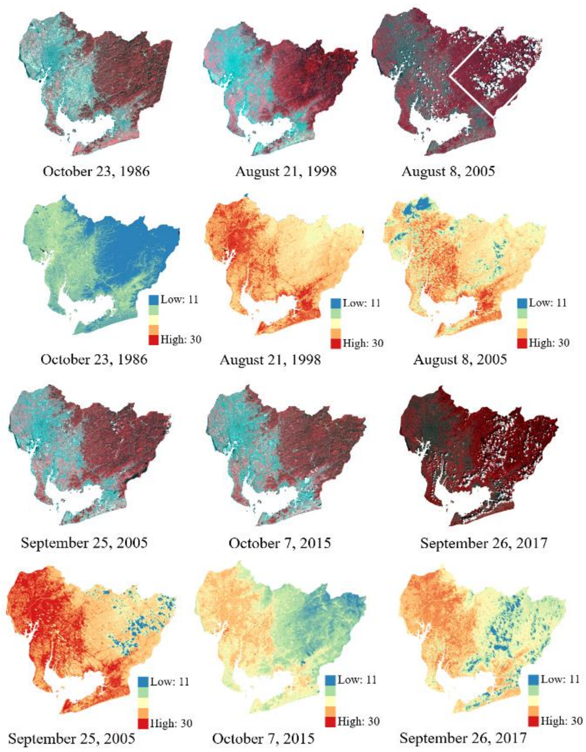

Fig. 4. Comparison during the autumn season (August - October).

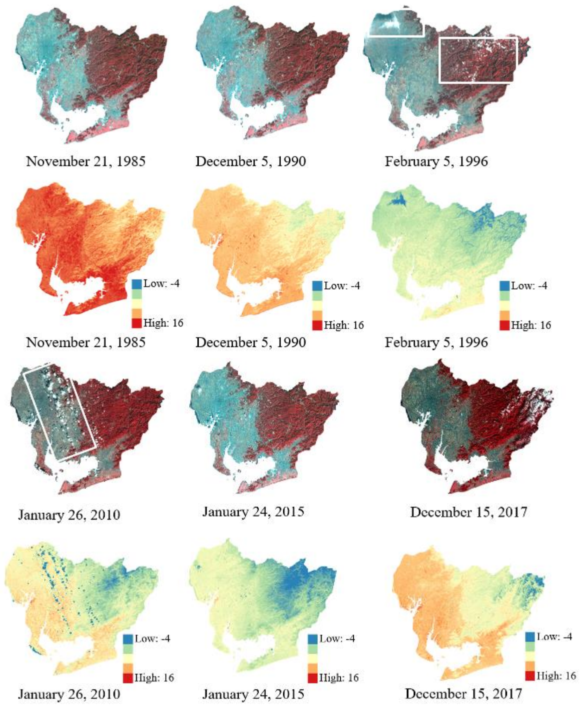

Fig. 5. Comparison during the winter season (November-February).

A. *Meteorological Database for the Near-Real Time Web-Based Application*

The web application was developed to support information sharing (Fig. 6), especially for those living in communities facing potential dangers from floods. The application uses a Geoserver to host the spatial data, and the web-based application shows rainfall station locations and daily precipitation data.

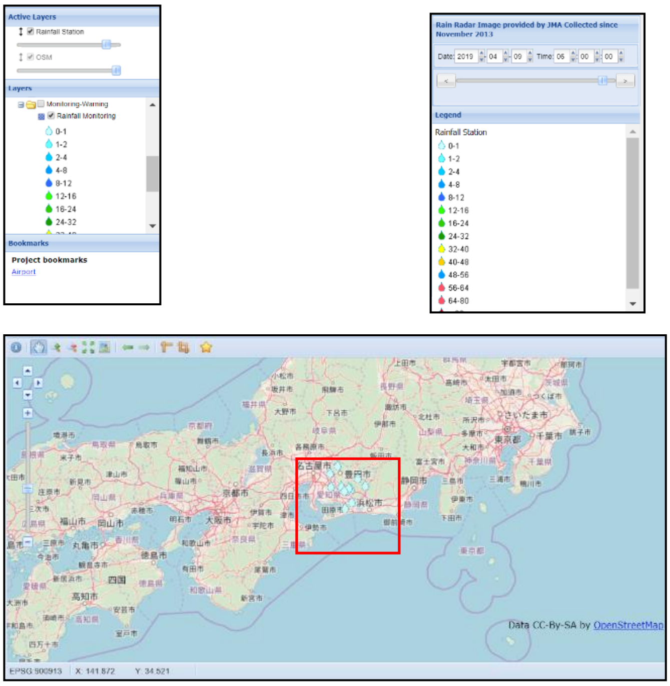

Fig. 6. Web-based communication infrastructure.

IV. Conclusion

Meteorological factors (e.g., rainfall) scan significantly affect the rate of river discharge, and a flood warning database was developed in this study for the Aichi Prefecture in Japan. The centralized geo-database can provide monitoring data in near-real-time, and it is believed that this approach is reliable and may benefit communities prone to flood risks. The significant points of this work were to determine land cover trends derived from satellite imagery, and—ultimately—to make informative data available in a timely manner. The use of a near-real-time system will ensure that the public and relevant agencies can assess emergency information and initiate appropriate and prompt responses.

Flooding risks are expected to increase under continued climate change and human activities, and the new warning system could help to minimize these risks. Developed database would be capable of providing near-real-time information on flooding hazards.

Conflicts of Interest

The author declares no conflict of interest.

Author Contributions

P Limlahapun developed the concept, carried out the analysis of this study, as well as revised and finalize the article.

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References

[1] Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2018: Summary for Policymakers*, IPCC, Switzerland, 2018.

[2] K. E. Trenberth, "The impact of climate change and variability on heavy precipitation, floods, and droughts," National Center for Atmospheric Research, Boulder, Colorado, United States.

[3] A. S. Patil, S. Panhalkar, S. Bagwan, and S. Bansode, "Impact of land use land cover change on land surface temperature using geoinformatics techniques," *International Journal of Research and Analytical Reviews*, vol. 5, issue 4, pp. 550-559.

[4] Y. Feng, C. Gao, X. Tong, S. Chen, Z. Lei, and J. Wang, "Spatial patterns of land surface temperature and their Influencing factors: A case study in Suzhou, China," *Remote Sensing*, vol. 11, issue 2, January 2019, pp. 182-202.

[5] S. Dewitte and N. Clerbaux, "Measurement of the earth radiation budget at the top of the atmosphere," *Remote Sensing*, vol. 9, issue 11, November 2017.

[6] J. H. Davies and D. R. Davies, "Earth's surface heat flux," *Solid Earth Discuss*, vol. 1, pp. 5-24, February 2010.

[7] N. Levin, *Fundamental of Remote Sensing*, Remote Sensing Laboratory, Tel Aviv University, Esrael, 1999.

[8] G. Ireland, M. Volpi, and G. P. Petropoulos, "Examining the capability of supervised machine learning classsifers in extracting flooded area from landsat Tm imagery: A case study from a Mediterranean flood," *Remote Sensing*, vol. 7, issue 3, pp. 3372-3399, March 2015.

[9] U.S. Geological Survey (USGS). [Online]. Available: https://earthexplorer.usgs.gov/

[10] A. B. Pour and M. Hashim, "The application of Landsat-8 OLI/TIRS data for geological mapping: A case study from SE Iran," in *Proc. the 35th Asian Conference on Remote Sensing*, At Nay Pyi Taw, Myanmar, October 27-31, 2014.

[11] J. M. Edwards, "Simulation of land surface temperatures: Comparison of two climate models and satellite retrievals," *Geoscientific Model Development*, vol. 2, pp. 123-136, August 2009.

[12] U.S. Geological Survey (USGS). Landsat science products: Landsat surface reflectance. [Online]. Available: https://www.usgs.gov/land-resources/nli/landsat/landsat-surface-reflectance?qt-science_support_page_related_con=0#qt-science_support_page_related_con

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