Eskom	Standard	Technology

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Executive Summary

GIS Centre of Excellence under the Distribution Division - is responsible for all geographic information system and science standard compilation and implementation. It is also a voting member of national standards body SABS TC211 and actively involved in the work of the International Organization for Standardization ISO TC211. GIS CoE collaborates with SABS, governmental and non-governmental organisations on matters of standard compilation.

Standardising thermal mapping is critically important to Eskom to ensure safety of personnel, electrical infrastructure and ensuring security of power supply to its users. Eskom relies on coal fired power stations to produce approximately 90% of its electricity and 10% is generated from hydro, nuclear and renewables. Eskom is currently acquiring coal from Mpumalanga, Limpopo and Free State provinces. In the country there are active and inactive coal mines, however some decommissioned coal mines have coal seams which result in high land surface temperature.

Remote sensing technology is used to identify areas with high land surface temperature due to underground coal fire and to enable the specialist in the field to map the thermal anomalies. This document will serve as standard to be followed when performing thermal mapping and thermal anomalies. The LST is the estimated average ground surface temperature calculated from measured radiance (Norman & Becker, 1995). Thermal anomalies are understood to be caused by excessive soil heat flux transferred to the land surface through conduction and convention. The temperatures are normally higher than those of the surrounding areas or deviated from known normal temperature. The LST estimation depends on several factors such as the albedo, soil moisture and the vegetation cover. Vegetation and bare soil respond quickly to changes in incoming solar radiation due to cloud cover and aerosol load modifications and diurnal variation of illumination, and so does the LST.

The electrical infrastructure of the South African power utility (Eskom) is its main asset in ensuring that the utility delivers on its mandate to supply energy to this country. Part of the land on which the said structures are built is an area with old abandoned coal mines which were not properly rehabilitated thereby causing spontaneous combustion of coal due to coal oxidation.

Spontaneous combustion causes the land surface temperature to rise above normal temperature causing the ground to subside and areas to be of high temperature. Various methods for detecting and monitoring coal seam fires using thermal infrared remotely sensed data have been developed.

1. Introduction

The electrical infrastructure of the South African power utility (Eskom) is its main asset in ensuring that the utility delivers on its mandate to supply energy to this country. Part of the land on which the said structures are built has high surface temperature causing these structures to weaken and collapse, resulting in an interrupted power supply to its customers. The term 'surface temperature' in this case refers land surface temperature anomaly caused due to coal spontaneous combustion, especially for the underground coal seam or any other thermal matter. This is generally due to the lack of rehabilitation of decommissioned mines. The high land surface temperature may cause ground instability or pose danger to people. Extreme high surface temperature could cause devastating damage to any infrastructure; such as buildings, bridges or utility infrastructure, such as pylons, high voltage lines, coal silos and communities.

This standard is required to ensure that there is homogeneous remote sensing and GIS of thermal mapping products. It also defines the validation stages and product validation methodologies.

A classification system can be used to subdivide any geographic area into small units, each of which carries an identifier that describes its type. The results can then be represented as a discrete coverage as described in ISO 19123-1.

The intention of this standard is not to define a comprehensive classification thermal mapping, but to specify the contents of categories that are of critical importance.

2. Supporting clauses

2.1 Scope

This document outlines the processing, validation and classification of land surface temperature due to localised geothermal anomalies derived from remote sensing product/s.

In order to accomplish this purpose, this part of standard specifies elements that are necessary to achieve acceptable product. It specifies the use of discrete coverages to represent the result of applying the classification system to an area in accordance with SANS 19144-1:2012/ISO 19144-1:2009.

2.1.1 Purpose

The purpose of this document is to provide Eskom subject experts and service providers with clear understanding of thermal mapping classification in localised land surface temperature geothermal anomalies product/s validation method.

2.1.2 Applicability

This document shall apply throughout the Eskom Holdings SOC Limited, its Divisions and service providers.

2.2 Normative/informative references

Parties using this document shall apply the most recent edition of the documents listed below.

2.2.1 Normative

[1] ISO 9001, Quality Management Systems.

[2] 240-75884518 Mapping and Survey Standard for Datum Transformation (Cape to Hartebeeshoek Datum)

[3] 240-127886532, Land Cover Classification Standard

[4] 240-75884558, Standard for Metadata for Spatial Datasets

[5] 240-127750926, Geomatics Management PCM

[6] 240-75908613, Supply of Digital Orthorectified Imagery

[7] 240-150755574, Satellite Imagery Acquisition

2.2.2 Informative

[8] 240-75907219 Specification for Importation of Data into the National Geographic Information System

[9] Infrastructure for Spatial Information in Europe (INSPIRE) http://inspire.ec.europa.eu/Technical-Guidelines/Data-Specifications/2892

[10] Regulations Promulgated in Terms of Section 10 of the Land Survey Act, 1997 (Act No. 8 of 1997).

[11] 240-75909181, Directive Regarding the Sharing of Spatial Information

[12] Guidelines for using Remote Sensing Derived Information in support of the IPC Analysis at http://www.ipcinfo.org/fileadmin/user_upload/ipcinfo/docs/1_RemoteSensedData_IPC_JRC_guidelines.pdf

[13] A technical handbook supporting calibration and validation activities of remotely sensed data products http://qld.auscover.org.au/public/html/AusCoverGoodPracticeGuidelines_2015_2.pdf

[14] 19144-1, Geographic information - Classification Systems - Part 1: Classification system structure

[15] SANS 19144-2:2014/ISO 19144-2:2012 Geographic information- Classification systems - Part 2 Land cover Meta Language(LCML).

[16] SANS 1877:2004 A standard land-cover classification scheme for remote-sensing applications in South Africa.

[17] ISO/TS 19163-1 Geographic information — Content components and encoding rules for imagery and gridded data — Part 1: Content model, as sent to ISO for publication

[18] ISO/TS 19129:2009 Geographic information - Imagery, gridded and coverage data framework.

[19] ISO/TS 19159-1:2014 Geographic information — Calibration and validation of remote sensing imagery sensors and data – Part 1: Optical sensors

[20] Land Surface Temperature Product Validation Best Practice Protocol(pp.27)https://lpvs.gsfc.nasa.gov/PDF/CEOS_LST_PROTOCOL_Feb2018_v1.1.0_light.pdf

2.3 Definitions

2.3.1 General

Definition	Description
Attribute	Named property of an entity
DEM	The digital elevation model is a digital model or 3D representation of a terrain's surface
Gridded data	Data whose attribute values are associated with positions on a grid coordinate system
Imagery	Representation of phenomena as images produced by electronic and/or optical techniques
Img file format	ERDAS IMAGINE Image
Jpeg 2000	Is a compression standard enabling both lossless and lossy storage
Orthorectified	An image that has a constant scale where features are represented in their ‘true’ positions through removing distortion and making the image conform to a map projection and correct terrain displacement.

Definition	Description
Remote Sensing	Remote sensing is the science of acquiring data and its information technology to monitor, identify and measure objects on earth’s surface without coming into direct contact with it
Shapefile (shp) file format	ESRI, Inc. digital vector (non-topological) storage format for storing geometric location and associated attribute information for geographic information systems software.
Spatial Resolution	Number of pixels utilised in construction of a digital image.
Spectral Resolution	Number of bands on the multispectral image.
Temporal resolution	Satellites revisit time on the same spot of the earth’s surface.
Thematic data	Gridded data whose attribute values describe characteristics of a grid coverage feature in a grid format

2.3.2 Disclosure classification

Controlled disclosure: controlled disclosure to external parties (either enforced by law, or discretionary).

2.4 Abbreviations

Abbreviation	Description
AOI	Area of Interest
CoE	Centre of Excellence
EM	Electro-Magnetic
ESRI	Environmental Systems Research Institute
GeoTiff	Georeferenced Tagged Image File Format
GIS	Geographical Information Systems
GIS CoE	Geographic Information Science Centre of Excellence
ISO	International standardisation organisation
ISO/TS	International standardisation organisation technical standard
Jpeg2000	Joint Photographic Experts Group 2000
KML	Keyhole Markup Language.
KMZ	Keyhole Markup language Zipped
LCML	Land cover Meta Language
LPV	Land validation product
LST	Land surface temperature
PCM	Process control manual
RMSE	Root Mean Square Error

2.5 Roles and responsibilities

GIS CoE is responsible to ensure implementation and compliance of this standard. GIS CoE, and/or the department that will be collecting the data, will assess and ensure that the final products have been quality assured and fit for business use. All parties working with or working for Eskom Holdings SOC Limited and its subsidiaries shall comply with the contents of this document.

2.6 Process for monitoring

Quality assurance results and final product will inform GIS CoE, and/or the department if the document is adhered to.

2.7 Related/supporting documents

Not applicable.

3. Thermal survey mapping

3.1 Data Acquisition

Images are acquired from visible and infrared sensors by detecting the radiation reflected or emitted from target objects [ISO/TS 19101-2]. Different materials reflect, absorb or emit radiation at different wavelengths, and accordingly each object type has a spectral signature. Analysing spectral signatures within remotely sensed images identifies differentiation between these objects. Thus, images may be classified depending on the number of spectral bands, for example multispectral, thermal infrared and hyperspectral.

The specialist will create an AOI polygon or kmz files to be used to identify the location of data to be acquired. To map land surface temperature, specialised sensors on-board of platform shall have thermal infrared wavelength. Thermal aerial camera calibration certificate need to be presented with the results of which need to be calibrated according to ISO/TS 19159-1:2014. The acquisition shall conform to Geomatics Management PCM. All acquisition and pre-processing of imagery shall be done in accordance to satellite imagery acquisition standard 240-150755574 and Supply of Digital Orthorectified Imagery 240-75908613.

3.2 Analysis

Thermal infrared satellite images and aerial images extract ground surface temperature values through the use of LST algorithms. In areas with high temperature and humidity (Wang et al., 2019) recommended the use Split-Window (SW) algorithm because of its ability to yield the best results as compared to mono-window algorithm (MWA) and the single-channel (SC) method. Annexure A to annexure C is SW, MWA and SC algorithm workflow.

3.2.1 Geothermal anomaly detection

LST estimation provides users with the potential for identifying geothermal anomalies. Areas used for coal mining and areas that are prone to volcanic activities tend to have higher surface temperatures than what is deemed normal temperature for the surrounding area.

A study by (Qin, Zhang, Nan, and Chai, 2011) detected geothermal anomalies as areas with temperatures of approximately 4-10 K (4 to 10 degrees Celsius) higher than the surrounding area.

LST values with higher than normal value are selected for further analysis, such as heat source, geological structures and to check for any false anomaly detection. Areas with temperatures above normal ground temperature were verified and classified as a possible geothermal anomaly. In all instances, the hotspots were verified taking into account the surrounding environment such as:

- Geology
- Vegetation
- Water/wetland areas

- Topography
- Under Mining
- Land use / type (mining, farming and so forth).
- Land cover

Where surface temperature was 4 to 10 degrees Celsius higher than the normal surrounding areas were identified as possible anomalies, and subsequently verified to exclude false anomaly detection.

$LSTanomaly = LSTclass/LST\ mean$

Where,

LSTclass = individual mean LST for each land cover type.

LSTmean = average of all the mean for all land cover types

3.3 Validation Stages of thermal mapping Product

To ensure that the thermal mapping product is of high quality standard and aligned to international body of knowledge such as CEOS WGCV Land Product Validation (LPV) subgroup, as shown in **Table 1** Eskom has identified three validation levels corresponding to increasing spatial and temporal representativeness of samples used to perform direct validation. The thermal mapping validation protocol (Guillevic et al., 2017) includes these aspects and supplements them with requirements for assessing the spatial and temporal precision of individual products.

Table 1: Land Product Validation Stages

Stages	Validation
Stage 0 Validation	Raw data collected. No validation reported.
Stage 1 Validation	Apply adjustment of errors technique. Product accuracy is assessed from a small (typically < 30) set of locations and time periods by comparison with in situ or other suitable reference data.
Stage 2 Validation	Product accuracy is estimated over a significant set of locations and time periods by comparison with reference in situ or other suitable reference data. Spatial and temporal consistency of the product with similar products has been evaluated over globally representative locations and time periods. Comparison of computer processed results vs ground measured results
Stage 3 Validation	Uncertainties in the product and its associated structure are well quantified from comparison with reference in situ or other suitable reference data. Re-computing of the data used (RMSE error) measured results.

3.4 Validation Methods

Product validation is a critical to ensure that the thermal mapping data can be used with confidence and to assess thermal mapping products compliance with specifications and to ensure that the product is of highest quality (Li et al., 2013). The following methods have been widely used to validate and determine the uncertainties in thermal products derived from remote sensing imagery;

1) Temperature-based method (T-based) validation approach involves comparisons of satellite LST product and ground-based LST (in situ LST) product. This method is the most recommended to validate satellite LST measurement. From the satellite LST product the specialist need to identify thermally homogeneous area, secondly the specialist is required to go to the field and measure several points by ground instruments within the validation site and compared with the satellite-derived LST at the pixel scale.

2) The Radiance-based (R-based) method is an advanced alternative method for validating satellite LST measurements, it does not require in situ measurements, but instead requires accurate estimates of channel specific surface emissivity values, as well as atmospheric temperature and water vapour profiles coincident with the satellite overpass. The advantage of the R-based method is that it can be applied to sites where the emissivity is known.

3) Cross validation method is an alternative method for LST validation if there are no atmospheric profiles or ground LST measurements available or if the T- and R-based validations cannot be conducted. The LST product need to be well validated and to use it as a reference and compares the satellite-derived LST to be validated with the referenced (well validated) LST derived from other satellites (Trigo et al., 2008). Due to the large spatial and temporal variations in the LST, geographic coordinate matching, temporal matching, and viewing zenith angles (VZA) matching have to be performed before the two satellite-derived LST products can be compared.

3.5 Classification of validates results (data)

It is crucial for the dataset to be classified so that the engineers and other stakeholders can make accurate decisions regarding the next actions to be taken. The actions can be; whether to relocate the infrastructure or develop risk strategy to avoid costly collapse of infrastructure.

The classification of the final data product shall be presented as follows;

- Numerical (quantitative) – it must be in degree Celsius (Minimum precision – 1 degree Celsius interval).
- Categorical (qualitative) - thematic map.

Raster - the data will be classified according to the temperature in degree Celsius showing the five classes

For shape files - all polygons provided shall have temperature class attribute with temperature values and land use attribute field.

3.5.1 Colours Ramp and classification ranking

Four temperature classifications ranking where identified in **Table 2** to ensure better understanding on a decision that need to be undertaken on infrastructure.

Table 2: Colours Ramp and classification ranking

Temperature values in °C	Classification	Colour Code	Description
< 0	Below Freezing	Blue	Any land surface temperature that is below 0°C is classified as below freezing point. The blue colour shall not be interpreted as representing water bodies.
0 – 20	Cool	Green	Any land surface temperature that is between 0°C and 20°C is classified as cool. The green colour shall not be interpreted as representing vegetation.
20 - 40	Warm	Yellow	Any land surface temperature that is between 20°C and 40°C is classified as warm. False anomalies shall be verified and excluded in the data.
40 - 60	Hot	Orange	Any land surface temperature that is between 40°C and 60°C is classified as hot. False anomalies shall be verified and excluded in the data.
≥ 60	Extremely Hot	Red	Any land surface temperature that is above °C and 60°C is classified as hot. False anomalies shall be verified and excluded in the data.

The above classification may also be represented in degree value range of 0°C to10°C and 0°C to 5°C as may be deemed necessary by the specialist discretion. This is done to accommodate other scenarios that may arise during a geospatial analysis.

4. Coordinate reference system (CRS)

A coordinate system is a reference system for identifying locations on the surface of the earth. Locations on the earth's surface are measured using two planes, equator and prime meridian. A location is therefore defined by latitude value and a longitude value, but on projected coordinate system is X and Y. all satellite images shall be supplied using the following coordinate system except specified otherwise.

- Geographic coordinate system

Unit: Decimal degrees

Ellipsoid: WGS84

Datum: Hartebeeshoek94

- Projected coordinate system;

Coordinate system: Lambert conformal conic

Unit: Meters

Ellipsoid: WGS84

Datum: Hartebeeshoek94

Format of data

The product shall be delivered in one or more of the following formats and any deviation shall be authorized by Eskom:

Rendered data

- Jpeg 2000 - preferred
- GeoTiff
- Imagine (IMG)

Raster lossless format

- CSV
- GeoTiff
- Gridded format

Data delivery

All data shall be supplied in digital format on an external memory device or file transfer facility e.g. FTP, large file transfer or any other means acceptable to Eskom.

The image shall be clipped into one degree, half degree grid, Quarter degree or three minutes grid and named as such including polygon shapefile or kmz. All supplied data product should be accompanied by a Metadata file, according to Eskom Standard for Metadata for Spatial Datasets 240-75884558.

The following shall form part of the deliverable package.

- Raw dataset
- Rendered map(s);
- Validation results;
- Metadata;

- Grid file;
- Full report with methodology and validation technique used;

5. Authorization

This document has been seen and accepted by:

Name and surname	Designation
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6. Revisions

Date	Rev	Compiler	Remarks
Oct 2020	1	T. Mphaphuli	First issue

7. Development team

The following people were involved in the development of this document:

- Tshisikhawe. Mphaphuli
- Thandi Msibe
- Derrick Wells
- Lydia Zeko
- Dumisani Sibande

8. Acknowledgements

Not applicable.

9. Bibliography

Guillevic, P., Göttsche, F., Nickeson, J., Hulley, G., Ghent, D., Yu, Y., Trigo, I., Hook, S., Sobrino, J., & Remedios, J. (2017, pp.27). Land surface temperature product validation best practice protocol. Version 1.0. *Best Practice for Satellite-Derived Land Product Validation*, 60.

Li, Z.-L., Tang, B.-H., Wu, H., Ren, H., Yan, G., Wan, Z., Trigo, I. F., & Sobrino, J. A. (2013). Satellite-derived land surface temperature: Current status and perspectives. *Remote Sensing of Environment*, *131*, 14–37.

Norman, J. M., & Becker, F. (1995). Terminology in thermal infrared remote sensing of natural surfaces. *Agricultural and Forest Meteorology*, *77*(3–4), 153–166.

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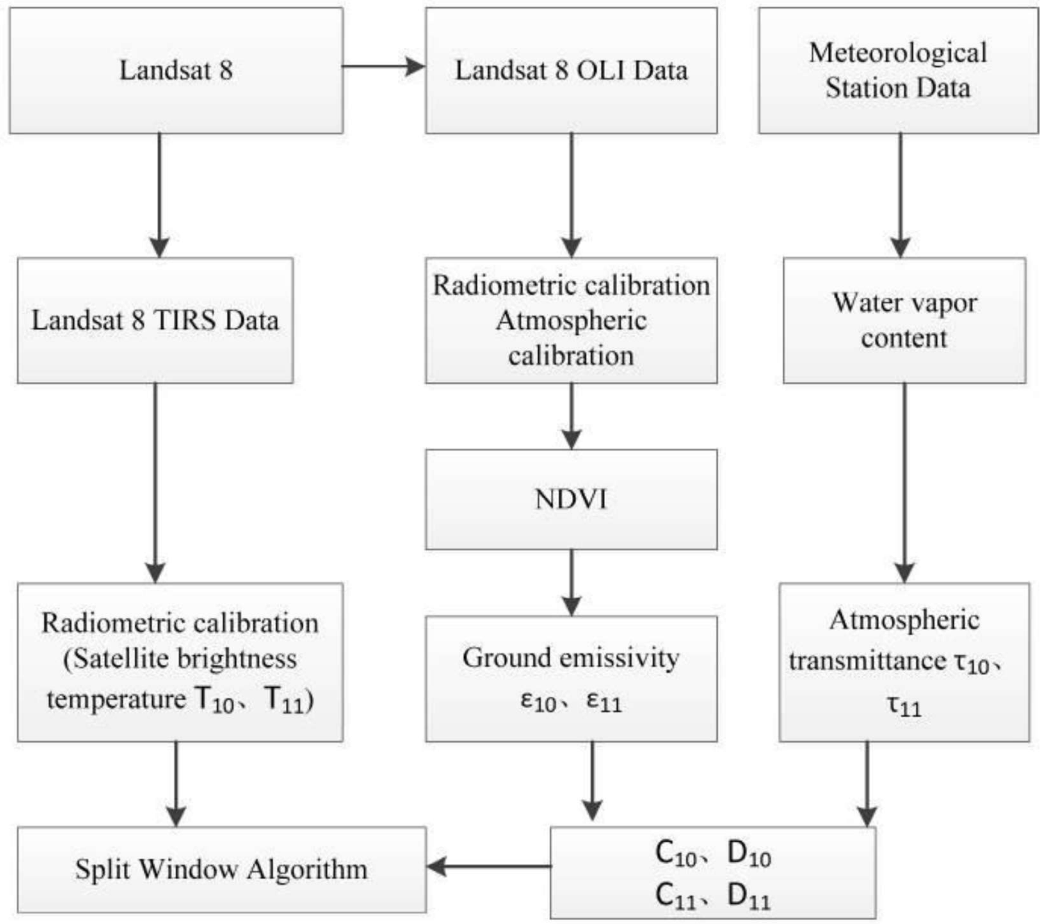
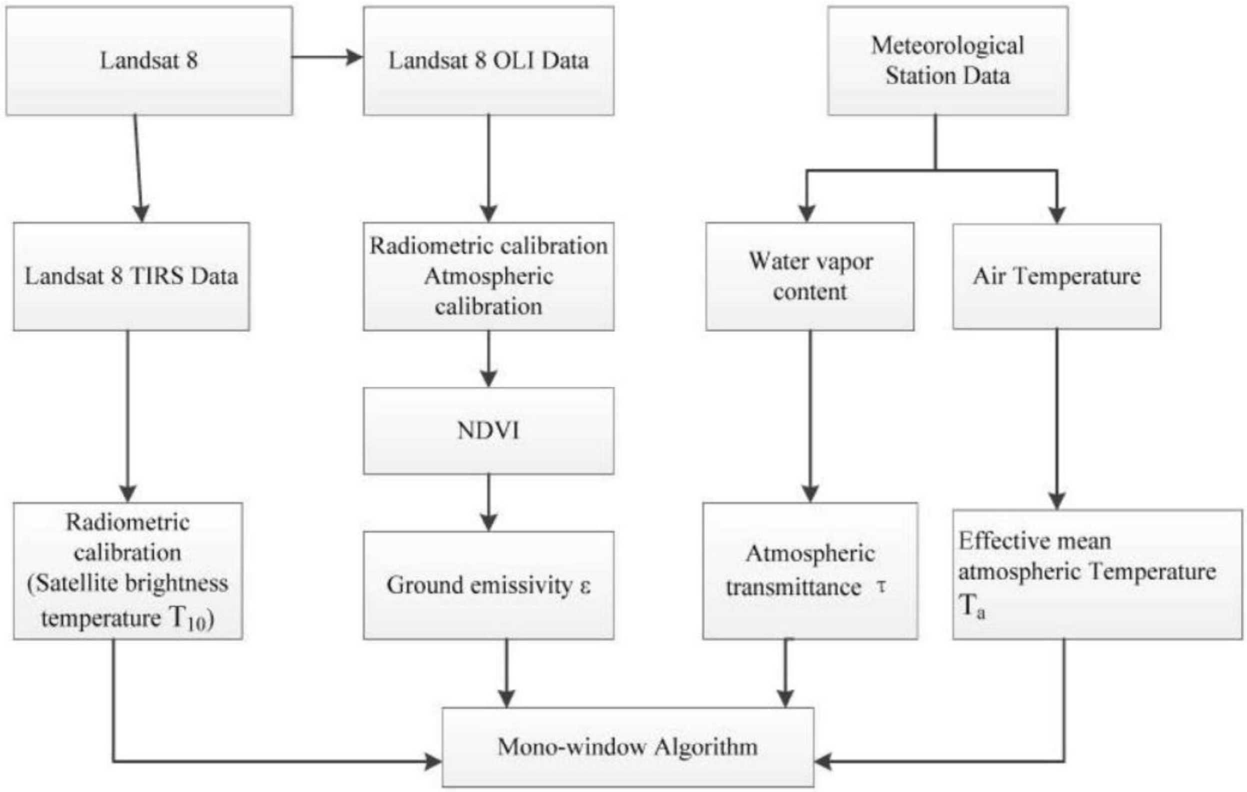
Wang, L., Lu, Y., & Yao, Y. (2019). Comparison of Three Algorithms for the Retrieval of Land Surface Temperature from Landsat 8 Images. *Sensors (Basel, Switzerland)*, *19*(22), 5049. PubMed. https://doi.org/10.3390/s19225049

Annex A – Flow chart of the split window algorithm



Annex B – Flow chart of the mono-window algorithm



The above diagram present method to be used to extract the terrestrial surface temperature from satellite images.

LST is land surface temperature; LSE is land surface emissivity

Annex C – Flow chart of the single-channel method

Working scheme of the single-channel method for Landsat 8 images;