
Thermal Infrared Remote Sensing For Detecting Groundwater Seepage in Earthen Embankments

Dr. Arjun Mehta

Associate Professor

Department of Civil Engineering

National Institute of Technology, Jaipur

Email: *arjun.mehta@nitj.ac.in*

Ms. Riya Sharma

Research Scholar

Department of Geoinformatics

National Institute of Technology, Jaipur

Email: *riya.sharma@nitj.ac.in*

Abstract

Groundwater seepage in earthen embankments poses a significant threat to the structural stability and safety of dams, levees, and irrigation canals. Traditional seepage detection techniques often require extensive manual inspection and invasive testing, which can be time-consuming and costly. Thermal Infrared (TIR) remote sensing has emerged as a non-invasive, cost-effective, and efficient technique to identify seepage zones by detecting thermal anomalies caused by temperature contrasts between infiltrating water and surrounding soils. This paper reviews the principles of TIR remote sensing applied to seepage detection, discusses the methods of data acquisition and processing, and analyzes the interpretation of thermal patterns in embankment monitoring. A case study is presented to demonstrate the use of satellite and UAV-based thermal imaging to map seepage in a large earthen dam. A table summarizing key thermal parameters used for seepage identification is included. Limitations, challenges, and future prospects of TIR sensing in geotechnical engineering are also

discussed. The paper concludes that TIR remote sensing is a promising tool that supplements conventional techniques, enabling timely identification and mitigation of seepage-related failures.

Keywords: *Thermal Infrared Remote Sensing, Groundwater Seepage, Earthen Embankments, Thermal Anomalies, UAV Thermal Imaging, Satellite Thermal Data, Embankment Stability*

INTRODUCTION

Earthen embankments, including dams, levees, and canals, are critical infrastructures for water resource management and flood control. Groundwater seepage through these embankments can lead to internal erosion, piping, and eventual structural failure. Detecting seepage zones at an early stage is vital for maintenance and risk mitigation.

Traditional seepage detection methods such as piezometer installation, visual inspections, and drilling are often labor-intensive, expensive, and provide point-based information. Thermal Infrared (TIR) remote sensing offers a rapid, non-contact alternative that identifies seepage by detecting temperature differences caused by cooler groundwater infiltrating warmer embankment soils or vice versa.

This paper explores the application of TIR remote sensing in detecting groundwater seepage in earthen embankments, detailing the sensing mechanisms, data acquisition platforms, data interpretation techniques, and practical case studies.

PRINCIPLES OF THERMAL INFRARED REMOTE SENSING FOR SEEPAGE DETECTION

Thermal infrared sensors measure emitted radiation in the wavelength range typically between 8 and 14 micrometers, corresponding to the Earth's surface temperature. Water infiltrating through soil affects the surface temperature due to its thermal properties and heat capacity differences compared to dry soil.

- **Temperature Anomalies:** Seepage zones appear as thermal anomalies—either warmer or cooler patches—depending on ambient conditions, seepage water temperature, and diurnal cycles.
- **Heat Flux Dynamics:** Infiltrating water alters the local heat flux at the surface by conduction and convection, creating detectable thermal contrasts.
- **Temporal Variability:** Thermal signatures of seepage may vary with time (day/night cycles), requiring multi-temporal observations for accurate mapping.

DATA ACQUISITION AND PROCESSING

Platforms:

- **Satellite-Based TIR Sensors:** Satellites like Landsat 8 TIRS and MODIS provide multispectral thermal data with moderate spatial and high temporal resolution, useful for large embankment systems.
- **Unmanned Aerial Vehicles (UAVs):** UAVs equipped with high-resolution thermal cameras offer flexible, high spatial resolution imaging suitable for targeted seepage investigations.
- **Ground-Based Thermal Cameras:** For detailed inspections, handheld or tripod-mounted thermal cameras provide localized data.

Data Processing Steps:

1. **Radiometric Calibration:** Conversion of raw sensor data to at-surface temperature values.
2. **Atmospheric Correction:** Removing atmospheric effects such as water vapor absorption.
3. **Image Enhancement:** Contrast stretching and filtering to highlight thermal anomalies.
4. **Change Detection:** Multi-temporal thermal images are compared to identify persistent seepage areas.
5. **Georeferencing and Integration:** Thermal maps are integrated with GIS data for spatial analysis and correlation with known seepage points.

INTERPRETATION OF THERMAL DATA

- **Thermal Patterns Identification:** Seepage zones generally exhibit distinctive temperature deviations relative to surrounding areas.
- **Influencing Factors:** Ambient temperature, solar radiation, soil moisture, vegetation cover, and wind affect thermal readings and must be accounted for.
- **Validation:** Ground truthing through soil moisture measurements, piezometers, or borehole data is essential to confirm seepage detected from thermal anomalies.

TABLE 1: Thermal Infrared Parameters for Groundwater Seepage Detection

Parameter	Description	Relevance for Seepage Detection	Typical Range
Surface Temperature	Temperature of embankment surface	Anomalies indicate seepage zones	10–35 °C (varies by location)
Thermal Contrast	Temperature difference between seepage and dry areas	Highlights seepage-induced anomalies	1–5 °C difference
Diurnal Temperature Variation	Change of surface temperature from day to night	Persistent anomalies confirm seepage	3–10 °C variation
Emissivity	Surface material’s thermal radiation efficiency	Important for accurate temperature retrieval	0.90–0.98
Thermal Gradient	Spatial rate of temperature change	Sharp gradients often correspond to seepage locations	Variable

Table 1: Key thermal parameters utilized in seepage detection.

CASE STUDY: SEEPAGE DETECTION IN A LARGE EARTHEN DAM

A study was conducted on the [fictional] Rajapur Earthen Dam, located in a semi-arid region with a history of seepage issues. Landsat 8 TIRS data were analyzed over a six-month period to

detect thermal anomalies. Subsequently, UAV thermal imaging provided high-resolution data focusing on suspected zones.

Key findings included:

- Satellite thermal data identified broad areas with cooler temperatures correlating with known seepage locations.
- UAV data revealed fine-scale thermal patterns with anomalies aligned to seepage exits visible during field inspection.
- Multi-temporal analysis confirmed persistence of thermal anomalies, ruling out transient surface temperature effects.
- GIS integration with embankment structural data enabled prioritizing monitoring and repair actions.

DISCUSSION

Thermal infrared remote sensing is an effective non-invasive technique to detect groundwater seepage in earthen embankments. Advantages include large area coverage, rapid data acquisition, and the ability to monitor inaccessible locations.

Challenges include:

- Environmental factors (e.g., weather, vegetation) that can mask seepage signatures.
- Need for multi-temporal and multi-sensor data to improve reliability.
- Requirement of complementary ground data for validation.

Future research should focus on integrating TIR with other geophysical methods and developing automated anomaly detection algorithms to enhance seepage monitoring efficiency.

CONCLUSION

Thermal Infrared remote sensing provides valuable insights into groundwater seepage detection in earthen embankments by capturing surface temperature anomalies linked to infiltrating water. The combined use of satellite and UAV thermal imaging enables effective mapping and monitoring of seepage zones over different scales and temporal resolutions. Despite environmental limitations, TIR remote sensing supplements traditional techniques, improving early warning and maintenance planning. Continued advancements in sensor technology, data

processing, and integration with GIS will strengthen its role in geotechnical and water resource engineering.

.

REFERENCES

- [1] Abdel-Aal, M. et al., “Thermal Infrared Remote Sensing for Detection of Seepage in Earthen Dams,” *Journal of Hydrology*, vol. 556, pp. 693–703, 2018.
- [2] Chang, N.B., et al., “Multi-Temporal Thermal Infrared Imaging for Dam Safety Monitoring,” *Remote Sensing*, vol. 11, no. 3, pp. 298, 2019.
- [3] Dutta, D., et al., “Applications of UAV Thermal Imaging in Embankment Monitoring,” *Geotechnical Engineering*, vol. 172, pp. 103-110, 2020.
- [4] Jackson, T.J., “Microwave Remote Sensing of Soil Moisture and Seepage Detection,” *Hydrological Processes*, vol. 23, no. 5, pp. 678–687, 2017.
- [5] Li, W., et al., “Thermal Anomaly Detection for Groundwater Seepage Using Landsat Data,” *Environmental Monitoring and Assessment*, vol. 191, 2020.
- [6] Smith, J., and Brown, R., “Integration of Thermal Remote Sensing and GIS for Dam Safety,” *Journal of Infrastructure Systems*, vol. 26, no. 4, 2020.
- [7] Turner, D., et al., “Thermal Remote Sensing for Geotechnical Applications,” *IEEE Transactions on Geoscience and Remote Sensing*, vol. 54, no. 7, pp. 3898–3907, 2016.
- [8] Wu, C., et al., “Thermal Remote Sensing for Seepage Monitoring: Challenges and Opportunities,” *International Journal of Remote Sensing*, vol. 40, no. 3, pp. 1095–1112, 2019.