SAR-NDWI Integration in Ephemeral Water Detection Mapping for Hydrological Analysis in ASALs

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Abstract

Arid and semi-arid lands (ASALs) like Marsabit and Isiolo Counties in Kenya face significant water scarcity, necessitating accurate mapping of surface water resources. Even with mostly dry and arid conditions in these regions, the areas also experience flash floods and downpours that quickly flow through wadis and rivers flowing away from these regions. This study leverages a multi-sensor remote sensing approach, combining Synthetic Aperture Radar (SAR) data from ALOS PALSAR and optical data from Landsat 8 (NDWI), to map water availability in the years 2020 and 2019. The research being the first step series to leveraging multi-sensor analysis and Digital Twins to understand the dynamic nature of ASALs. The results highlight the superiority of SAR in detecting ephemeral and obscured water features, revealing a vast "SAR-only" water area compared to a minimal "common water" area identified by both sensors. A novel experimental Multi-Sensor Water Index (MSWI) was developed to enhance detection accuracy, demonstrating its utility in capturing dynamic hydrological processes. These findings underscore the critical role of SAR in water resource management for ASALs, providing insights for drought resilience, pastoralist livelihoods, and sustainable water planning.

Acronyms/Abbreviations: **SAR** (Synthetic Aperture Radar), **NDWI** (Normalized Difference Water Index), **ASALs** (Arid and Semi-Arid Lands)

1. INTRODUCTION

Water scarcity in arid and semi-arid lands (ASALs) poses a significant challenge for communities and ecosystems. Marsabit and Isiolo Counties are amongst the 17 counties in Kenya, characterized by erratic rainfall and prolonged droughts, rely heavily on transient water resources that fail to meet the needs of human settlements and pastoralist communities. Traditional optical remote sensing methods, such as the Normalized Difference Water Index (NDWI), often fail to capture regions exhibiting ephemeral water features like wadis, seasonal rivers or flat river valleys due to cloud cover and vegetation obscuration. [1] Synthetic Aperture Radar (SAR), with its ability to penetrate clouds and detect surface smoothness, offers more insight into the water situation of a region and how it can be harnessed to improve the lives of people living in the region. [2] [3] [4]

This study aims to:

1. Evaluate the effectiveness of SAR (ALOS PALSAR) and optical (Landsat 8 NDWI) data in mapping surface water.
2. Develop a Multi-Sensor Water Index (MSWI) to improve water detection accuracy.
3. Assess the implications of these findings for hydrological analysis and water resource management in ASALs, using outlier region (Nakuru) to assess if the method holds up in various regions. Link to outlier; MSWI - Nakuru

2. METHODOLOGY

2.1. Study Area

Marsabit and Isiolo Counties in northern Kenya, spanning approximately **92,259.2** sq. km, were selected for their representative ASAL conditions and reliance on seasonal water resources. [8]

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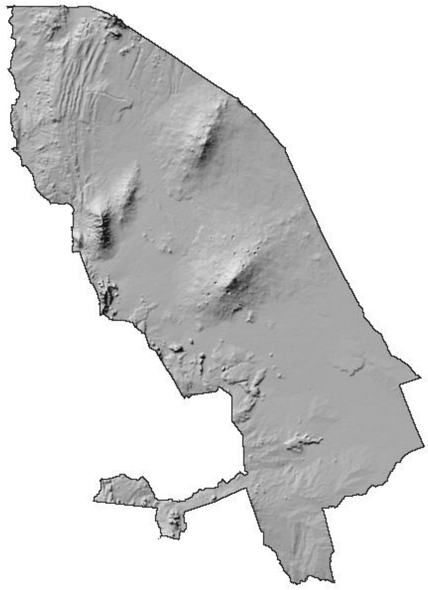

Figure 1 : STRM 30m DEM of Isiolo and part of Marsabit County.

2.2. Data Sources and Processing

- ALOS PALSAR (2020): Processed to derive a water mask using HH and HV backscatter thresholds.
- Landsat 8 (2020): Annual median NDWI composite, cloud-masked to minimize atmospheric interference. [5]
- Ancillary Data: CHIRPS precipitation, SRTM DEM, and ESA WorldCover land cover data provided environmental context.

2.3. Water Mask Overlay Analysis

Water masks from SAR and NDWI were overlaid to classify areas into:
- *Common Water*: Detected by both sensors.
- *SAR Only Water*: Detected exclusively by SAR.
- *NDWI Only Water*: Detected exclusively by NDWI.

2.4. Multi-Sensor Water Index (MSWI)

The MSWI was developed to synergize SAR and optical data:

MSWI = NDWI_Scaled × SAR_Smoothness_Factor

*MSWI - Proposed Multi-Sensor Water Index is calculated using the above formula, utilizing analyzed data from NDWI scaled in to between 0 and 1 then multiplied with the SAR smoothness Factor.

where:
- *NDWI_Scaled: Normalized* NDWI values (0–1).
- *SAR_Smoothness_Factor*: Derived from backscatter coefficients, with low backscatter indicating smooth water surfaces.

By calculating normalized backscatter, this factor assigns higher values to very smooth (water-like) surfaces and lower values to rough (land-like) surfaces.

3. RESULTS

3.1. Water Detection Comparison

- Common Water: 12.18 sq km (permanent water bodies).
- SAR Only Water: 23,145.09 sq km (ephemeral and obscured water).
- NDWI Only Water: 0.748 sq km (minor optical-specific detections).

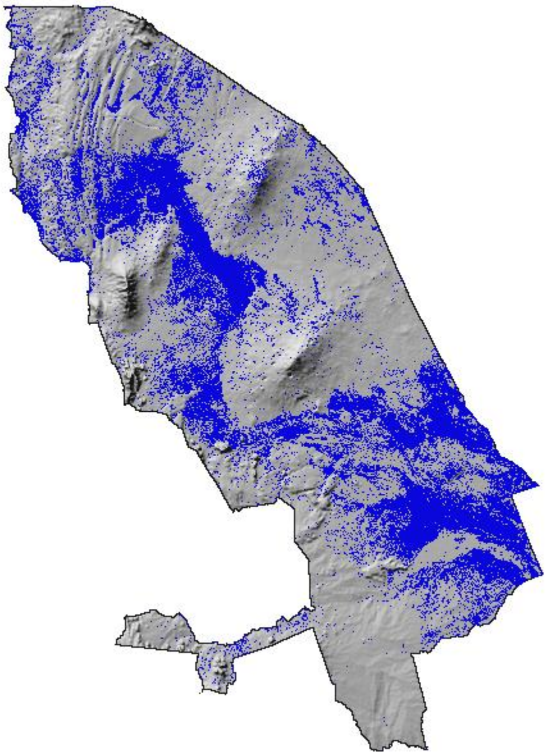

Figure 2: SAR Only Water Mask overlayed over STRM 30M DEM.

3.2. MSWI Performance

The MSWI successfully identified:

- High-confidence water (MSWI ≈ 1): Strong, confident detection of open, clear surface water. This often corresponds to permanent or consistently filled water bodies like larger dams, perennial river sections, or deep lakes.

- Intermediate values (0.3–0.7): Inundated Vegetation, Seasonal Wetlands, Turbid Water and Shallow Water / Mixed Pixels.

- Zero value (MSWI ≈ 0): Dry or No surface water available in the region.

Link to exported maps; [Original Maps]

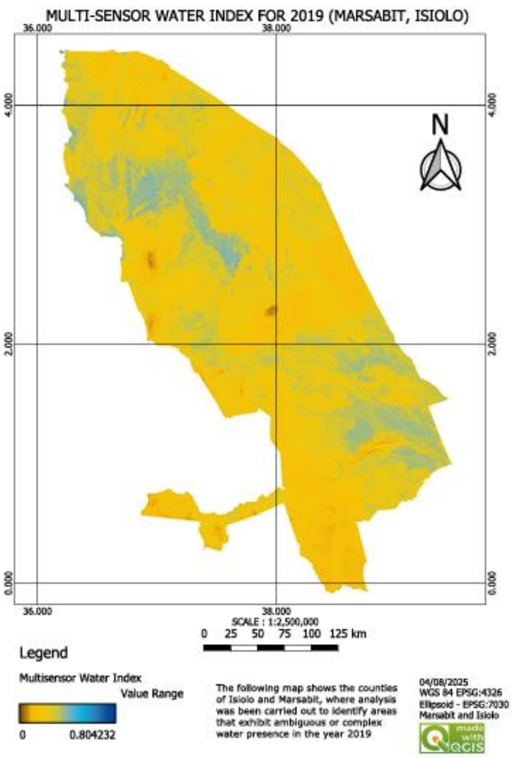

Figure 3: Experimental MSWI 2019 (Isiolo and part of Marsabit)

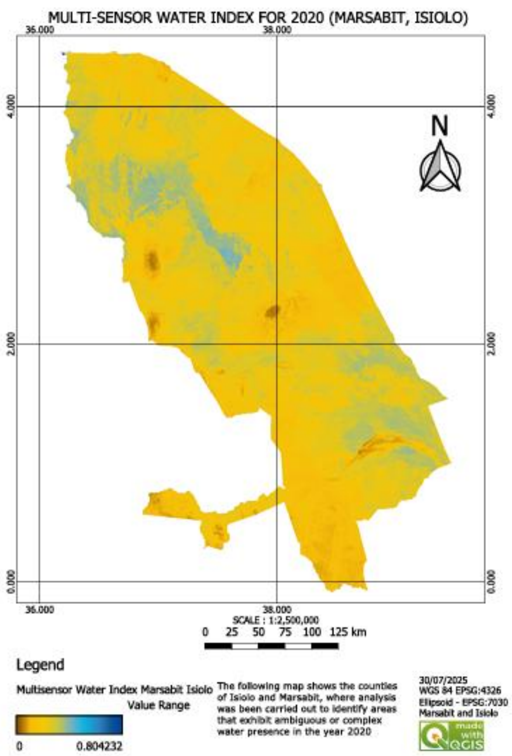

Figure 4: Experimental MSWI 2020 (Isiolo and part of Marsabit)

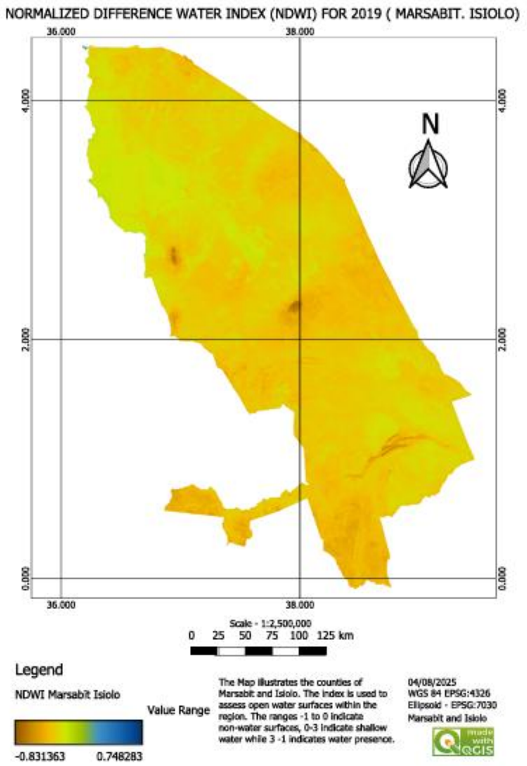

Figure 5 : NDWI 2019 (Isiolo and part of Marsabit)

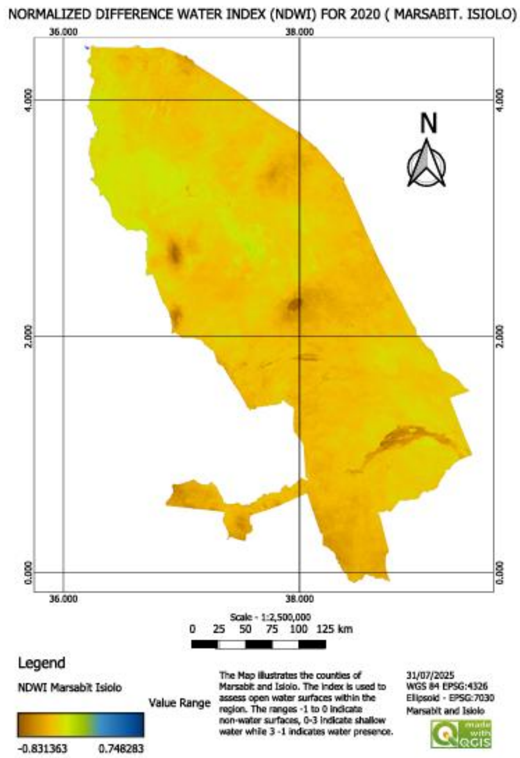

Figure 6: NDWI 2020(Isiolo and part of Marsabit)

4. **DISCUSSIONS**

4.1. SAR's Superiority in ASALs

The vast 'SAR-only' area of 23,145.09 sq. km underscores SAR's ability to detect ephemeral water bodies, critical for pastoralist communities and drought resilience, yet on its own, the results would not be entirely conclusive due to the low spatial resolution of the SAR sensor as well as data capture errors like speckle noise, ionospheric distortion or frequency synchronization errors. [6] Optical sensors, while useful for observation of clear continuous water surfaces, significantly underestimate water extent in ASALs indicating an area of 0.748 sq. km due to the dynamic nature of such regions. [7]

4.2. Implications for Water Management

- Drought Resilience: SAR-detected ephemeral water can help support drought early warning systems.
- Livestock Migration: Dynamic water maps can be used to guide pastoralist movements, if information can be made available to these communities.
- Flood Management: If the same methods can be used to analyze flooding periods, it would enable more real-time analysis of floods even with cloud cover. Highlighting areas likely affected for on-time response and even preparation.
- Infrastructure Planning: Help in the identification of sites for water harvesting (both rain and surface run-off) and to help in building recharge structures i.e., sand dams.
- Soil Health Analysis – The detection of ephemeral water is inextricably linked to the study of soil stability and surface runoff dynamics. In Arid and Semi-Arid Lands (ASALs), unmanaged surface runoff is a primary driver of land degradation, stripping nutrient-rich topsoil and leading to severe erosion. These maps would be useful in determining regions adversely affected by this

and lead to interventions that would promote soil health and allow for percolation and water capture strategies in such areas.

4.3. Limitations and Future Work

- Temporal Dynamics: Frequent multi-year analysis is needed to capture variability. Additionally, EO Platforms and data sources with better revisit timelines (weeks to months) would assist in detecting real time changes. This is guided by an evidence of lack of frequent earth observations over populated ASALs due to the business model of satellite tasking.
- Field Validation: Ground-truthing is required to confirm SAR-detected water and the overall conditions of these sites. While, 10cm spatial resolution, drone imagery was utilized as a form of ground truthing, it remains a challenge to actively work within these remote areas,
- Algorithm Refinement: Better Machine learning algorithms could be developed specifically with ASAL conditions when utilizing Synthetic Aperture Radar, helping to enhance visualization in these areas and in turn analysis.

5. CONCLUSION & RECOMMENDATIONS

This study demonstrates the indispensability of SAR for water mapping in ASALs, revealing a hydrological landscape that optical sensors miss. This relationship aligns with soil distribution maps and hydrological analysis previously carried out in the region, albeit at a smaller scale. The MSWI offers a robust tool for integrated water detection, with significant implications for sustainable water management in Marsabit, Isiolo, and similar regions within similar characteristics. Future efforts should focus on temporal analysis and field validation to further refine these methods.

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