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Automatic Detection of Flooded Areas in Polarimetric Radar Images From the Sentinel-1 Satellite

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ABSTRACT

The free availability of Synthetic Aperture Radar (SAR) data from the sentinel satellite offers a unique opportunity for developing countries. The research work focuses on the floods in the town of Yagoua. The choice of this area is based on the multitude of floods causing enormous damage. Existing methods, primarily based on machine learning and deep learning algorithms, present major limitations such as sensitivity to radar noise, algorithmic complexity, and dependency on training data. The methodology proposed here uses the Kolmogorov algebraic method algorithm, which will be applied to the pre-processed images. The Fuzzy C-Means algorithm will then be used to generate a change map consisting of two output classes (water and not water). coupling these two methods gives good results and analysis of pre- and post-flood images resulted in an average improvement of 12% compared to state-of-the-art methods. This approach enhances rapid and reliable flood monitoring.

KEYWORDS

Radar, Polarimetric Radar, Algebraic Method, Climate Change, Flooded Areas, Fuzzy C-Means

INTRODUCTION

With advances in satellite imagery, it is now possible to monitor nature and predict natural disasters (Fransson et al., 2002). The radar satellite imagery used here is based on the fact that it is active and not passive as is the case with optical imagery. Sentinel imagery is free and easy to use. Complete coverage of Cameroon by this satellite has been observed since December 2015, enabling remote observation of the globe (Jacob et al., 2020). These free services are COPERNICUS products. The main objective of radar imagery is to improve living conditions for humans on Earth, while addressing climate change. Radar imagery gives us the privilege of observing the soil and subsoil (Elbialy et

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al., 2013), as well as crop monitoring (Liew et al., 1998), agriculture being of vital importance in the development of a region.

Radar imagery is a power image, always positive and based on the reflexivity of objects. It is a complex image with an average size of 1GB, which makes it difficult to manipulate.

However, the refection of radar images depends on the characteristics not only of the target, but also of the ground. For this backscatter, we have: the hybrid method (Matgen et al., 2011) and the algebraic method (Jordi, 2011), Otsu's algorithm (Li et al., 2015), statistical analysis (Bolanos et al., 2016; Tison et al., 2004; Moser et al., 2006; Lamberdo et al., 222002; Conradsenet al., 2003), gamma distribution (Liang et al., 2020). There are also supervised methods (Huang et al., 2018; Khaldoune et al., 2008) and methods using convolutional neural networks (Yan et Al., 2024; Arabi et al., 2016).

Machine learning (ML) and deep learning (DL) techniques have revolutionized flood detection by enabling rapid analysis of large datasets from sensors, satellite imagery, and weather forecasts (Huang et al., 2024). They offer near real-time processing capabilities, increased accuracy, and efficient automation, thereby facilitating the monitoring of extreme events. However, these approaches also present significant limitations. The quality and availability of training data are often insufficient, particularly in poorly instrumented regions, which can lead to overfitting or poor generalization of models. Moreover, DL models, in particular, are often viewed as “black boxes,” making it difficult to interpret their decisions and thus limiting their adoption in critical contexts. Furthermore, the algorithmic complexity and computational resources required for training and running these models can be major obstacles, especially in emergency situations where speed is essential. Lastly, sensitivity to environmental conditions such as cloud cover or topographic variation can affect the robustness of predictions. Thus, while ML and DL techniques offer promising prospects for flood detection, it is crucial to acknowledge and address their limitations to ensure their effectiveness and reliability in real-world applications.

This article presents a novel methodological approach for the automatic detection of flooded areas using polarimetric radar images from the Sentinel-1 satellite. The main contributions are as follows:

- Development of a hybrid method combining Kolmogorov algebra, Fuzzy C-Means clustering, and SAR image processing, enabling effective segmentation of flooded zones without the need for supervised training data.
- Addressing limitations of existing approaches, particularly their sensitivity to radar noise, computational complexity, and reliance on labeled training datasets, which are often unavailable in crisis contexts.
- Experimental validation in the city of Yagoua (Cameroon) using pre- and post-flood Sentinel-1 imagery, demonstrating the operational relevance of the proposed method in high-risk flood-prone areas.
- Concrete support for environmental monitorin, by enabling fast, reliable, and automatic detection of flooded areas, even under extreme weather conditions.

The overall aim of this work is to be able to automatically detect changes in a stack of two radar images, one image taken before flooding and the other taken after flooding. As flooding is increasing in the town of Yagoua, we will be able to clearly show the flooded areas in our images in order to limit the damage and be able to take steps to deal with these disasters as effectively as possible. The remainder of this article is organized into two main phases:

- The image pre-processing phase: this phase is characterised by a succession of actions to be carried out, such as satellite location correction, thermal noise correction, on-board noise correction, radiometric correction, coregistration, noise filtering (speckle) and geometric correction.