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Comparison of DEMs Spatial Resolution for Geomorphological Study in a Small Volcanic Island of Tidore, North Maluku, Indonesia

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Abstract: This article intends to examine the Digital Elevation Model (DEM) spatial resolution's effect in generating morphological information, i.e., slope, aspect, and curvature, in Tidore, a small volcanic island in the eastern part of Indonesia. We used a 1:50,000 scale of Indonesian topographic maps to generate the first DEM and the second DEM from a national DEM of Indonesia, which have a 0.27-arcsecond spatial resolution. Descriptive and statistical analysis has been used to compare both DEMs for each parameter. The results show that high-resolution DEM can better identify the morphological parameters in a small volcanic island of Tidore. However, not all parameters have a positive correlation with the DEM's. For example, slope and curvature positively connect with DEMs, while a negative value connects aspect or slope direction with the DEM.

Keywords: morphology, small islands, volcanic islands, Maluku, Indonesia.

印度尼西亚北马鲁古蒂多尔小火山岛地貌研究数字高程模型空间分辨率比较

摘要：本文旨在研究数字高程模型空间分辨率在印度尼西亚东部小火山岛蒂多尔生成形态信息（即坡度、坡向和曲率）方面的效果。我们使用 1:50,000 比例的印度尼西亚地形图从印度尼西亚的国家数字化评价模型 生成第一个数字化评价模型 和第二个数字化评价模型，它们的空间分辨率为 0.27 角秒。描述性和统计分析已用于比较每个参数的两个数字化评价模型。结果表明，高分辨率数字化评价模型可以更好地识别蒂多雷火山小岛的形态参数。但是，并非所有参数都与数字化评价模型 呈正相关。例如，坡度和曲率与 DEM 正相关，而负值将坡向或坡度方向与数字化评价模型 相关联。

关键词：形态，小岛，火山岛，马鲁古岛，印度尼西亚。

1. Introduction

The transformation of the surface expression system has profoundly modified the basic expression mode of terrains in the geomorphological study. The contour map approach has since been converted to a digital elevation model (DEM) approach. DEM data at various scales will support the analysis of geomorphological phenomena and greatly enhance the overall knowledge of geomorphological aspects [1], [2]. However, global DEM data, such as the Shuttle Radar Topography Mission (SRTM), which has medium-resolution between 1-arcsecond (30m) - 3-arcseconds (90m), have a more significant standard deviation; hence it has an immense bias with field data in Indonesia [3]. At the moment, high-resolution DEM data may perform a detailed simulation of geomorphological aspects by simultaneous sampling and modeling of present-day elevation [1].

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The high-resolution Indonesian Digital Elevation Model (DEMNAS) availability is beneficial in the geomorphological study, i.e., landscape evolution, reconstructing the paleo-topography, regional topography, or its relation with coastal ecosystems [4], [5], [6], [7]. However, this DEMNAS data is still relatively new and has not been fully utilized for further research in Indonesia. Furthermore, previous research shows that DEM's spatial resolution impacts the mean, standard deviation, and accuracy [3], [7], [8], [9], [10], [11], [12]; thus, it will affect the further geomorphological analysis. In Indonesia's case, although it is located in the Pacific Ring of Fire, last year's Indonesia has faced problems with the lack of high-resolution spatial data to help manage and analyze regional potential and risk, especially in the eastern part of Indonesia.

In the last several years, geomorphologists in Indonesia are very dependent on the Digital Elevation Model (DEM) medium spatial resolution, either from Indonesian topographic maps or global DEM such as ASTER GDEM and SRTM [3], [13], [14], [15]. The high-resolution DEMNAS is built from several data sources, including IFSAR (5m resolution), TERRASAR-X (5m resolution), and ALOS PALSAR (11.25m resolution) data, by adding the stereo-plotting Masspoint data. DEMNAS's spatial resolution is 0.27-arcsecond, it covers all regions in Indonesia, and it is available online at [16].

Indonesia has more than 17,000 islands as archipelago countries, and 76% are categorized as small islands [17]. An island's definition refers to Article 121 of the United Nations Convention on the Law of the Sea (UNCLOS) 1982 [17]. An island is a land area naturally formed, surrounded by waters, and remains visible above sea level during high tide. Meanwhile, the definition of a small island used in this study refers to Indonesian Law number 27 of 2007 concerning the Management of Coastal Areas and Small Islands in Article 1 point three, i.e., a small island is a land area that has less than or equal to 2,000 km^2.

The developments of small islands in Indonesia are intrinsically related to Indonesia's geological location at the confluence of three main active plates in the world. Therefore, it is conceivable that these small islands are also small volcanic islands. In the context of disaster risk management, there is an increase in the elements at risk that can be affected by the morphology of small volcanic islands in the future, especially on several islands with dense populations, like in Tidore. Tidore is a small volcanic island located in the North Maluku Province in Indonesia's eastern part (Fig. 1).

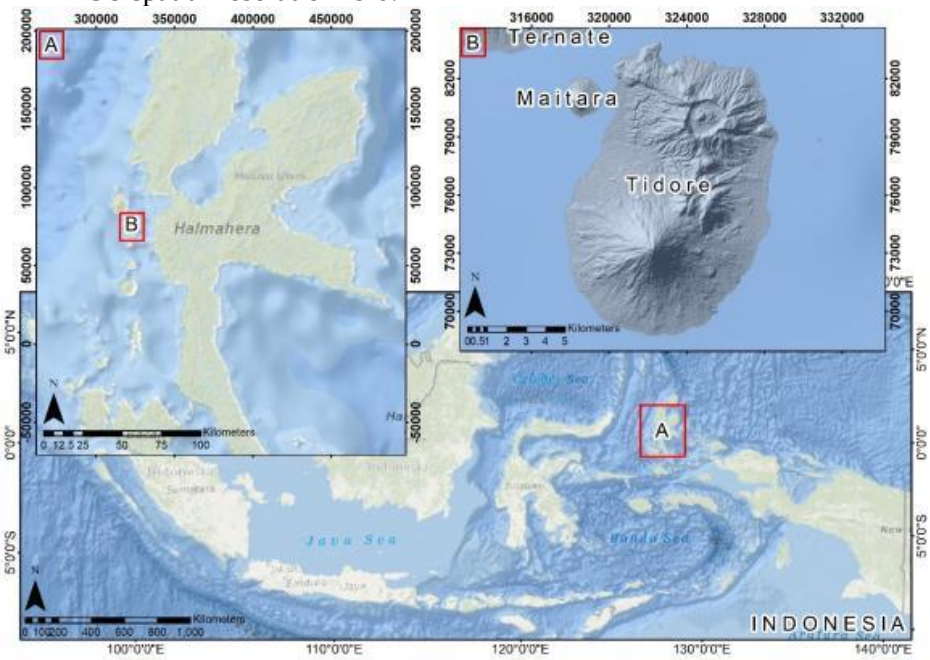

Fig. 1 Research area in Tidore, North Maluku – Indonesia

This paper aims to investigate the effect of DEM spatial resolution in generating morphological information, i.e., slope, aspect, and curvature parameters, in a small volcanic island of Tidore. Morphological analysis of small volcanic islands related to its geomorphic features and past activities of its volcano is one strategy for disaster risk reduction (DRR) in those small islands.

2. Research Methods

We compare the morphological parameters derived from two DEMs, i.e., first, a DEM derived from a topographic map of Indonesia (RBI) at a scale of 1:50,000, which was downloaded from the Indonesian Geospatial Agency at [18]; and second, a DEMNAS with a 0.27-arcsecond spatial resolution, which was downloaded from [16]. The RBI elevation model was generated by interpolating from a series of contour

lines in ArcGIS using the Topo to Raster technique.

Comparative investigation of RBI and DEMNAS has been analyzed concerning the formation from its surface, i.e., slope, aspect, and curvature. Those three parameters are often used as a starting point to further and more detailed analysis related to applied geomorphology, i.e., disaster risk reduction, landscape modeling, soil-landscape analysis, or geomorphometry [5], [20], [21], [22]. Both DEMs are used to examine geomorphological features in the ArcGIS map. We used spatial analyst extension in ArcGIS software.

Furthermore, we also performed the band collection statistics in the multivariate tools to examine the accomplished results. The correlation matrix displays the correlation coefficient functions that reflect the relations between various datasets.Correlation values vary between +1 and -1. A strong correlation implies a similar association between two layers. Otherwise, a negative correlation indicates that one variable varies in the opposite direction to the other. A correlation of 0 indicates that the 2 layers are unrelated to one another.

3. Results and Discussion

Based on height information in Fig. 2, it can be observed that there are certain variations between DEM data from RBI and DEMNAS over Tidore Island. For example, RBI produces values of height ranging from 0-1,673 meters above sea level (a.s.l.) with a mean value of 305.7 and standard deviation value of about 295.4, while the height range of DEMNAS ranges from 0-1,710 meters a.s.l. with a mean value of 296.1 and standard deviation value of about 296.5.

With a height of less than 2,000m, Tidore is categorized as a small-size volcanic island [20]. Unlike the large volcanic island, which has a height of more than 5 km, a small volcanic island with a height of less than 2,500mis gravitationally stable; thus, the possibility of large-scale mass wasting events that may trigger tsunami is relatively slight [23], [24], [25].

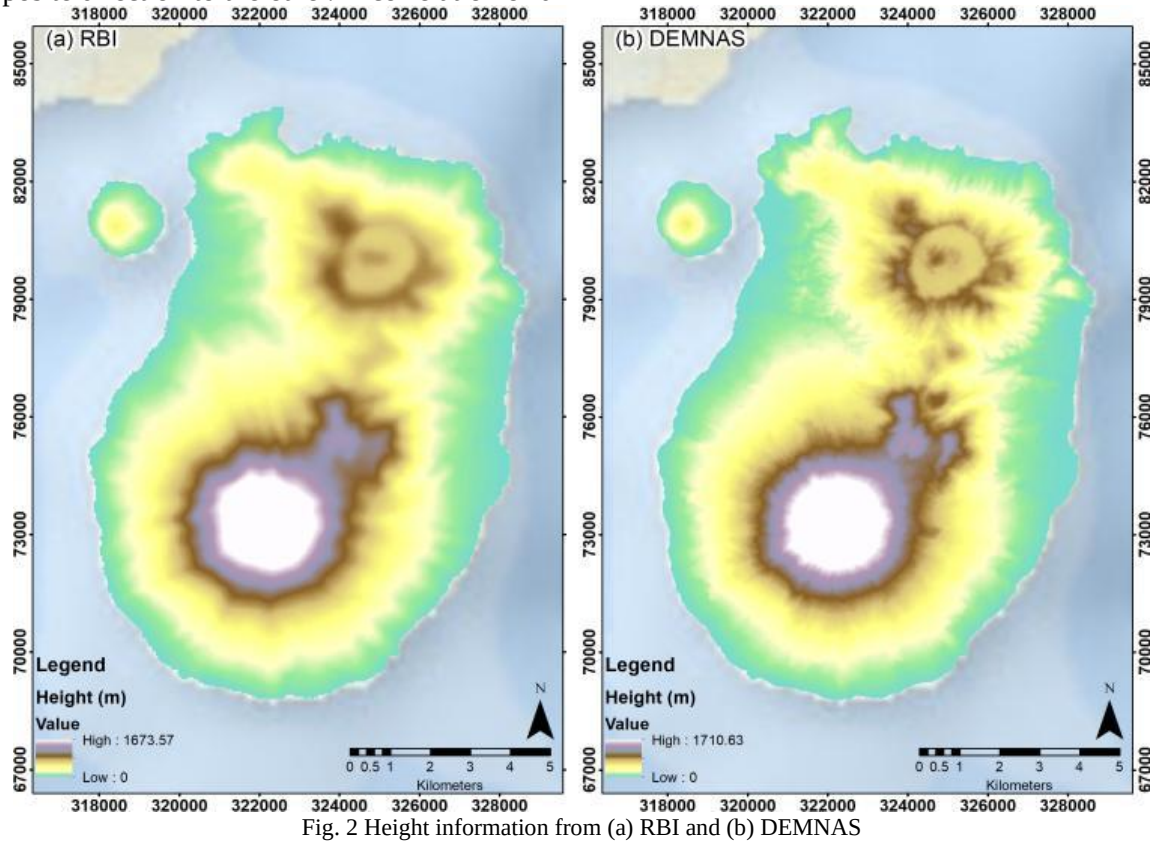

Fig. 2 Height information from (a) RBI and (b) DEMNAS

A visual comparison of slope maps from RBI and DEMNAS is presented in Fig. 3. We divided the slope class into seven categories, i.e., 0^0-2^0 (flat), 2^0-4^0 (gentle), 4^0-8^0 (undulating), 8^0-16^0 (slightly steep), 16^0-35^0 (steep), 35^0-55^0 (very steep), and more than 55^0, which is extremely steep. Based on Fig. 3, we can see differences between the slope map from RBI (Fig. 3a) and DEMNAS (Fig. 3b).

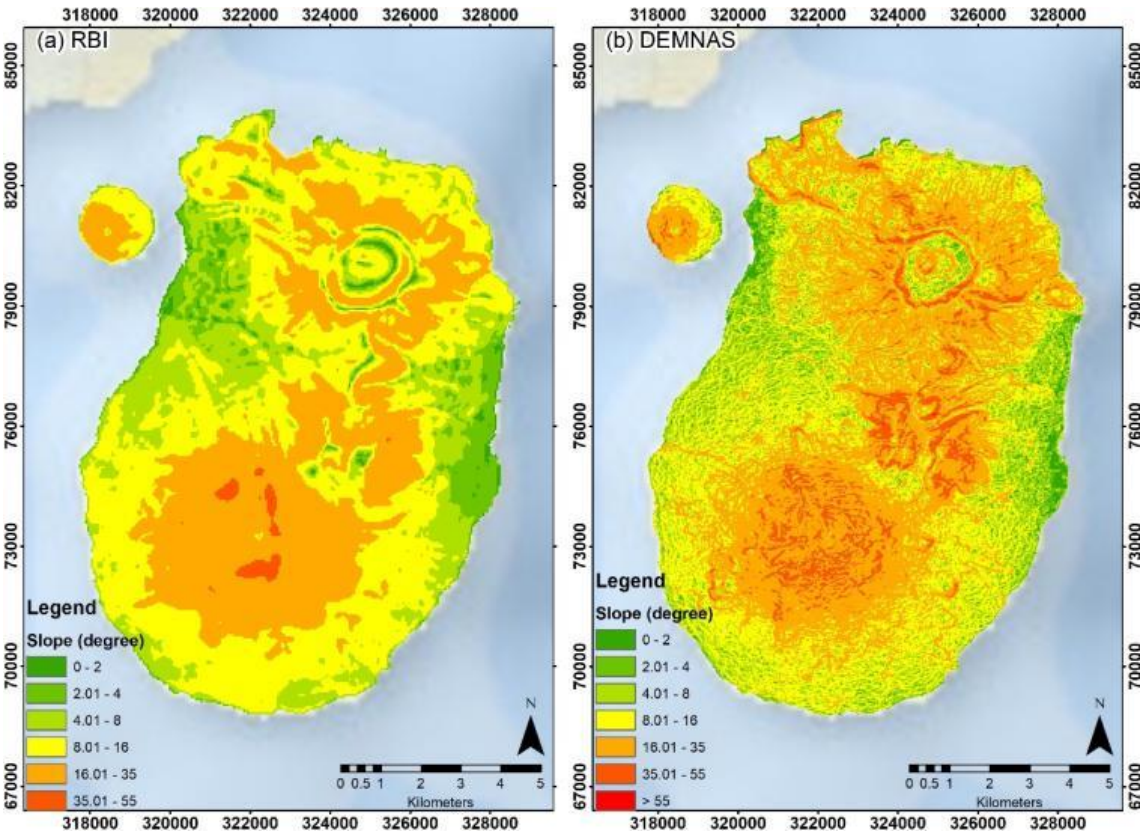

Fig. 3 Slope data (in degree) from (a) RBI and (b) DEMNAS

The number of slope classes also different between these two data, where the slope map from RBI did not have an extremely steep class (>55 degrees) like the slope map from DEMNAS. However, extremely steep classes, which have characteristics of exposed rocks, a robust denudation process, rock falling prone area, and rarely/limited grown plants, are identified in the slope map from DEMNAS in some area centers Tidore and near the caldera in the northern part of islands.

RBI produces slope values ranging from 0-44.1 degrees with a mean value of 14.0 (slightly steep) and a standard deviation value of about 8.0. The slope range of DEMNAS ranges from 0-62.1 degrees with a mean value of 17.4 (steep) and a standard deviation value of about 10.4. As the resolution is roughened, the slope is more vulnerable to changes, with a significant reduction in maximal values, mean values decrease, and standard deviation [12].

The difference in slope information will undoubtedly affect further detailed analysis, such as mapping landslide hazards. Compared to natural disasters all around the globe, at least 17% of all deaths are caused by landslides [26]. More detailed DEM data will result in more accurate data since the slope data is considered the most important parameter related to landslides [27]. In addition, the slope governs other critical parameters, such as vegetation, soil water quality, and precipitation in a specific region. The area with a steeper slope means more vulnerability to landslides and may raise shear pressure in unstable soil cover [26], [27], [28].

The downslope orientation of the maximal value change's rate from each cell and its neighborhood cell is identified by aspect. Aspect is one parameter that affects soil erodability. That is because the aspect is related to the sunlit area and precipitation, which will also affect the micro-climate, evapotranspiration, and soil displacement [27], [29]

Related to aspect or slope direction parameters of DEM (Fig. 4), RBI generates an aspect with a mean of 183.3 (slope direction to the South) and a standard deviation value of about 104.0. At the same time, DEMNAS produces an aspect with a mean of 184.2 (slope in the South direction) and a standard deviation value of about 104.5.

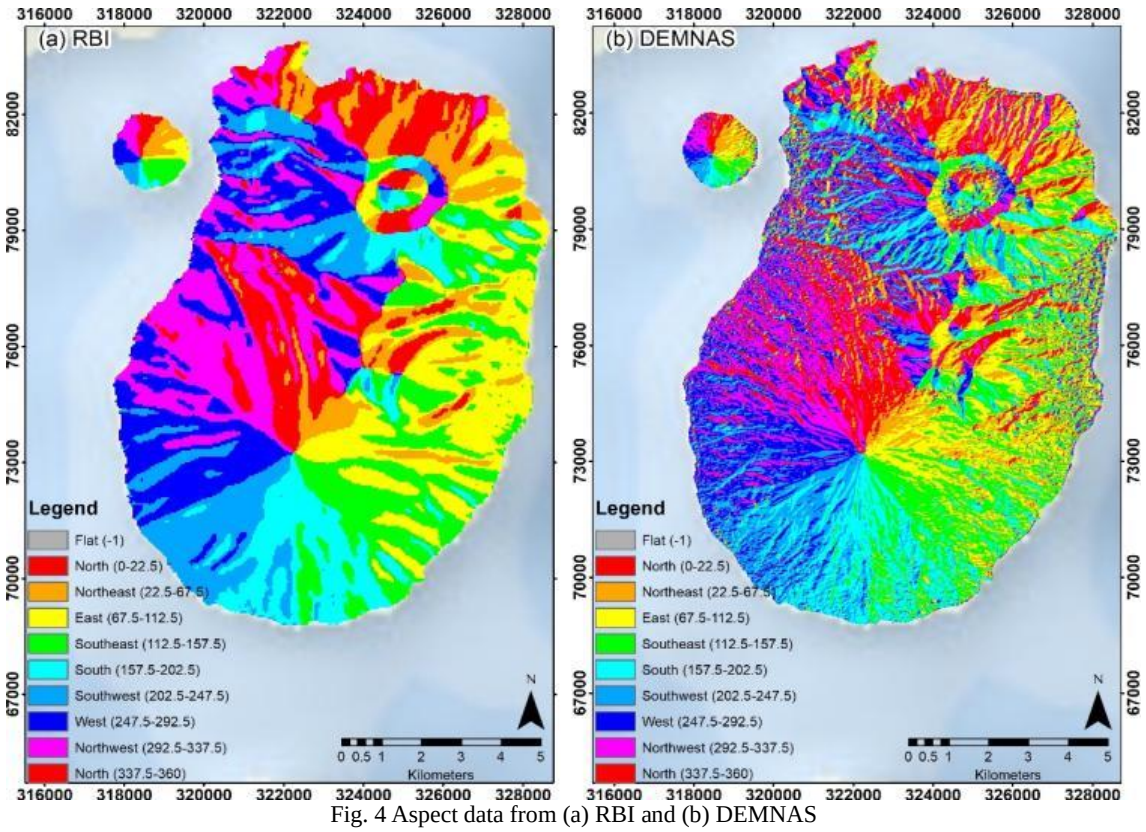

Fig. 4 Aspect data from (a) RBI and (b) DEMNAS

Furthermore, the mean value of curvature from RBI is about -0.004, with a standard deviation value of 0.15. The mean value of curvature from DEMNAS is about -0.093, with a standard deviation value of 1.12 (Fig. 5). Although the mean value of curvature from RBI and DEMNAS are almost the same, DEMNAS has a stronger negative value that indicates Tidore, in general, is upwardly convex. The slope is decreasing like a dome. Convex surfaces in some areas are characterized by harder bedrock among the loose rocks [27]. Curvature analysis combined with other parameters is very useful to identify the crater or caldera in a volcanic landform since it helps to highlight the geomorphological pattern [30]. Other than that, curvature also influences soil erodability and hydrological properties by controlling runoff following the topography and slope [27].

Furthermore, plan curvatures obtained from high-resolution DEM can assist in identifying better areas prone to debris flows in mountainous terrain than medium-resolution DEM [31]. Since Tidore has about 77.6% hill and mountainous morphology, it has caldera in the northern part of the island, and the percentage of the steep slope is more than 25%. Therefore, Tidore can be classified as a small volcanic island [32], [33], [34], [35], [36].

We examine the correlation between height, slope, aspect, and curvature parameters for both DEMs using band collection statistics in the multivariate tools of ArcGIS. Based on the results, we had identified that DEMs have a positive correlation with slope and curvature, yet, DEMs have a negative correlation with aspect. It means that DEMs directly connect with slope and curvature; thus, when DEMs' values increase, the values of slope and curvature also tend to increase. A negative value implies that one component moves to the other inversely. A zero value implies that the two parameters are autonomous from each other. Tables 1 and 2 show the correlation matrix between DEMs, slope, aspect, and curvature.

Table 1 Correlation matrix RBI, slope, aspect, and curvature

Layer	RBI	Slope	Aspect	Curvature
RBI	1.00	0.77	-0.01	0.21
Slope	0.77	1.00	-0.05	0.11
Aspect	-0.01	-0.05	1.00	0.00
Curvature	0.21	0.11	0.00	1.00

Table 2 Correlation matrix DEMNAS, slope, aspect, and curvature

Layer	DEMNAS	Slope	Aspect	Curvature
DEMNAS	1.00	0.62	-0.02	0.05
Slope	0.62	1.00	-0.03	0.02
Aspect	-0.02	-0.03	1.00	0.00
Curvature	0.05	0.02	0.00	1.00

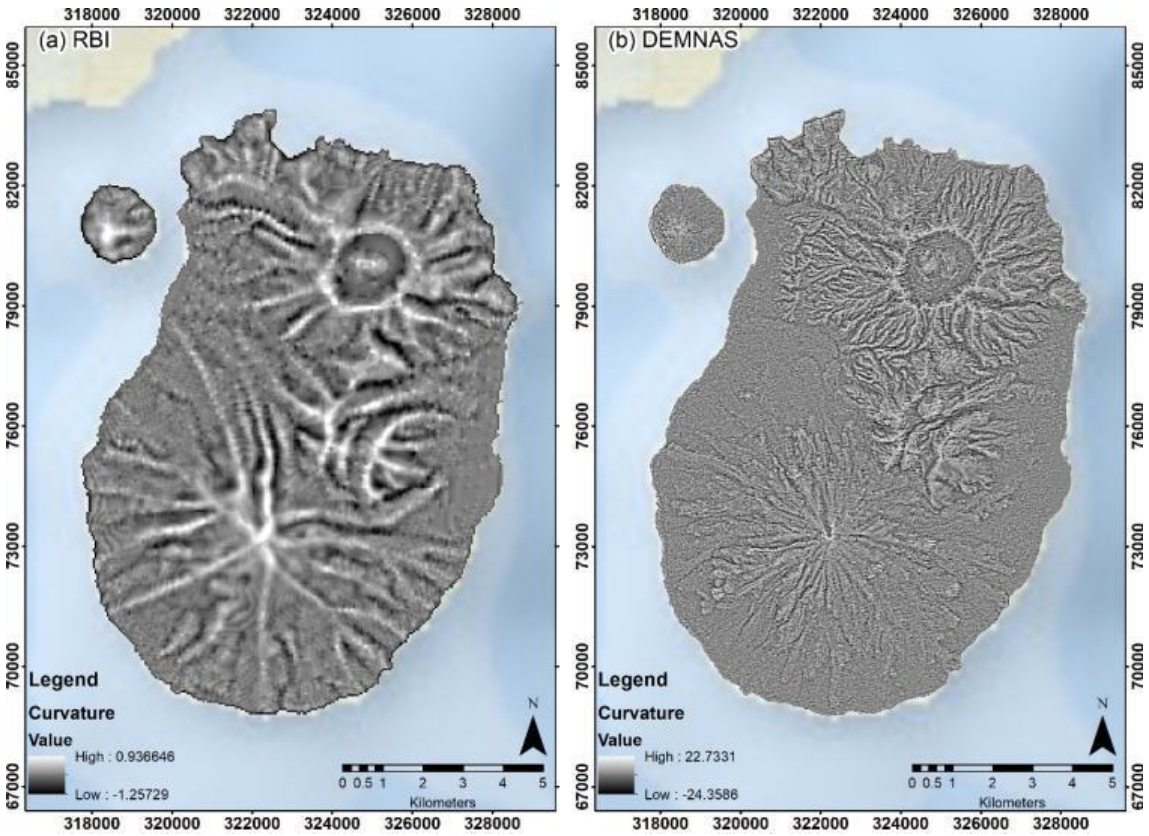

Fig. 5 Curvature data from (a) RBI and (b) DEMNAS

4. Conclusion

High-resolution DEM can help to identify better the morphological parameters in a small volcanic island of Tidore. Through morphological analysis of DEM, we also can identify the characteristics of small volcanic islands, i.e., have a height of less than 2km, dominated by hill and mountainous morphology, has a caldera or dome which can be identified through curvature, and more than 25% of the steep-slope percentage. Thus, DEMNAS, which has better resolution than RBI, can support further geomorphological analysis with better results and facilitate better work in the field. Furthermore, slope and curvature positively connect with the DEM, while aspect and DEM have a negative correlation.

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