Orthorectification of Sentinel-1 SAR (Synthetic Aperture Radar) Data in Some Parts Of South-eastern Sulawesi Using Sentinel-1 Toolbox

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Abstract. Sentinel-1 satellite uses active microwave sensor that has a better ability than the optical system in generate satellite image without clouds cover and can operate in day or night in all weather conditions. However, the side looking viewing geometry of SAR system and the object height variation or topography on the surface of the earth causing various distortions of geometry in the SAR (Synthetic Aperture Radar) image. It needed to be corrected through orthorectifiation process before the further implementation. This research aims to Orthorectifying the Sentinel-1 of SAR data in some regions of Southern Sulawesiusing Sentinel-1 Toolbox software and assessing the geometrical accuracy of orthorectification's results. Two orthorectify methods have been used, namely Range-Doppler Terrain Correction and SAR-Simulation Terrain Correction. Each SAR data orthorectify results (resampling to 30 m resolution) compared qualitatively and quantitatively. Qualitative by visual comparison between the results orthorectify. Quantitative by the calculation of the accuracy results orthorectify both methods on the GLS (Global Land Survey) 2000 Landsat image using 99 test points coordinate then calculated the RMSEr (Root Mean Square Error). The results showed that, there is no significant differences in visual geometry between the orthorectify results. Orthorectified SAR image in some parts of South-eastern Sulawesi from both method showed the same RMSEr value is 25.27 m which means the horizontal accuracy is less than one pixel.

Keywords: SAR Sentinel-1, Sentinel-1 Toolbox, Orthorectification, RMSEr; Southeast Sulawesi

1.Introduction

Indonesia as one of the widest countries, needs information sources which are fast, accurate, and also can cover the entire area for monitoring purposes. Remote sensing data is one of the data sources that is able to meet these basic requirements for extractingthe physical phenomena information on the Earth's surface rather than to do a field survey.

European Commission (EC) in collaboration with the European Space Agency (ESA) triggers a program of earth observation, called Copernicus which aims to provide information that is accurate, up to date and accessible for enhancing the environmental management, understanding, and reducing the

climate change's impacts, and also guaranting the civil security [1]. Sentinel 1-A satellite is the first of seven Missions of remote sensing satellite imagery which was launched on April 3, 2014, and it has an active sensor in the Band-C. SAR imagery data can be downloaded for free throughout the data portal of Sentinel-1 on https://scihub.esa.int/.

Sentinel-1 SAR data availability can be optimally used due to the active microwave sensor which has a better ability than the optical system in generate imagery without clouds cover, and also it can be operated both day and night in all weather conditions [2]. However, the side looking viewing geometry of SAR system and other conditions of topography and object height, can cause geometric distortions such as foreshortening, layover, and shadow [3]. Orthorectification is needed to reduce those geometric distortions and especially to generate the information in accurate position.

Moreover, ESA also develop an open source software called Sentinel-1 Toolbox (S1Tbx) for processing SAR data including the orthorectification process especially Sentinel-1 data. Orthorectification known as a process to conversion of the two-dimensional image from a sensor-coordinate to a map-coordinate [4]. Radar image geometry correction is quite difficult to do. The availability of this software can be the solution to generate corrected SAR data especially for Sentinel-1 SAR data. There are two orthorectification methods in this software, namely Range Doppler Terrain Correction and SAR-Simulation Terrain Correction. The results of both methods are need to be evaluated for digital image processing.

Researchers wanted to do the orthorectification process on one of the Sentinel-1 data which covers some parts of South-eastern Sulawesi using S1 Tbx. This area to be area of study because of its position that close to the equator and optical data available on the scope of the region disturbed by cloud cover. The writers expect that this study can be used as a reference on Sentinel-1 application.This research aims to orthorectification of Sentinel-1 SAR data in some parts of South-eastern Sulawesi using Sentinel-1 Toolbox software and assess geometrical accuracy of the orthorectify results.

2. Data and Methods

2.1. Study Area
South-eastern Sulawesi were selected as the study area. The study area is administratively located on Southeast Sulawesi Province, Indonesia. Figure 1 shows the data coverage Sentinel-1 SAR in the research area on google earth.
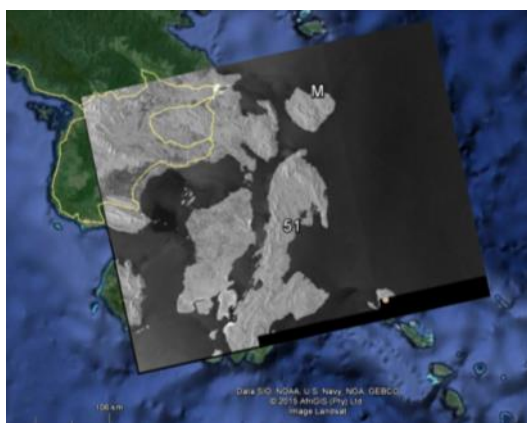

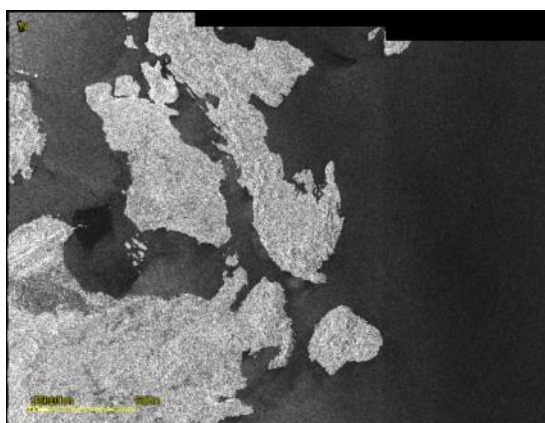**Figure 1**. Display of sentinel-1 map overlay data on google earth.

Figure 2. Sentinel-1 SAR data some parts of South-eastern Sulawesi before the orthorectification.

2.2. Data
Figure 2 shows the data that used in this research. The chosen data of South-eastern Sulawesi was orbit/track 3086/39 which obtained on November 1st 2014, Ascending.The SAR data used in this research was Sentinel-1 data with Band-C (5250-5570 Mhz), Level 1 GRDH (Ground Range Detected

High Resolution), Interferrometric Wide-Swath Mode (IW), VV polarization, pixel size of 10 meter, azimuth x range resolution = 20 x 22 m.

When a DEM (Digital Elevation Model) of the observed geographical area is available, a procedure called orthorectification can be applied on allowing the correction of some geometric distortions [5]. Ideally, DEM data has a same resolution toward SAR data, so it would produce a better orthorectified imagery. Because of limited DEM data in high resolution, DEM SRTM 3Sec V.4 on Sentinel-1 Tbx was chosen as an input for processing the elevation data. GLS-2000 of Landsat imagery was used as data reference on determining the Ground Control Points (GCPs). Path/ row of scenes that used in this study were P112/R64, P113/63, P112/R63, P113/R64.

2.3 Methods

Figure 3shows the orthorectification steps of Sentinel-1 SAR data using Sentinel-1 Toolbox and its accuracy assessment.The data were imported into BEAM-DIMAP format then separately processed using orthorectification operator on S1Tbx. Imported data would be processed using Terrain Correction operator for orthorectification process, there are Range Dopler Terrain Correction (RDTC) and SAR-Simulation Terrain Correction (SARSimTC) on Sentinel-1 Toolbox version 1.0.3 (released date: November 3rd, 2014). Process running on computer with Linux operating system and 16Gb RAM(Random Access Memmory). The output is made in the format of BEAM-Dimap.

*2.3.1. Range Doppler Terrain Correction.*The Range Doppler Terrain Correction (RDTC) operator implements the Range Doppler orthorectification method (Small and Schubert, 2008) for geocoding SARimagery from single 2D of raster radar geometry. It uses available orbit state vector information in the metadata, the radar timing annotations, the slant to ground range conversion parameters together with the reference DEM data to derive the precise geolocation information [6]. Detail algorithm of this method can be found in Small and Schubert[7]. First step is input/output parameter, using the imported SAR data as an input in orthorectification and choose the directory output for save the orthorectified image. Input and output data saved in one project file. The second step is defining the parameters and band amplitude VV which will be processed using SRTM 3 Sec as inputs to the DEM data, it will be automatic downloaded, both of DEM and Image Resampling use bilinear interpolation method. Define pixel spacing (m) of 30 m, corrected image resampled from 10 m to 30 mthus this size will fit both to the orthorectified SAR data size in the GLS-2000 and the map projection that is used, UTM (Universal Transfer Mercator) and also the datum, WGS (World Geodetic System) 1984. The areas without elevation will be masked based on DEM data. After defining the parameters, then the process will be running automatically.

*2.3.2. The SAR-Simulation Terrain Correction.*The SAR-Simulation Terrain Correction (SARSimTC) operator generates orthorectified image using rigorous SAR Simulation. There are some major steps in this operation[6].

- SAR simulation: Generate simulated SAR image using DEM, the geocoding and orbit state vectors from the original SAR image, and mathematical modeling of SAR imaging geometry. The simulated SAR image will have the same dimension and resolution as the original image;
- Co-registration: The simulated SAR image (master) and the original SAR image (slave) are co-registered and a WARP function is produced. The WARP function maps each pixel in the simulated SAR image to its corresponding position in the original SAR image;
- Terrain correction: Traverse DEM grid that covers the imaging area. For each cell in the DEM grid, compute its corresponding pixel position in the simulated SAR image using SAR model. Then its corresponding pixel position in the original SAR image can be found with the help of the WARP function. Finally the pixel value for the orthorectified image can be obtained from the original SAR image using interpolation.

Some parameters on SAR-Simulation Terrain Correction Operator are defined like on Range Doppler Terrain Correction Operator because we would compare the orthorectification result from

both of method. SAR simulation steps are using Amplitude as source band, SRTM 3 Sec as DEM data, and bi-linear interpolation method for DEM resampling.GCP selection is done by set the parameters as default and define the RMS Threshold 1.0. Next step on SARSim-Terrain Correction we define RMS Threshold 1.0 with 1 WARP polynominal Order, bilinear interpolation method for image resampling, 30 m pixel spacing and projected to UTM Datum WGS1984.
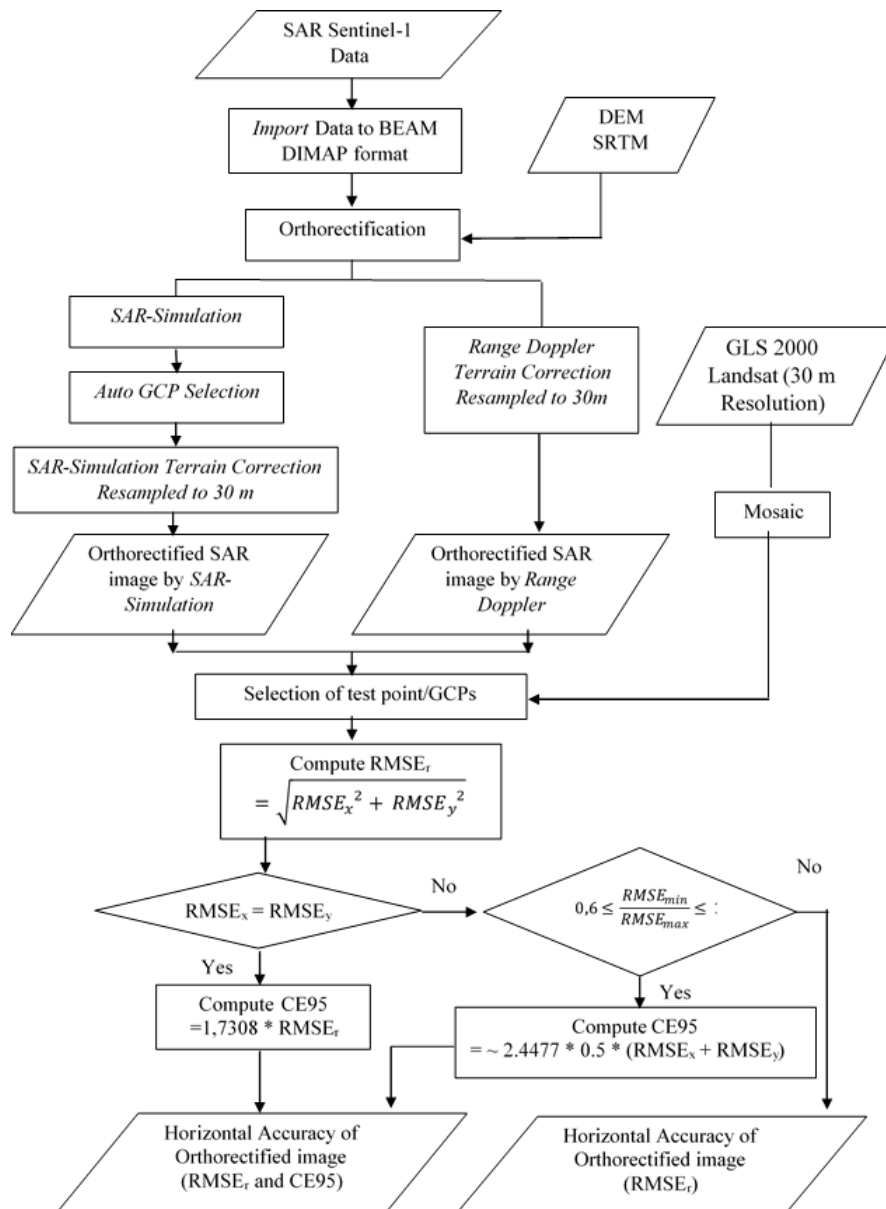

Figure 3. Flow chart of the orthorectification and accuracy assesment.

2.3.3. Accuracy Assessment. Each orthorectified data (resampled 30 m) will be compared qualitatively and quantitatively. The qualitative analysis is conducted by making an RG composite of the orthorectified imagery. The orthorectified data (Range Doppler method) is displayed in red channels, meanwhile the SAR-simulation method is displayed in the green channel. When there was a difference of significant registration occured, the distinct edge of the features boundaries are being observed.

Qualitative analysis was conducted by calculating the accuracy both of orthorectified data on the mosaic of GLS-2000 using GCPs.The GLS-2000 of Landsat imagery will be used as basic imagery on

coordinates acquisition of GCPs in ENVI software. The GCPs will be located separately across the plain area at the linear or any objetcts intersections such as crossroads, irrigation canal and bridge. On the mountainous area at the ridge which can easy identified. The number of GCPs on mountainous area is more than on plain area. The total number of points refers on Lopez [7] for the calculation of the horizontal accuracy using a circular error (CE) 95% is requires about 95 to 100 sample check points. So, for the montainous area, the samples were 57 points and for the plain area were 42 points. The same location of GCPs is used on orthorectified image from both method. We calculate the residual error between the GCPs to generate the residual vector that represent shift direction between GLS 2000 landsat and orthorectified image. It is represented by vector line using XY to Line facilities on ArcGIS 10.1 Software.

Accuracy assesment is conducted by calculating RMSE (Root Mean Square Error) such as error value on X and Y coordinate (RMSEx and RMSEy), accumulation of roots RMSEx squares and RMSEy Squares (RMSEr), and CE95 (Circular Error 95%) value, based onhorizontal accuracy of NSSDA (*National Standard for Spatial Data Accuracy*) [9].Calculation performed on both of orthorectified image (Range Doppler and SAR Simulation method), on the plain area coordinate GCPs, mountainous area, and all coordinate GCPs.Error value on X axis ($RMSE_x$) and Y axis ($RMSE_y$) are calculated using these equations below:

$$RMSE_x = \left(\sum \frac{(x_{data\,i} - x_{ref\,i})^2}{n} \right)^{1/2} \tag{1}$$

$$RMSE_y = \left(\sum \frac{(y_{data\,i} - y_{ref\,i})^2}{n} \right)^{1/2} \tag{2}$$

Where: $x_{data\,i}$, $y_{data\,i}$ = coordinates of the ith check point in the dataset
$\quad\quad\quad\quad$ $x_{ref\,i}$, $y_{ref\,i}$ = coordinates of the ith check point in the independent source of higher accuracy
$\quad\quad\quad\quad$ n   = the number of tested check points

The RMSEx and RMSEy values are used as inputs in the RMSEr as showed on the equation (3) below.

$$RMSE_r = \left(RMSE_x^2 + RMSE_y^2 \right)^{1/2} \tag{3}$$

We compute circular error at the 95% confidence levelto obtain horizontal accuracy of the orthorectified image from Range Doppler and SAR Simulation method. There were 2 cases for calculating the accuracy,

Case1: when $RMSE_x = RMSE_y$. RMSEy. The accuracy of the value should be calculated using equation (4):

$$Accuracy_r = 1.7308 * RMSEr \tag{4}$$

Case 2: Approximating circular standard error when $RMSE_x \neq RMSE_y$. If $RMSE_{min}/RMSE_{max}$ is between 0.6 and 1.0 (where $RMSE_{min}$ is the smaller value between $RMSE_x$ and $RMSE_y$ and $RMSE_{max}$ is the larger value), circular standard error (at 39.35% confidence) may be approximated as 0.5*($_{RMSEx}$ + RMSEy). If error is normallydistributed and independent in each the x- and y-component and error, the accuracy value accordingto NSSDA may be approximated according to the following formula (5):

$$Accuracy_r = \sim 2.4477 * 0.5 * (RMSE_x + RMSE_y) \tag{5}$$

3. Results and Discussion

3.1. Visual Comparison of Orthorectification Results.
SAR imagery (Figure 2) is not projected on the map coordinates of each pixel but still in the original coordinate position of data (rows/columns) in the field of ground range. As the recording data in ascending way, the objects are visible on the upper side is the South side.

In the Figure 4 it showed the orthorectified imagery in South-eastern Sulawesi. Generally, the imageery is in the actual position based on the orthorectification process of RDTC and SAR-SimTC methods. Each of pixels that have been corrected and projected will visually appear in the actual position. Visually it appears that mainland of Southeast Sulawesi as well as other islands beneath it has been stretched to the actual position which is to the southeast. Pixels that were previously in the position coordinates of the original data has been located on the actual position. We can observed that the top side of the SAR image before orthorectification has been located on the south side after corrected. The appearance of marine waters are initially dark grey to bright grey. It turned into grey after the orthorectification process. This masking process happened automatically when the pixels have no radiometric information (value = 0).
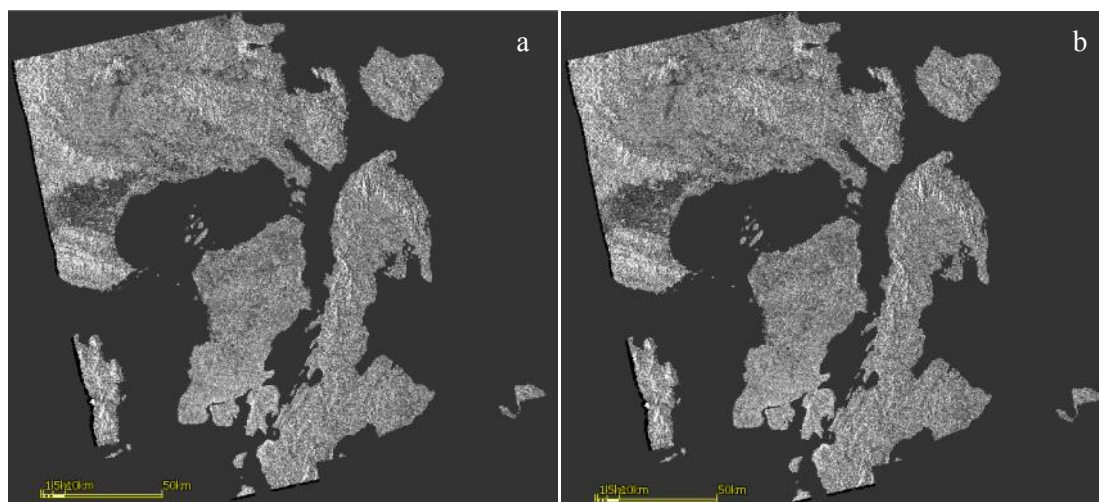

Figure 4. Orthorectified SAR ImageOrthorectified SAR imagery in some parts of South-eastern Sulawesiby Range Doppler Method (a); by SAR-Simulation Method (b).

Visual land observation can be conducted after the orthorectification process is done as showed in Figures 4.There were some changes in the hue color that turned into darker color, it was because of the resampling pocess and interpolation analysis (bilinear interpolation).Speckle noise has been slightly reduced, but based on figure 4 generally there are no significant visual difference between orthorectified image from Range Doppler and SAR Simulationas well as the differences in the appearance of the geometry of the image including image rotation.
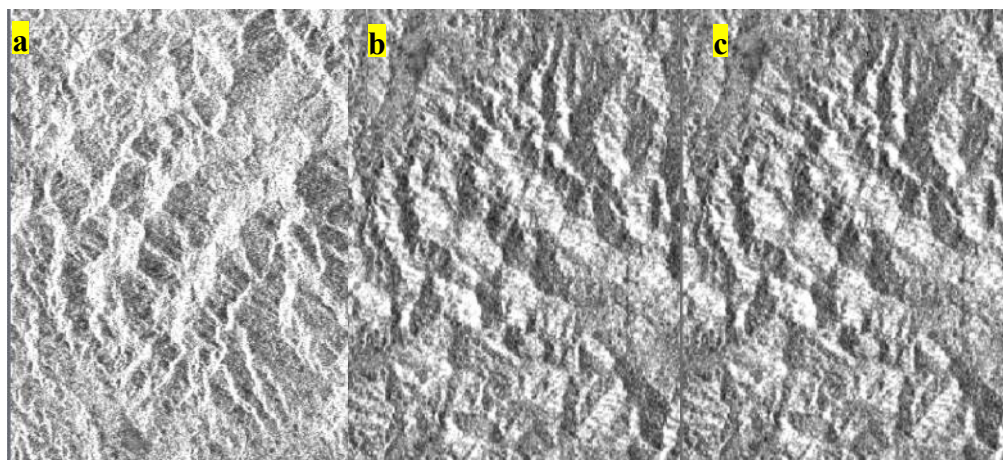
Figure 5. Foreshortening Effect on Sentinel-1 SAR Data (a) compare to the data after Range Doppler Orthorectification (b) and after SAR Simulation Orthorectification.
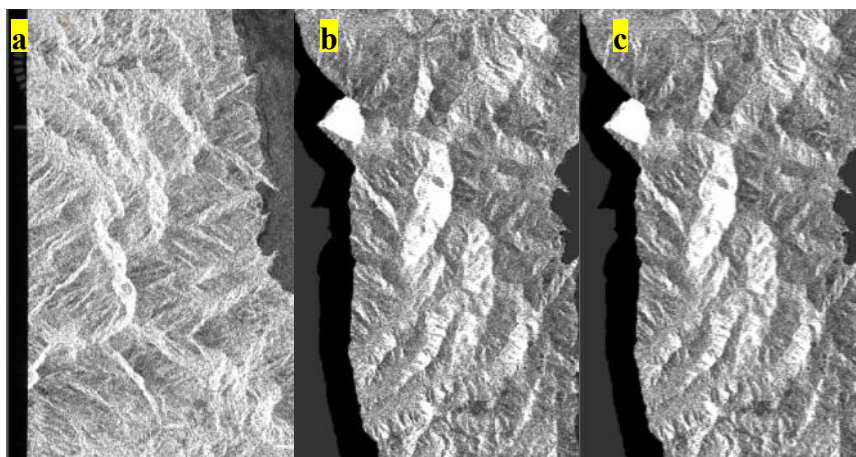

Figure 6. Layover Effect on Sentinel-1 SAR Data (a) compare to the data after Range Doppler Orthorectification (b) and after SAR Simulation Orthorectification.
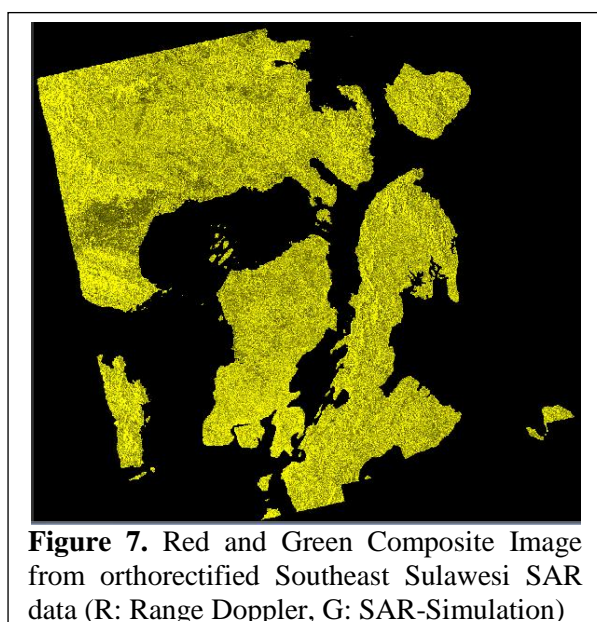

Figure 7. Red and Green Composite Image from orthorectified Southeast Sulawesi SAR data (R: Range Doppler, G: SAR-Simulation)

Based on Figure 5 and 6 we can summarize that both of methods are visually effective in reducing the geometrical distortions on the forshortening and layover effects. Before the orthorectification process, the hilly topogaphy which has a foreshortening effect is shorten than the actual size. After the correction process it has been returned to the actual size. The bright pixels were represent the strecthed slopes. The mountainous topography with layover effect looked like close to the nadir point, but after the orthorectification process, the hill tops are back to the actual position..

Figure 7show the orthorectified image from both of methods that had been Red and Green composited. Orthorectified SAR image by RDTC method on the red channel and orthorectified SAR image by SAR-SimTC method on the green

channel. The yellow color shows the pixels match (has same pixel position and its values are almostequal), meanwhile the green and red colours were indicated the shift between the images. Based on figure 7 we can observe that there are no significant color changes or the red or the green color for the entire coverage of the image, which should be identified easily on the edge of the masking results between sea and land.

Figure 8both on plain terrains (*a* and *b*) and mountainous (*c* and *d*) showed visually that there were no differences after orthorectification process was done both from RDTC and SAR-SimTC methods. In detail the shift between the imagegery is not significant. Based on Figure 8 There were no distinctions of edge effects which showed by Red and Green colours, meanwhile, in the border and adjacent objects, there were differences.Figure8(*a*) showed that there was no shift between crossroads and rivers, as well as runway (picture 8(*b*)), and also ridge on mountainous and hilly area(picture 8(*c*)). Red and Green pixels which appeared in the imagery was Radiometric aspect of orthorectification results.
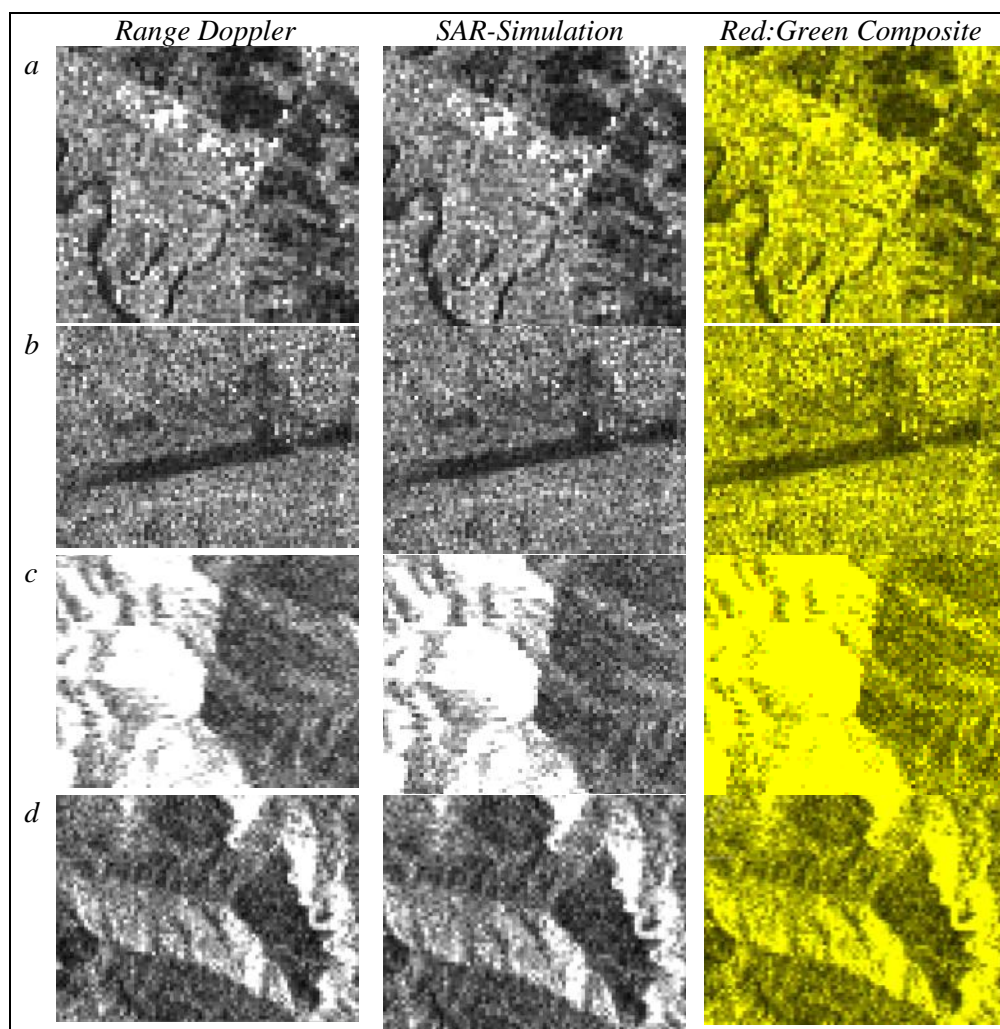

Figure 8. Comparison of composites of orthorectified SAR data.

Based on geolink facility on ENVI software Based on the *Geolink* facility on ENVI software as shown in the Figure 9, showed that the same objects are located on the same coordinates eventhough using different methods. Picture *e* was indicated object as vegetation coverage and Picture *f*was indicated as the ridge of mountainous area.
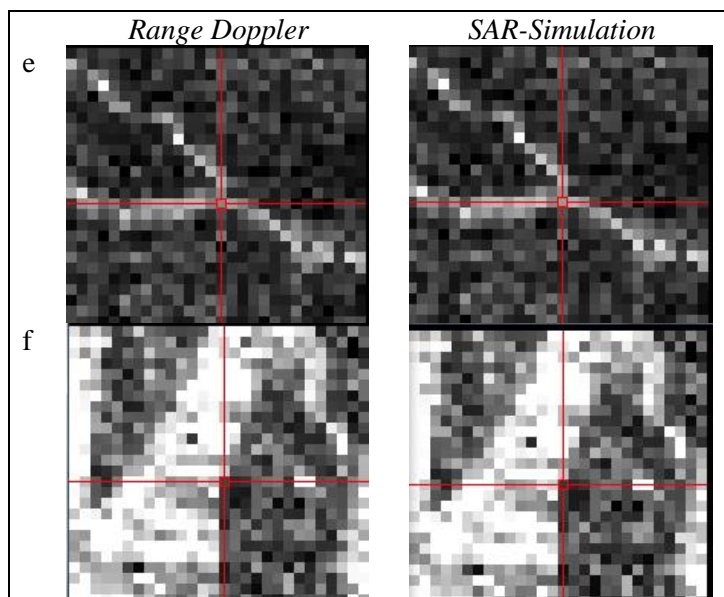
Figure 9. Comparison of object positions on the plain and mountainous area.

3.2. Comparison Results Between Orthorectified SAR data and GLS-2000 of Landsat Imagery.
Residual vector show the shift between orthorectified results of both methods,direction of the arrow is a residual vector between the coordinates of a reference to the coordinates on the same object on orthoretified SAR image, which there were 99 test points/GCPs.

The length and direction of the arrows Length and direction of the arrows are indicated the length and direction shifts that of the arthorectified data in the actual positions.The distances of arrow points from the reference into the GCPs are showed in theFigure 10 and 11.This distance is not the actual distance but it has been magnified 400 times.

Based on Figure 10the shifts which has happened on the orthorectified data showed the random pattern as slightly tilted to the eastern on plain area and the hilly area on the top of image. south side of the South-eastern island (Kabaena Island). Besides, the shifts were also tend to the south-eastern part with the pixel was less than one pixel on the mountainous area (Kabaena Island) (the left bottom corner of the image).Moreover, the shift direction of plain terrain in the mainland of Muna District was lead to the northeast. The magnitude of shift direction which has more than one pixels was located on the east side of the image (Mainland of Baubau District) and especially on the hilly or mountainous areas.

Based on the residual vectors, we can analyse the shift of the orthorectified data. The shift of the plain terrain was smaller than the mountainous one. It could be indicated by the short green arrows which distributed around the plain terrain, meanwhile the longer green arrows were distributed around the undulating, hilly, and mountainous areas. On the areas which have big and steep slopes, the amplitudes are indicated by the red arrow and it has an shift more than 30 meters.

There were different pattern of arrows that lead into northwest direction especially in the mountainous areas. This is caused by the possibility of morphological changes, for example erosion on hilly and mountainous areas, since the difference recording years of based image (GLS-2000)and SAR data. Based on figure 10 and 11there were no significant differences of two results both in geometrical orthorectification and Range Doppler and SAR-SimTC methods, either on the magnitude of shift or the direction
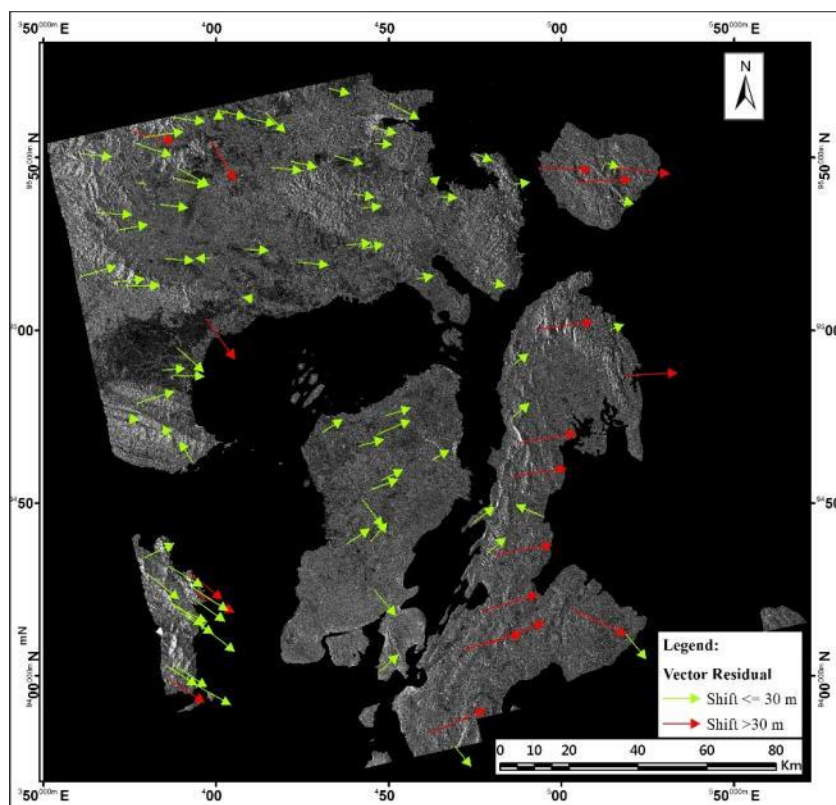
Figure 10. Residual Vector Scene: 3086/39; Orthorectified Sentinel-1 SAR by Range Doppler Method in Some Parts of South-eastern Sulawesi using multiple factor of 400 times.
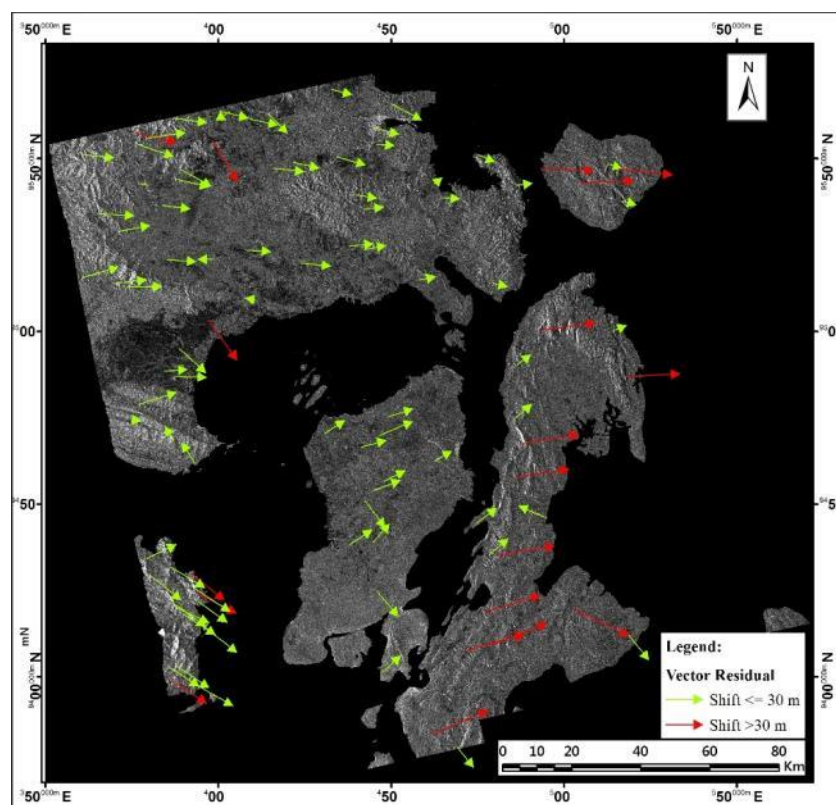

Figure 11. Residual Vector Scene: 3086/39; Orthorectified Sentinel-1 SAR by SAR-Simulation Method in Some Parts of South-eastern Sulawesi using multiple factor of 400 times.

Table 1 was indicate the quantitative analysis of Orthorectified SAR Sentinel-1 in some parts of South-eastern Sulawesi. The RMSE value was determine the horizontal accuracy. The value of RMSE and CE95 will be used as inputs on calculating the horizontal accuracy based on the NSSDA using 99 GCPs, but in this study, only RMSEr value was counted. Since the value of the ratio RMSEx and RMSEy not circular (RMSEx ≠ RMSEy) and the ratio was 0.46 (RMSEmin/ RMSEmax) are not on a value between 0.6 and 1, which is a requirement to calculations of CE95.

Table 1. Accuracy calculation results of Orthorectified SAR Sentinel-1 data based on RMSEr

Method	Topography	Number of GCPs	$RMSE_x$	$RMSE_y$	$RMSE_r$
Range Doppler Terrain Correction	Plain	42	17.77	10.58	20.68
	Mountainous	57	26.06	10.71	28.18
	All Areas	99	22.91	10.68	25.27
SAR-Simulation Terrain Correction	Plain	42	17.77	10.58	20.68
	Mountainous	57	26.06	10.71	28.18
	All Areas	99	22.91	10.68	2527

The results of RMSE calculation both on the orthorectification and Range Doppler and SAR-SimTC methods showed the similar values (see Table 1). In the plain area, the error value was smaller than in the mountainous area. Both of shifts on the RMSEx and RMSEy are 17.77 m and 10.58 m, meanwhile, in the mountainous area are 26.06 m and 10.71 m. The value of RMSEr on the plain terrain with 42 GCPs is 20.68 m, which is smaller than the RMSEr value on the mountainous area with 57 GCPs as 28.18 m.

Based on Table 1, shows that the value of RMSEx always bigger than RMSEy. This is indicates that the shift results of orthorectified image are biggeronthe range direction than the azimuth direction [10]. RMSEr values based on Table 1 shows the same value (25.27 m) on both of the RDTC and SAR-SimTCBoth RDTC and SAR-SimTC methods have the same value based on the 99 GCPs as 25.57 m. the same value is generated based on the GCPs taken on the same objects. This showed that there was no significant geometrical difference between two results of orthorectification. Each pixel represents the same object which has the same coordinates.

The shift value was caused by the orthorectification process. DEM data has a low spatial resolution which is less than 90 meters and the resampling process is at 30 meters, thus the process of resampling is conducted from 10 m to 30 m in the GCPs determination. Because of the difference of recording time of GLS-2000 of Landsat imagery and Sentinel-1 SAR imagery, it is possible to find not matched existing object because the change of land cover and terrain in observation area.

It was interesting to see there is no significant differences in visual geometry between the orthorectified imagery on Range Doppler and SAR-Simulation method. There should be generate different geometry of orthorectified image, regarding the difference in principle between orthorectified Range Doppler method and SAR-Simulation.But those differences still can be found in the case of Radiometric value.

3.3. Radiometric Comparison of Orthorectification Results.
Figure 12showed the enlarged orthorectified imagery and composites on the plain area (*p* and *q*), undulating terrain (*r*), and the hilly-mountainous terrain (*s* and *t*). Each picture shows the green and red pixels which is spread up in the different intensities. Picture p and q are displayed as linear objects, thus the appearance of red and green colours in the surrounding pixels are indicated the heterogenous objects. The pixels which are formed of the red and green pixels in the composite have different intensity values of grey that can be considered as noise of SAR imagery, meanwhile the yellow colours are formed from the pixels which have the similar or equal value of intensities.
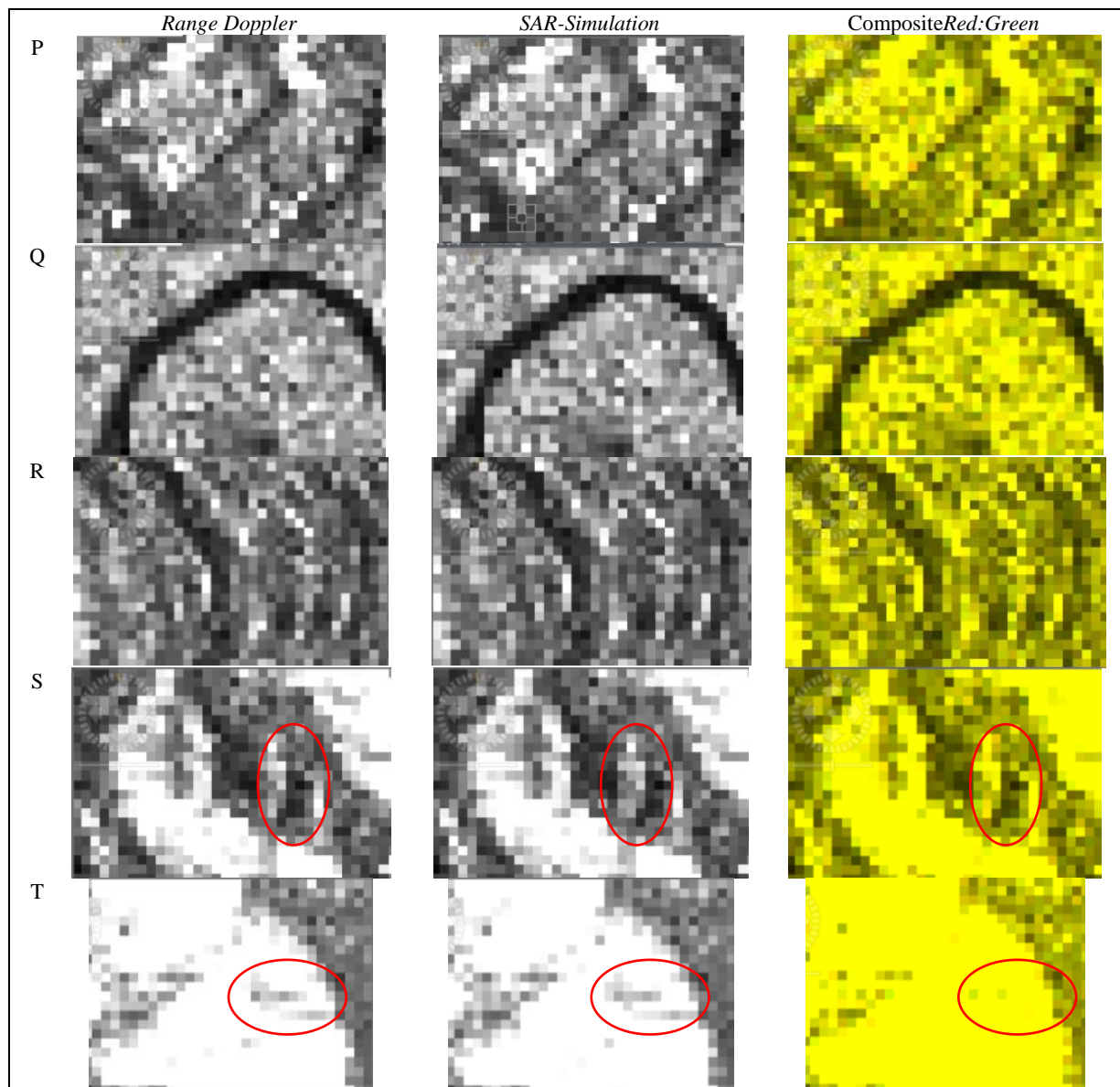
Figure 12. Detail comparison on Composited Orthorectified SAR Image

The green and red composite images are caused by the pixels that having different intensities in the undulating areasshown on the object (r). Same as the picture of *s* and *t,* the mountainous area showed in the red circled, which has a different intensity or brightness values but still in the same geometrical patterns. The picture *t* showed that most of the pixels in the yellow colour are indicated the same value. Moreover, there are some green and red pixels which appeared in the areas, this means that the pixel has different value.

These results showed that both methods can do generate the orthorectified SAR data in different pixel value intensity or backscatter value but not significant.But in the geometrical terms, it still has the same object form which is not much different. So, it may be a necessity to do radiometric calibration process while doing the orthorectification process using Sentinel-1 Tbx.

Those accuracy of orthorectified Sentinel-1 SAR data in some parts of South-eastern Sulawesi from each method may be due to issues during orthorectification process such as DEM data input have low spatial resolution (90 m) than Sentinel-1 SAR data, the resampled Sentinel-1 SAR data to a

lower pixel spacing. The quality of the DEM is important during orthorectification, particularly in relation to the location of features, stretching effects and generation of local incidence angle information, but also for radiometric calibration [11]. Moreover, the geometry distortion of GLS-2000 landsat data and human error factor such as confusion in selecting GCPs which used to accuracy assesment should be considered.

4. Conclusion
The orthorectification process of SAR data in some parts of South-eastern Sulawesi has been done by using Range Doppler and SAR-SimTC methods on Sentinel-1 Tbx. There were 99 GCPs taken using GLS-2000 of Landsat Imagery which is used as the referenced imagery. The results of horizontal accuracy showed there is no significant differences in the geometrical visual of orthorectified image from both methods of Range Doppler and SAR-SimTC. The RMSEr value is 25.27 m which means that the horizontal accuracy is less than one pixel. There is still a difference that can be found in the radiometric aspect between the orthorectified SAR data from each method.

5. Acknowledgment

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