DOI : https://doi.org/10.7186/wg462202007

The effect of land reclamation on water clarity in Tanjung Tokong using remote sensing

Nurulamani Rosman, Aisah Taufik, Ismail Ahmad Abir*

School of Physics, Universiti Sains Malaysia, 11800 Gelugor, Pulau Pinang, Malaysia
* Corresponding author email address: iahmadabir@usm.my

Abstract: Reclamation land project in Tanjung Tokong, Penang is one of the sign of the rapid urbanization of Penang island due to the increase in population and a need for land. However, recent increase in public awareness of the negative effects of land reclamation projects on the local fishing community and the marine habitats has made it important to study the changes in the coastal water quality that relates to these projects. Therefore, this study is an initial attempt to measure water quality, mainly water clarity, using cost-effective satellite remote sensing images. Secchi disk depth measurements is collected around the Tanjung Tokong reclaimed land at the same time as the Landsat 8 image of Penang island is recorded. The Secchi disk measurements are compared and correlated with the reflectance data of the Landsat image resulting in a correlation equation. Based on the equation, water clarity is then estimated for previous Landsat images of Penang. Finally, Secchi disk depth measurements is also collected for the west coast of Penang island for comparison purposes. Our results show that the NIR (Near-infrared) band is the most sensitive for water clarity estimation. Furthermore, the water is generally clearer in the area to the west of Penang island where there are no land reclamation projects. However, there are other environmental factors which were not take into account, such as tidal changes, that will also affect water clarity.

Keywords: Water clarity, remote sensing, Secchi depth, landsat

INTRODUCTION

Penang Island is one of the fastest-growing and most densely populated places in Malaysia with a population of 752,800 (Department of Statistics Malaysia, 2015) and a density of 1663/km^2 (Penang Institute, 2016). The population on the 299 km^2-island has increased by more than 40% since 1970 (Department of Statistics Malaysia, 2015) and is projected to rise exponentially over the next 15 years (Penang Transport Master Plan Study, 2013). Due to the rapid population growth and the simultaneous increase in urbanization, land reclamation has been extended to the construction of man-made islands (artificial islands) (Chee *et al.,* 2017). Land reclamation in Penang began in the early 1800s (City Council of Georgetown,1966) during the British administration, but recent large-scale coastal development projects have contributed to the alteration of the coastline of Penang to make way for transportation and infrastructure (City Council of Georgetown,1966; Khoo & Wade, 2003).

Land reclamation is a process of creating new land in water bodies either along coastal areas or in the form of new islands (man-made island). Coastal reclamation has become a serious development option in Malaysia (Ghazali, 2006). Reclamation land in coastal areas may have a significant effect on the ocean water. The main issue is water pollution and this may affect marine life and also human. The recent public protest regarding the newly planned reclamation projects in south Penang Island shows that the public is becoming more aware of their negative impacts, especially to the environment (FMT News, 2019). The fisherman community to the north of Penang Island (Tanjung Tokong) has been complaining about the significant loss of fish and other marine life during the reclamation project. Due to the public and environmental concerns, this work was conducted as an initial attempt to monitor the quality of coastal water of Penang Island in relation to reclamation projects. Hence, it is important to monitor water clarity from time to time. Water clarity defined as a physical characteristic of how clear or transparent the water. Water clarity has been measured in standing water bodies using a Secchi disc. Secchi disk is the simplest and one of the most effective tools for estimating water column productivity. It is also a measurement of water clarity where water transparency directly affects the amount of light penetration into water column.

However, field work is costly and time consuming. Therefore, this work focus on utilizing remote sensing to estimate the water clarity based on the reflectance data. Reflectance values that we obtained from processed

Landsat data were used to correlate with Secchi depth (SD) measurements. Reflectance remote sensing (Rrs) can be defined as the ratio of water leaving radiance to the total downwelling irradiance just above water (Pahlevan *et al.*, 2017). SD measurements were collected on the same date as the Landsat 8 image so that we can correlate based on the linear regression approach.

The study area chosen was Tanjung Tokong, Penang (05° 26' 51" N, 100° 18' 24" E). The area is located within the north-west coast of Peninsular Malaysia which is in the northeast of Penang Island (Figure 1). The Tanjung Tokong Beach is located west of Tanjung Tokong headland. It is categorized as a moderately exposed sandy beach with medium to fine sand. Shell debris can be found easily on the foreshore of this beach. The water is often turbid indicating a relatively high content of suspended sediments (Ramly, 2008). In addition, to compare the measurements of ground-based data with Tanjung Tokong, a different study area was chosen, which is the Penang National Park (05° 27' 42" N, 100° 11' 24" E). This area is located on the north-western tip of Penang (Figure 1). The Penang National Park is the only considerable natural forested areas left on Penang Island. It is considered one of the protected areas under the management of the Department of Wildlife and National Parks (DWNP) (Kaffashi *et al.*, 2015).

DATA AND METHODS

Ground data acquisition

Secchi depth (SD) measurements were collected and correlated with satellite data. The correlation between actual Secchi depth and satellite data will be used to estimate the Secchi depth from archive satellite images. 25 SD readings were collected surrounding the land reclamation project which covers 1km per square with the same date as Landsat-8 image (Figure 2). The data was gathered on 20th December 2017.

Satellite data acquisition

Landsat 8 imagery was downloaded from Earth Explorer - United States Geological Survey (https://earthexplorer.usgs.gov/) with Path Type WRS 128 and Row 56. The date of acquisition of the imagery is 20th December 2017, which covers the area of northeast of Tanjung Tokong coastal area. The projection of the imagery is UTM WGS84 Zone 47 and its spatial resolution is 30 m x 30 m.

It was important to acquire Landsat image that was recorded at the same time as field data collection. This will result in better correlation. The image was downloaded in a package containing a total of 11 spectral bands in GeoTiff format, 1 quality assessment band and 1 metadata file in ASCII format. However, only the visible-near infrared bands, which are bands 1-7, were used for analysis.

Satellite and ground data processing

For the processing of the data, Envi® 5.3 and ArcMap 10 were used for image analysis. The techniques involved are:

1. Landsat 8 multispectral image data underwent radiometric calibration to provide calibration

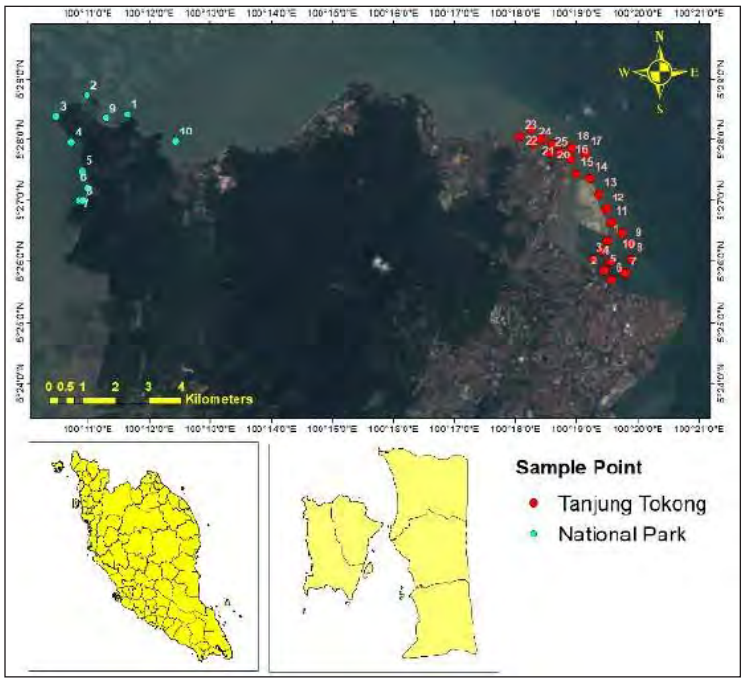


Figure 1: Study area around Tanjung Tokong (reclamation land) and Penang National Park (control area) which are located in Penang, Malaysia.

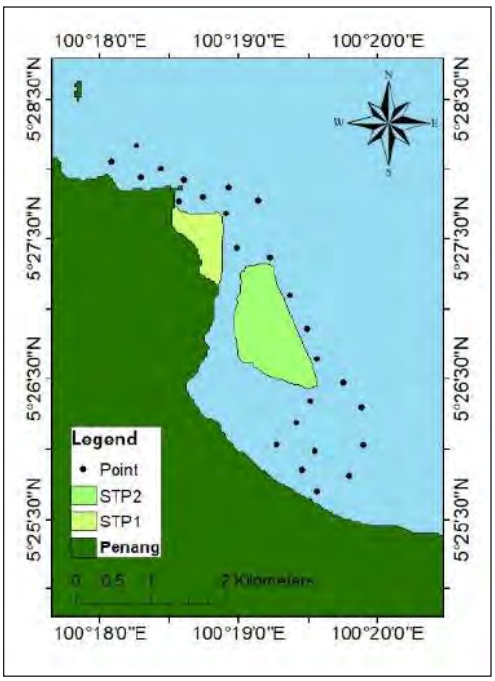


Figure 2: The dot points show the stations of collected data.

coefficients to convert from digital numbers (DNs) to Top of Atmosphere (TOA) Reflectance.

2. Dark subtraction was applied to remove the effect of atmospheric scattering from an image by subtracting a pixel value that represents a background signature from each band.
3. From the imageries, the digital number of reflectance values for every band on a specific date and location was extracted using ArcMap 10.

The data was added into ArcMap which were then processed by using interpolation tools named IDW (inverse distance weighting) to produce Secchi depth distribution map of the study area.

In order to test the relationships between the Secchi disk depth within the study area and the reflectance from Landsat 8 image, linear regression was used. This is done through Microsoft Excel software.

Estimation of Secchi depth for archived satellite images by using selected model

After the linear regression has been run, we used the equation with the highest R squared to estimate the Secchi depth for archived Landsat 8 images. A total of six Landsat 8 images were downloaded. Images in the best condition were viewed and selected with less cloud cover. Moreover, we selected images from before and after the reclamation project for comparison purposes.

The calculation was done by using ENVI 5.4 software by inputting the equation in the band math. Then the value was extracted by using ArcGIS software. Steps for this data processing are shown in Figure 4.

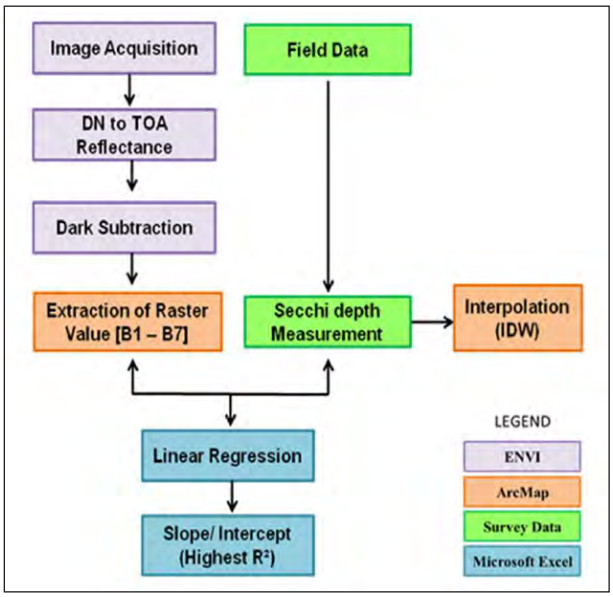


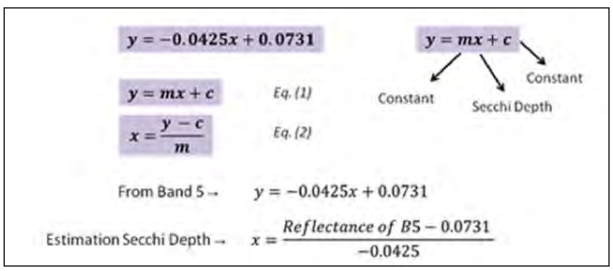
Figure 3: The overview flowchart of overall methodology shows the flow diagram from acquisition of satellite image until the estimation of Secchi depth.

RESULTS AND DISCUSSION

Secchi depth distribution in Tanjung Tokong coastal area

The distribution shows different result from the hypothesis where the water columns located close to the land reclamation project are supposed to be more turbid compare to undisturbed coastal area. However, there are a lot of environmental factors such as waves, tide and current cycles that were needed to be considered that could affect the Secchi disk readings. All the factor mentioned are categorized as uncontrollable factors and will introduce error in the interpretation of factors that could affect the Secchi measurements.

To better understand the effect of reclamation land, comparison of data with controlled area (Penang National Park) was done using Secchi depth measurements. There is a slight contrast of SD measurement between land reclamation area and control area. In general, all ten sample sites of the coast of Penang National Park show increase in SD readings (Figures 5 and 6). This is an indication of higher water clarity. The Secchi depth readings on this particular area reached ~2 m of water column depth. High Secchi depths are associated with high water clarity and low turbidity. In contrast, the Secchi depth for the Tanjung Tokong area is only up to ~1 meter in depth.



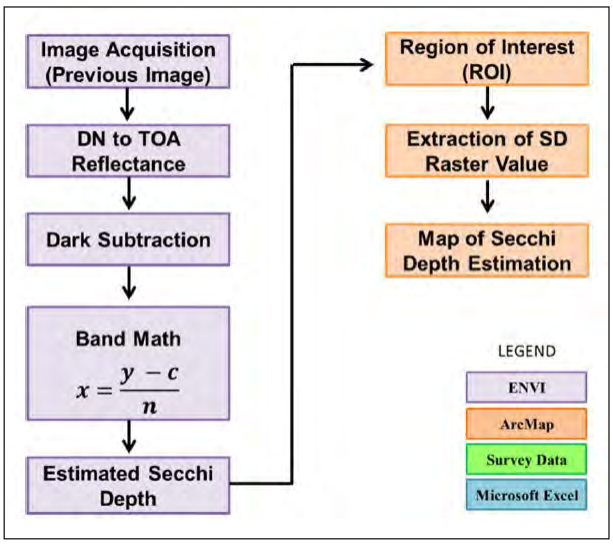


Figure 4: Flow chart of process to determine the estimate value of Secchi depth.

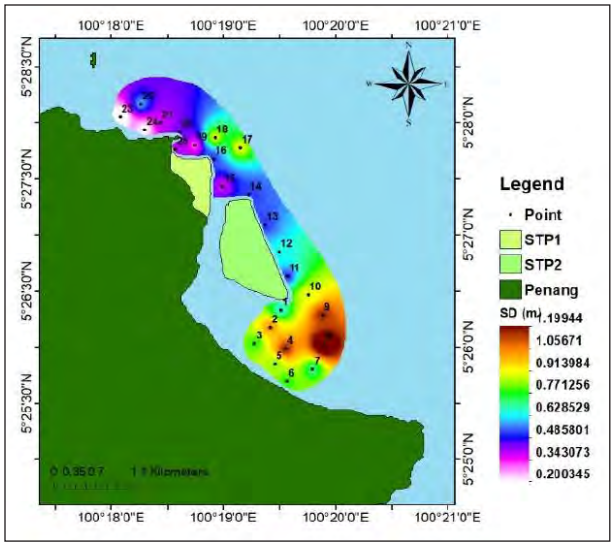


Figure 5: Distribution of Secchi depth measurements of Tanjung Tokong coastal area.

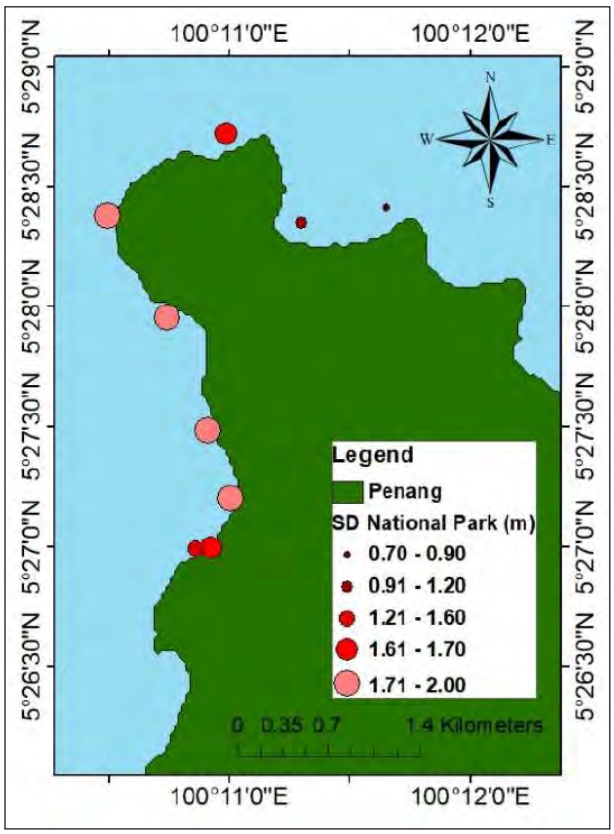


Figure 6: Distribution of Secchi depth measurements in Penang National Park.

Correlation between Secchi depth and reflectance value

Based on the Table 1, we can clearly see the differences of the coefficient of determination between all bands. Band 5 shows the highest coefficient of determination (R^2=0.7051)which shows that the model

Table 1: Summary of the performance statistics linear regression using different band.

	Regression Equation Coefficients	R^2
SD vs Reflectance-B1	y = -0.0226x + 0.1776	R^2 = 0.557
SD vs Reflectance-B2	y = -0.0289x + 0.1711	R^2 = 0.5351
SD vs Reflectance-B3	y = -0.0398x + 0.1663	R^2 = 0.558
SD vs Reflectance-B4	y = -0.0711x + 0.1495	R^2 = 0.6533
SD vs Reflectance-B5	y = -0.0425x + 0.0731	R^2 = 0.7051
SD vs Reflectance-B6	y = -0.0123x + 0.0264	R^2 = 0.5726
SD vs Reflectance-B7	y = -0.01x + 0.0194	R^2 = 0.5643

equation fits the data relatively well when compared to other bands (Figure 7). It shows that an increase the values of Secchi depth correlates with the decrease in the reflectance values. Others band also shows correlation with the Secchi depth readings: Band 1(R^2 = 0.557), Band 2(R^2 = 0.5351), Band 3 (R^2 = 0.558), Band 4 (R^2 = 0.6533) and Band 6 (R^2 = 0.5726).

One has to consider that in conditions where there's an increase of electromagnetic wavelength, water has a lower reflectance. In the NIR (Near-Infrared) (0.845 – 0.885 µm) range, water has a strong absorption capacity and produces less remote sensing reflectance. In the use of NIR, the latter relationship require an assumption of equivalent spectral dependency for back scattering and scattering. As the electromagnetic wave radiation of NIR travel into the water, it will be absorbed. For such area which is turbid (lower Secchi depth), it consist of suspended particle, thus suspended matter in water causes scattering of the radiation.

Estimation of Secchi depth

The linear regression equation was applied to estimate the water clarity parameter based on band 5 (Near-Infrared) of Landsat 8 image. The use of consistent band helps us make the analysis of different images comparable and is an important step towards standardizing produced maps.

Figure 8 represents contour maps for predicted Secchi depth model at Tanjung Tokong near the reclamation land (on 23rd November 2013, 31st December 2015, 20th March 2016, 17th December 2016, 24th April 2017 and 11th June 2017). From the maps, the changes of historical coastal water up to the extent of reclamation land can be seen. It

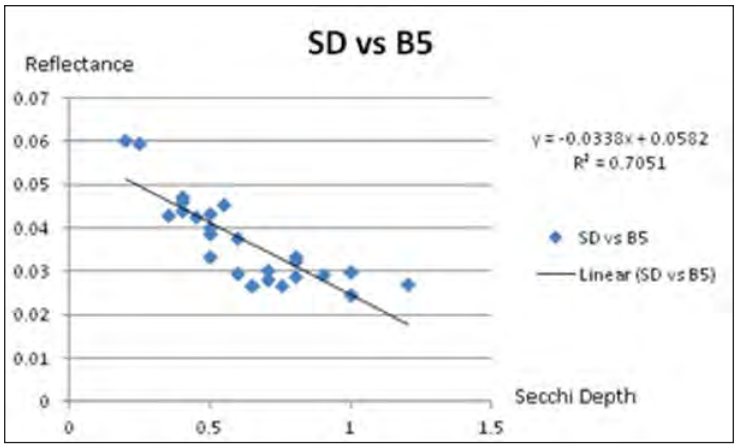


Figure 7: Correlation between Band 5 and Secchi depth.

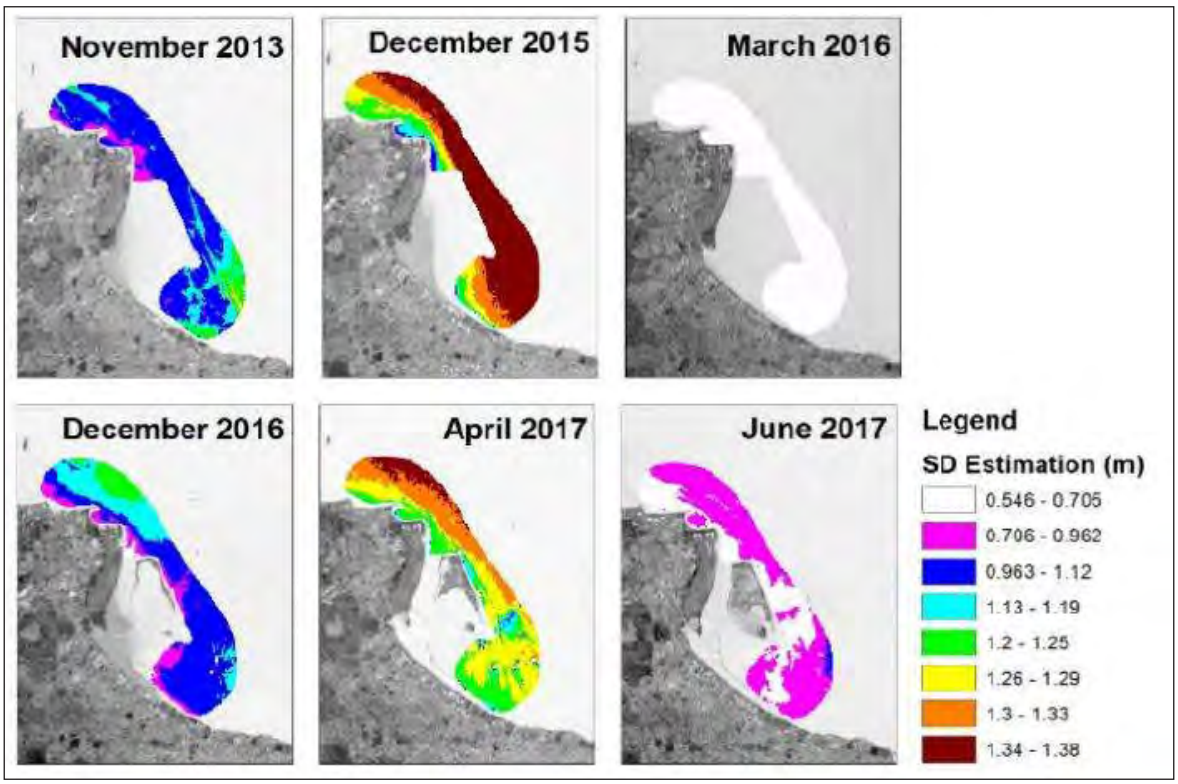


Figure 8: Maps show Secchi depth estimation derived from Landsat 8 imageries based on region of interest from November 2013 to June 2017.

is observed that the levels of Secchi depth varied and are unevenly distributed. It indicates that the use of Landsat 8 image to measure water clarity in coastal areas is sensitive, especially to weather and other environmental factors.

Interesting observations from the map pattern show that the predicted SD significantly gets lower throughout the year, as indication of poor water clarity. This lower SD coincides with increased turbidity observed in those areas. Undoubtedly, negative effects on the island's natural coastal habitats and water will be inevitable.

CONCLUSION

In conclusion, it was noticeable that land reclamation in Tanjung Tokong affects the water clarity in terms of light penetration. It showed that the water become turbid. The best regression is found from the high correlation value between reflectance of NIR band and Secchi Depth.

ACKNOWLEDGMENTS

This work was funded by USM Short Term Grant (Grant No. 304.PFIZIK 6315053). The authors wish to

thank the Department of Geophysics, Universiti Sains Malaysia (USM) and School of Biology for their assistance during the data acquisition, especially En. Yaakob. Also, thanks to Dr. Nordin Abu Bakar, Dr. Amir Shah Ruddin, Mr. Ermizan, Mr. Dwiky Cesarian, Mr. Faiz Asyraf and Mr. Safwan Najmi who have helped the authors in finishing the paper.

REFERENCES

Chee, S. Y., Othman, A. G., Sim, Y. K., Adam, A. N. M. & Firth, L. B., 2017. Land reclamation and artificial islands: walking the tightrope between development and conservation. Global Ecology and Conservation, 12, 80-95. https://doi.org/10.1016/j.gecco.2017.08.005.

City Council of Georgetown, 1966. Penang: Past and Present 1786–1963. The Ganesh Printing Works. Supplementary Map, Penang, Malaysia.

Department of Statistics Malaysia, 2015. Jumlah penduduk dan kepadatan penduduk mengikut daerah pentadbiran bagi negeri Pulau Pinang, 2014e2015.

FMT News, 2019, "Nearly 5,000 protest against Penang land reclamation". Published 8th September, 2019 (https://www.freemalaysiatoday.com/category/nation/2019/09/08/nearly-5000-protest-against-penang-land-reclamation/).

Ghazali, N. H. M., 2006. Coastal Erosion and Reclamation in Malaysia. Aquatic Ecosystem Health and Management, 9(2), 237–247.

Kaffashi, S., Radam, A., Shamsudin, M. N., Yacob, M. R. & Nordin, N. H., 2015. Ecological conservation, ecotourism, and sustainable management: The case of Penang National Park. Forests, 6(7), 2345-2370.

Khoo, S. N. & Wade, M., 2003. Penang Postcard Collection 1899-1930s. Janus Print & Resources.

Pahlevan, N., J. R. Schott, B. A. Franz & Giuseppe Zibordi, 2017. Landsat 8 Remote Sensing Reflectance (Rrs) Products: Evaluations, Intercomparisons, and Enhancements. Remote Sensing of Environment, 190, 289–301. http://dx.doi.org/10.1016/j.rse.2016.12.030.

Penang Institute, 2016. Penang: Estimated Population by District. Available at: http://penanginstitute.org/v3/resources/data-centre/122-population.

Penang Transport Masterplan Study, 2013. Kajian/Masterplan bagi Pengangkutan dan Pengurusan Lalu Lintas Pulau Pinang. Pejabat Setiausaha Kerajaan Negeri Pulau Pinang. p. 4.

Ramly, S., 2008. Impact on the coastal areas of the Tanjung Tokong Land Reclamation Project, Penang, Malaysia-Effects on wave transformation, sediment transport, and coastal evolution. Master thesis, Lund University. 76 p.

Manuscript received 5 March 2019
Revised manuscript received 23 September 2019
Manuscript accepted 2 October 2019