The future of Wallace region in Lombok: the pristine natural resource under climatic and anthropogenic threat

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Abstract. Wallace region is mostly comprised of the southeast archipelagoes of Indonesia, namely West and East Nusa Tenggara. Lombok is a west border of the Wallace line which biologically delineate the distinguished fauna and climate in the eastern Indonesia. However, the pristine natural resource is under climatic and anthropogenic threat. A case study by means of a Descriptive method was conducted to identify any contradictive use of natural resource leading to environmental degradation, as well as to study ruination impact of climate uncertainty. Long term satellite images of Lombok from 1980’s up to the latest date were traced to identify any changes in land cover, land use and settlement. Climate data were analyzed to find its trend and forecast its potential impact on the environment. Overall, the results showed that the pristine environments, namely forests, hillocks and cliffs, particularly in tourism destination sites had been accordingly overburdened by contradictive use of resources. Lack of law enforcements in environmental protection was a key point to be addressed as a major factor resulted in losses of the most valuable value of Lombok natural scene. In addition, manmade disaster is becoming more frequent with climate change commonly accused. In conclusion, the future of the natural resource in Lombok would not be merely relied on world class facilities of tourism industry, but on to what extend effort to naturally sustain the beauty of natural scene, stop degrading the lands and be responsible to protect environment in line with regional development.

1. Introduction

Indonesia is one of the most seismically active region [1], where Wallace region is located. Alfred Russel Wallace officially declared Wallace line in 1863 and marked Lombok strait as the west border. The Wallace region is a transition zone between fauna of Asia and Australia origin in which diversity of flora and fauna linked with geological history of the region [2], as well as climate [3]. Indonesia laid on two main shelve, namely Sunda shelf at west part, belong to Asia continent group, and Sahul shelf at east part belong to Australia continent group [4]. Wallace region lies in between both shelve. The Wallace line runs from Lombok strait through Macassar strait and further north ward through border of Philippines and Indonesia [5]. Deep water surrounding Wallace region isolates the region from Asia and Australia continent. Therefore, the region is well known as oceanic islands that are sitting on ocean floor [6].

In term of geomorphology, Lombok consists of three main zones, namely mountainous complex in the north (a), plateau in the middle (b), and hill ranges in the south (c). Each zone possesses its typical natural threat or disaster, i.e., volcanic earthquake at northern zone, meteorological related disaster, e.g., drought and flooding in the middle zone and tsunami at southern beaches facing to Indian Ocean.
In addition, Lombok lies in between two tectonic forces, namely the back arch fault at off shore of the Flores sea at northern coast of Lombok, and the Pacific fire rems at south [7]. Lombok is naturally rich of valuable minerals contained in volcanic rocks [8], but it is under anthropogenic threat. Natural resources have been accordingly over exploited and people rely on the non-renewable resources. It makes Lombok susceptible to erosion and land slide. The mount Rinjani, which is one of global geopark [9] is being contaminated by accumulation of inorganic rubbishes carried by massive visitors. Hillocks have been demolished, while low lands or valleys were dumped. Pristine forests were cleared and water resource is becoming scare.

Climatically, standard parameters of climate change in Wallace region are negative [10]. Air temperature increased by 0.09°C per decade in a period of 1920 to 2020. It was relatively higher than a global rate of 0.07°C per decade [11]. Climate change could profound impact of anthropogenic disaster which may more horrified than pandemic of covid-19. Impact of climate change on social and economy would be more severe in developing countries where they merely rely on agriculture and natural resources. To avoid future impact of climate change, global leaders work hand by hand to sustain the increment level of air temperature less than 1.5°C [12]. National and local Government in Indonesia must be committed in protecting environment. So, oceanic archipelagoes like Lombok will be safe. Main objectives of this paper were to identify contradictive use of natural resources and to study impact of climate uncertainty.

2. Methods
Research was conducted by means of a Descriptive method focused on a brief history of land use, geology of Lombok, potential natural disaster, man-made disaster and climate parameters. Land use and changes over time was observed from time lapse satellite images from 1984 to 2020 [13]. Climate data were collected from relevant resources, namely air temperature, sea surface temperature, and rainfall. Sea surface temperature (SST) was recorded at southern Indian Ocean (115°E and 9.5°S).

2.1. Data Sources.
Satellite time lapse images of Lombok from 1984 to 2020 were downloaded from free access; https://earthengine.google.com/timelapse/ [13]. Precipitation data were freely downloaded from Bureau of Meteorology and Geophysics: http://www.bmg.go.id/ [14]. Terrestrial air temperature and sea surface temperature were downloaded from Stat World 2020: https://stat.world/biportal [15], and NOAA: https://www.ncdc.noaa.gov/cag/ [16].

2.2. Data analyses.
2.2.1. A Simple Linear Regression. Changes in climate parameters, namely annual rainfall and sea surface temperature over time period of 1990 to 2020 were analyzed by a linear regression as follows [17]:

\[ \hat{y} = \beta_0 + \beta_1 x + \epsilon \] (1)

\( \hat{y} \) was a predicted value of the linear model, \( \beta_0 \) is an intercept, \( \beta_1 \) is a regression coefficient, and \( \epsilon \) is a random error and variance, \( \sigma^2 \). \( \beta_1 \) and \( \beta_0 \) were calculated as follows:

\[ \beta_1 = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sum (x_i - \bar{x})^2} \] (2)

\[ \beta_0 = \bar{y} - \beta_1 \bar{x} \] (3)

Residual, \( \epsilon_i \) was calculated as

\[ \epsilon_i = y_i - \hat{y}_i \] (4)

2.2.2. Test of Coefficient Regression. Coefficient regression was assumed to have a random error term, which is independently distributed with a mean of zero and variance of \( \sigma^2 \). Here the t-test was used to test the regression coefficients, \( \beta_1 \) for rainfall and SST trends over period of 1990 to 2020. The statistical test \( t_o \) for this value was calculated as follows [17]:

\[ t_o = \frac{\beta_1}{s_e(\beta_1)} \] (5)

Where value of standard error \( s_e(\beta_1) \) was calculated as:
\[ S_4(\beta_1) = \sqrt{\frac{\sum_i e_i^2}{(n-2)\sum_i (x_i - \bar{x})^2}} \] (6)

2.3. Identification of Satellite Images.
Changes in land cover over time, mainly forests were identified by matching actual images and an interpretation key of satellite imagery color which is available in the West Nusa Tenggara from Space: Indonesia Tourism Volume 2. Bureau of Soil Survey and Mapping [18] and Time Lapse Satellite Images: https://earthengine.google.com/timelapse/ [13].

Procedure of identification was as follows: first of all, the island of Lombok was stratified into three parts, namely upper stream (the mount Rinjani ranges), middle stream (plateau in the middle), and down-stream (southern mount ranges). Targeted sites for observation were determined by a purposive sampling at the upper stream and down-stream. Satellite images used in this research were acquired from https://earthengine.google.com/timelapse/ in a period of 1984 to 2020 [13].

3 Results and Discussion

3.1. Land Use from Historical Perspective in Lombok.
A first map related to land use in Lombok was officially published in late 19th century [19]. It is clear from the map that three quarter area of Lombok was covered by forests [Figure 1]. Settlement area was only a quarter situated at low lands in the middle. Forests were on both sides, i.e. at Rinjani complex and at southern mount ranges. Nowadays, forests are sporadically spreading only in a particular area around the Rinjani national park and southern hill ranges (Figure 1b). Forest lands decreased due to land conversion for settlements and rice fields.

Figure 1. Map of Forest Area in Lombok Island: (a) In the Late 19th Century [25] and (b) In 21st Century [26]

Eruption of Mount Samalas in 1257 at the mount Rinjani complex left a caldera named lake Segara Anak. It is a center for hydrology cycle in Lombok [20]. Husni et al., (2017) reported that infiltration rate in forest ecosystem of the Rinjani foot slope was significantly higher than in agroforestry system and upland agriculture. It took a long time for deforested forests to return their original infiltration rate as it was in the native forests [21].

3.2. Contradictive Practices in Land Utilization.
Lombok has abundant natural resources. However, there were some particular contradictive issues identified, namely: (1) Local communities who were living nearby forests accordingly cultivated forest lands to grow seasonal crops for commercial purposes. This practice had resulted in preventing trees to naturally regenerate their population, (2) Program of Community Forest Policy (Hutan kemasyarakatan, HKm) [22] has been misperceived as individual right to excessively exploit forest lands without proper conservation practices. Farmers could grow non wood trees side by side with wood trees in proportional number, (3) Farmers in irrigated lands were reluctance
The Rinjani mount complex had been nominated as a Global Geo-park having an area of 280,000 Ha (Figure 3c). Global Geo-Park will obey the basic principal of Global Environmental Protection of the

to practice crop rotation, e.g. rice and legume crops. Instead, they were growing paddy all seasons. (4) Agriculture lands containing sandy soils, coarse sand, gravels, pumice and stones were excavated for quarry and stones. (5) In areas where there were valuable minerals, e.g. gold were illegally mined, and this resulted in environmental pollution by chemical compound [23]. (6) Villas and home stays were built on top hills. Hills were also demolished for quarry mining (Figure 2).

Excessive excavation of fragile lands contradicted to the Government policy and environmental law. National Government has strong commitment to protect environment under their long term development strategy which emphasizes that economic development must be in line with environmental sustainability [24].

3.3. A Brief Land Use in Lombok.
There were three typologies of land use in Lombok, namely rice fields (48%), forest (42%) and settlement area (10%) (Figure 3a). The conservation forests existed at the mount Rinjani complex onto which three out of four watersheds are attached to acquire fresh water. This is the most effective area in term capturing rainfall. Down-stream accounts for 52% of rice fields (Figure 3b). Government Rule as it is in the Decree of Department of Forestry stated that the area of forests (covered lands) should be no less than 30% of total terrestrial area of an island. [25]. Settlement area accounts for 10% inhabited by 2.7 million people. They are relied on freshwater and irrigation water delivered from the upper stream.

Figure 3. Type of Land Use in Lombok: (a) Proportion of Type Land Use, (b) Map of Spatial Distribution of Land Use, and (c) Proposed area of Mount Rinjani Geo-Park
United Nation. There will be three scenarios implemented in the Geo-park, namely conservation, education and sustainability [9].

It was unfortunate that fire spots (marked by red dots) were sporadically distributed in entire forest lands in dry season (Figure 3b). Fire in forest environment was a part of common practice in land clearing for land preparation and cultivation at upland agriculture.

3.4. Deforestation observed from satellite images.

3.4.1. Deforestation in Upper Stream. An indication of deforestation and land degradation were identified from long term satellite images from 1984 to 2020. Deforestation was indicated in 1999 with no indication in previous years, 1997. It means that forests in the upper stream were cleared in mid term of 1998. It was coincidence with a political transition period of Soeharto’s regime. Political instability led to lack of control by local Governments on forests in a period of 1998 to 2000.

A significant areas of land clearance were at foot slope of the mount Rinjani complex (Figure 4).

Figure 4. Deforestation in the Upper Stream: (a) Before Deforestation in 1997, and First Semester of 1998, (b) the First Appearance of Deforestation area in 1999, and (c) Forests in 1984, and 2020.

Figure 4 shows strong evident that native forests were hardly renewable natural resource. Once it had been cut off, it would take a long time to recovery. In a period of 2004-2016, primary forest in upper stream was cleared and replaced by orchard trees, such as fruits and bananas [22].

3.4.2. Land Degradation in Southern Hill Ranges. Deforestation was also taking place at conservation forests at southern hill ranges (Figure 5). It occurred at the same time as it was in the upper stream. Deforestation in 1988 simultaneously occurred in entire forests areas in Lombok. Tasantab (2021) reported that illegal mining and community activities within forest ecosystem were the major cause of forest destruction, land degradation and water resource pollution in most developing countries [26].

Figure 5. Deforestation at Southwest Peninsula and West Part of Lombok: (a) Early Stage in 1984, (b) After Deforestation Since 1998 to 2001 and (c) Current Stage in 2020.

3.5. Natural Resource and Climate Change Point of Views.

IPCC-2021 [12] had summarized that anthropogenic factor was the main driver in climate change. Global surface temperature in the first two decades of the 21st century (2001-2020) was 0.99 °C higher than a period of 1850-1900. Global sea surface temperature in 2011-2020 was 1.09 °C higher than it was in a period 1850-1900. The temperature increase over lands was 1.59 °C which was higher than that over oceans, with average 0.88 °C.

IPCC, 2007 [27] revealed that potential impacts of climate change on small islands were as follows: decreasing water resource, deterioration of coastal area because of erosion, coral bleaching.
due to sea water temperature increase, exacerbation of inundation area because of sea level rising which threatens vital infrastructure, settlement, facilities supporting livelihood of communities.

3.5.1. Air temperature. Data of present study (Figure 6a) shows that air temperature (in Indonesia) had changed since 1968; there was under average level before 1968, and it was above average afterward. Annual air temperature in Lesser Sunda region, where Lombok is a part of it has significantly increased since 1994. The annual change rate was +0.007 °C in a period of 1920 - 1994 and 0.01°C in a period of 1995 – 2020. World Meteorology Organization reported that global record of air temperature deviation in 2016 was +0.99°C, and it reached its peak deviation of +0.18°C in 1981[27]. Changes in air temperature resulted in unpredictable pattern of the monsoon wind in Asia, which affects climate in Indonesia [28].

![Figure 6](image)

(a) Long Term Temperature Anomaly: (a) Air Temperature in Indonesia (1920-2020), and (b) Sea Surface Temperature for Indian Ocean Close to West Nusa Tenggara

3.5.2. Sea surface temperature. Sea surface temperature (SST) is an important physical attribute of oceans. Global oceans SST gradually increased with an average rate of 0.007°C year^{-1} from 1901 to 2015 [29]. The SST in the Indian Ocean recorded at 115°E, 9.5°S (nearby Lombok) in a period of 1990-2020) is presented on Figure 6b. The trend of SST was positive with average of 28.47 ±0.5°C. Potential impacts of increasing SST are that formation of tropical cyclones, shifting storm tracks which potentially results in severe drought in some areas, and extreme rainfall in other parts and lengthening the growing season of poisoning bacteria affecting health [30].

3.5.3. Rainfall in the Wallace Region. Precipitation has profound effects on human well-being and ecosystems. Climate of Wallace regions is semi-arid tropics of type D3, D4 and E (Oldeman system) with only 2 – 3 wet months, and more than six dry months per year with annual rainfall of 1105 mm

![Figure 7](image)

(a) Precipitation in Wallace Region: (a) Difference of Rainfall between Sunda, shelf Sahul and Wallace Region, (b) Precipitation in Wallace Region

Trend of precipitation in Lombok steadily decreased throughout 1990 to 2020. Decreasing rate was -2.7 mm year^{-1}. Precipitation pattern in Lombok had switched from positive trend with a rate of + 10.4 mm year^{-1} before 2005 and the trend had been negative with a rate of -13.08 mm year^{-1} since 1995. General change of rainfall patterns were as follows: (a) increase precipitation in high latitudes (Northern Hemisphere), (b) reductions in Asia, Australia and the Small Island States in the Pacific and (c) increasing variance of precipitation in equatorial regions [31].
4. Conclusion

Lombok island is no longer as a pristine resource. Anthropogenic factor had been a major driver of manmade disasters stimulated by inconstancy between rule of environmental protection and its implementation. There were also lack of commitment, responsible and law enforcement toward sustainable environment. Climatic change amplified negative impacts of the manmade disasters. Therefore, proper monitoring and mitigation measures would diminish the impacts. The only option is to strictly control anthropogenic activities attributed to destruction of the valuable natural resource.

Acknowledgement

It is to acknowledge the Mataram University, and Faculty of Agriculture who provide free access for internet, as well as the Research Center for Water Resource and Agroclimate, Mataram Univesity who has provided climate data.

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