Spatial Pattern Of Soil Erosion In Cikapundung Watershed, Indonesia

Sri Malahayati Yusuf, Kukuh Murtilaksono, Yayat Hidayat, Yuli Suharnoto

Abstract: Application of GeoWEPP model in Indonesia has been facing a challenge in preparing the input data of both soil and plant management factors. Therefore, this research aims at detailing data of soil so that the model can represent well the spatial pattern of soil erosion. The research was carried out in Cikapundung watershed, West Java, Indonesia using GeoWEPP model for both watershed and flowpath methods. Soil erosion and sediment yield was analyzed based on three scenarios namely existing land cover year 2014 (scenario 1), 2030 predicted land cover (scenario 2), and allocation of land cover based on West Java's 2009-2030 regional planning (scenario 3). The result showed total runoff was amounted 410 mm of 2,093 mm yearly precipitation under existing condition. Hillslope erosion and sediment yield were approximately 359 tons/ha/year and 413 tons/ha/year, respectively. Regional planning scenario was able to reduce the amount of total runoff, hillslope soil erosion, and sediment yield of 3, 94, and 95%, respectively. Sediment yield was increased under 2030 predicted land cover scenario by 1.27%. The allocation of land cover based on 2009-2030 regional planning was the best scenario in reducing the soil erosion and sediment yield in Cikapundung watershed.

Index Terms: Total runoff, hillslope soil erosion, GeoWEPP, watershed management, Cikapundung watershed.

1. INTRODUCTION

Watershed is an area with complex interaction between various factors, including physics, biology, social-economy, and environment that affect hydrological and soil function, which support the sustainability of ecosystems [1]. Erosion is an important soil-related aspect since it caused land degradation in a watershed area [2], [3], [4]. The magnitude of erosion depends on the interaction between rainfall, soil, topography, land management, and soil and water conservation factor [2], [5], [6], [7], [8], [9], [10]. The amount of erosion is known from both field and laboratory measurement, but sometimes, it is difficult to understand the process because of the variability of factors affecting the erosion [6]. Therefore, utilization of erosion prediction model will increase the understanding of erosion process both spatially and temporally. USLE (Universal Soil Loss Equation) model is one of erosion prediction methods which is widely used in the world [6], [11], [12], [13], [14], [15]. Nevertheless, USLE model does not well describe all erosion factors, abandons significant slope in high rainfall intensity area, and has rainfall index which is based on rainfall size distribution [6], [16]. In consequence, the continuous improvement on erosion prediction method has been done, and WEPP is one of the models which are considered as USLE method replacement.

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WEPP (Water Erosion Prediction Project) model was developed by USDA-Natural Resources Conservation Service. WEPP is distributed and physically process-oriented model, predict erosion and sediment deposition from runoff, which is concentrated in small channel, and deposition in pond [6], [17]. WEPP model application in Asia and America showed that the model was able to predict the runoff and erosion [4], [18], [19], [20], [21]. Application of WEPP model in Indonesia shows the challenge in preparing the input model of both soil and plant management factor [22], [23], [24], [25]. Therefore, preparing plant management data in detail, and identification of soil factor accurately especially in soil erodibility factor will describe well the erosion process in tropical area [26]. Research was done in Cikapundung watershed, West Java Province, Indonesia. The study focused on preparing the detail data of soil so that the model will obtain adequate description on the spatial pattern of erosion in the field. The soil erosion in Cikapundung watershed is also predicted under West Java's 2009-2030 regional planning, and 2030 predicted land cover.

2 STUDY AREA DESCRIPTION

2.1 General Condition

Cikapundung watershed is located in West Java Province, Indonesia, and is a part of catchment of Upper Citarum Watershed. Geographically, it is located between 107.55º – 107.75º E and 6.75º - 7.01º S and covered 4 administrative area namely Bandung city, West Bandung Regency, Bandung Regency, and Sumedang Regency (Fig. 1). Land cover types in Cikapundung watershed is predominantly moor, approximately 28% from total watershed area, while the smallest land cover type is water body, constituting only 0.65%. The biggest area of soil type in the watershed is Typic Hapludands, Eutric Hapludands (18%). The topography varies from flat to very steep slope and dominated by flat topography (60% from total watershed area). Average annual rainfall for period 2007-2014 in the watershed is approximately 2,128.25 mm, where the rainy season occurs for 6 months from January-April and November-December. Average daily temperature ranges between 18 – 29°C with minimum and maximum relative humidity of 47 and 96%, respectively.

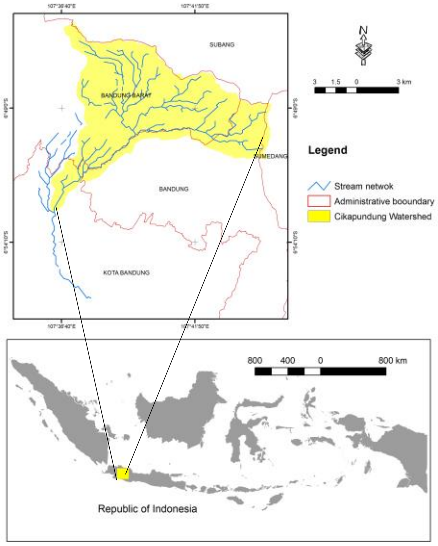


Fig. 1. *Study Location*

2.2 Data Collection

Soil sample, land management information, and channel characteristics were collected as primary data. Soil samples were compiled and observed in 12 soil profiles that are widely spread in the watershed and representative for soil type. Laboratory analysis were done to generate the organic matter using Walkley and Black method [27], cation exchangeable capacity with ammonium acetate method [28], and soil texture distribution using pipette method [29]. The data collected from plant management consist of land management history both before and after the tillage period, including type of tillage implemented in the field, and burned residue mass. The information was collected by interviewing the farmers. In addition, the initial condition of plant, soil tillage database, and annual crop database were also collected as described in Flanagan and Nearing [17]. Secondary data of this research is described in Table 1.

3 GeoWEPP Model Description

WEPP model was developed based on hydrology and erosion knowledge, process-oriented, and continuous simulation to predict erosion and sediment deposition from runoff [13]. This model calculates erosion distribution, and deposition both spatially and temporally, and predict when and where the erosion will occurs in watershed area or hillslope. The smallest analysis unit in simulation is called overland flow elements (OFEs) [17], [30], [31]. In the earlier stage of model development, WEPP model is operated under DOS interface. Due to increasing needs of complex watershed simulation, WEPP was developed using geospatial interface known as GeoWEPP [32]. Watershed delineation, hillslope and OFEs distribution in entire watershed is made possible to assess by using GeoWEPP.

Table 1. *Types and Sources of Secondary Data*

No.	Types of Data	Sources of data
1.	Digital Elevation Model	USGS Hydroshed Website
2.	Topography map scale 1:25,000	Indonesian Agency for Geospatial Information
3.	Soil map scale 1:100,000	Indonesia Agency for Agriculture Research and Development
4.	Ikonos image year 2014	Indonesian National Institute of Aeronautics and Space
5.	Climate data	Indonesian Agency for Meteorology, Climatology, and Geophysics,
6.	Regional planning map	Agency for Regional Development Planning of West Java Province, Indonesia
7.	Watershed boundary	Agency for Watershed Management of Citarum Ciliwung (BPDAS Citarum Ciliwung)

Plant growth, climate, soil, and river routing component are involved in the model process. Plant growth is used to simulate the temporal change in plant variable that affect runoff and erosion process. Climate is applied to generate rainfall, maximum and minimum temperature, solar radiation, and wind velocity and direction in daily average period [33]. Infiltration is calculated using Green and Ampt equation which was modified by Mein and Larson in Stone, Lane, Shirley, and Hernandez [34]. Runoff is routing using cinematic wave equation and prediction method with regression formula for both peak runoff and time to runoff to occur. Equation of sediment continuity is used to predict the erosion [35].

4 Research Procedure

Analysis of erosion in Cikapundung watershed was done through 3 stages consisting of preparing the model input of GeoWEPP, running model, and scenarios simulation of watershed management. Flowchart of research is displayed in Fig. 2.

4.1 Input Parameterization

4.1.1 Digital Elevation Model (DEM)

DEM data of area study have 90 m resolution and was downloaded from the website of Hydroshed USGS (United State Geological Survey). This data was used to generate river network, and watershed boundary of study area.

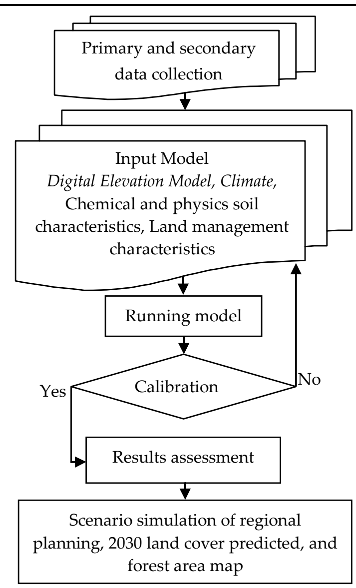


Fig. 2. *Research flowchart*

4.1.2 Soil Data

Information of soil characteristics for each horizon were collected from field survey and laboratory analysis result. Soil map was gathered from Indonesian Soil Research Center (Fig. 3), and the names of soil were categorized using USDA classification system. Cell size of soil map was fitted with resolution of DEM data.

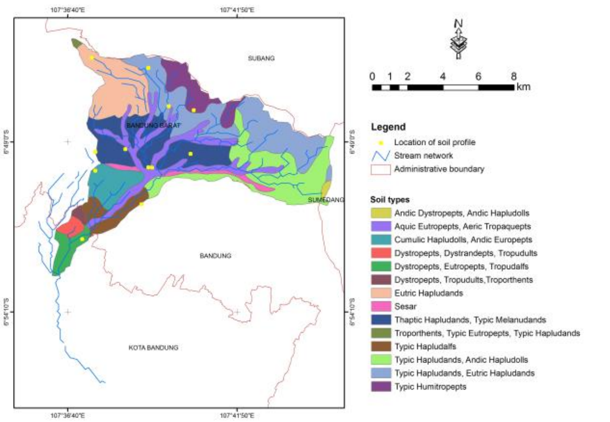


Fig. 3. *Soil map of Cikapundung watershed*

4.1.3 Land Cover and Plant Management Data

Data for plant management were collected from interview process with farmers. Existing land cover map year 2014 was generated from visual interpretation of Ikonos Image (Fig. 4). Types of land cover were determined using SNI 7465-2010 [36] and the area of each land cover types is represented in Table 2. Land cover map have the same resolution with DEM data.

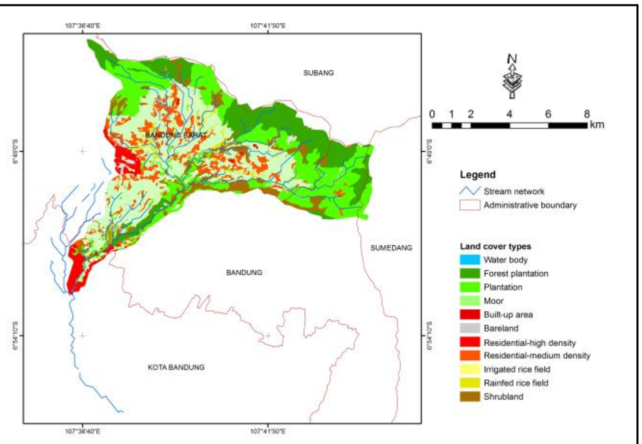


Fig. 4. *2014Land cover of Cikapudung watershed*

Table 2. *Types of 2014 Land Cover in Cikapundung Watershed*

Type of Land cover	Area	
	ha	%
Water body	8	0.1
Plantation forest	1,552	14.5
Plantation	2,533	23.7
Moor	3,027	28.4
Built up area	115	1.1
Bareland	68	0.6
Residential-high density	1,351	12.7
Residential-medium density	936	8.8
Irrigated rice field	196	1.8
Rainfed rice field	151	1.4
Shrubland	739	6.9
Total	10,675	100

4.1.4 Climate

Climate data including precipitation, solar radiation, relative humidity, and wind speed were collected from Indonesian Agency of Meteorology, Climatology, and Geophysics that located in Bandung, for period 2007-2014. In addition, there are 8 rain gauges that widely spread in entire Cikapundung watershed to cover the variability of rainfall (Fig. 5). Average rainfall for the area of Cikapundung watershed was calculated using Polygon Thiessen method. Actual daily data was used to generate the weather generator.

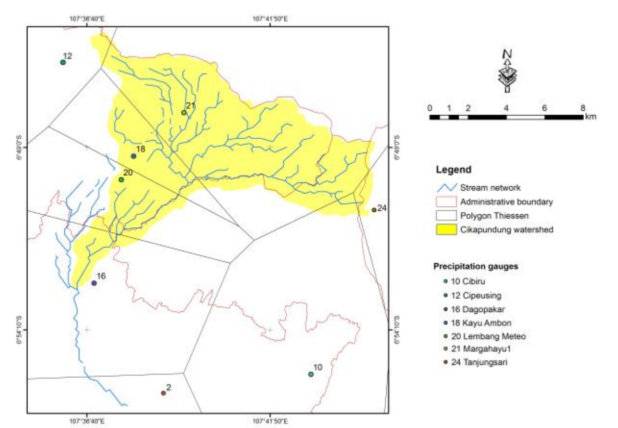
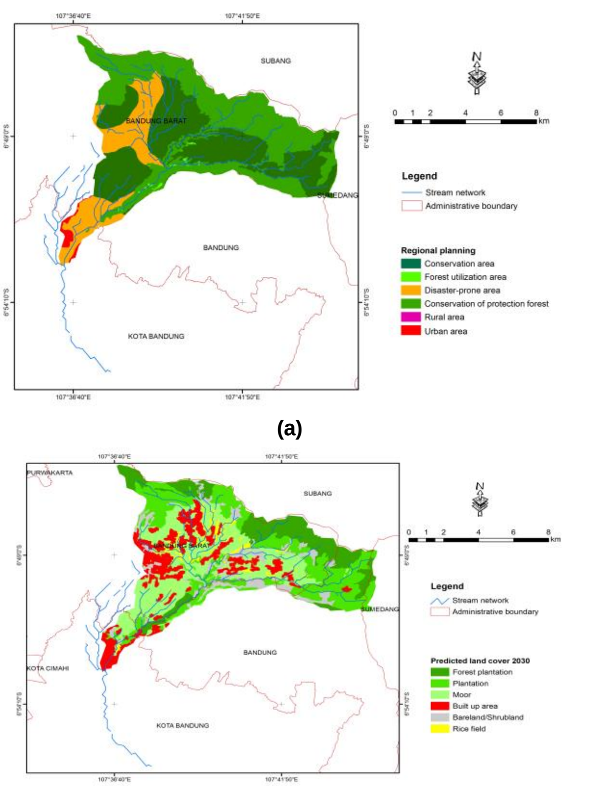


Fig. 5. *Precipitation gauges in Cikapundung watershed*

4.2 Model Simulation

Simulation of GeoWEPP model in Cikapundung watershed consist of 3 scenarios including scenario 1 (2014 existing land cover), scenario 2 (2030 predicted land cover (Fig. 6a)), and scenario 3 (2009-2030 regional planning map year (Fig. 6b)). The predicted land cover map year 2030 was generated from Cellular Automata-Markov Chain model [37], [38], [39] using 3 years data of year 2006, 2009, and 2014. Watershed and flowpath method for 8 periods were applied in the all scenario so the total runoff volume, hillslope erosion and sediment yield that occur in the watershed can be evaluated. Mapping of soil loss and sediment yield were done base on tolerable soil loss that approximately 24 tons/ha/year. Hammer method [40] was used to calculate the tolerable soil loss.



(a)

(b)

Fig. 6. *Regional planning (a), and 2030 predicted land cover (b) map of Cikapundung Watershed*

5 Results and Discussion

5.1 Watershed Deliniation

Delineation process of a watershed also generates sub catchment, associate as hillslope in GeoWEPP model. The number of hillslope depends on Critical Source Area (CSA) and Minimum Source Channel Length (MSCL). As the CSA and MSCL value increases, the number of hillslope will decrease because the values affecting the density of stream network and shorter channels, respectively. In Cikapundung watershed case, the use of 50 ha of CSA and 200 m for MSCL was resulting 210 hillslopes.

5.2 Existing Condition of Cikapundung Watershed

Results of GeoWEPP model simulation of existing condition are presented in Table 3. Amount of total runoff is approximately 20% from total precipitation in contributing area and calculated as water discharge in watershed outlet. The value was produced from 147 events of 227 total storms in the watershed. It means that only 147 events which were generated the excess rainfall to be calculated in runoff volume.

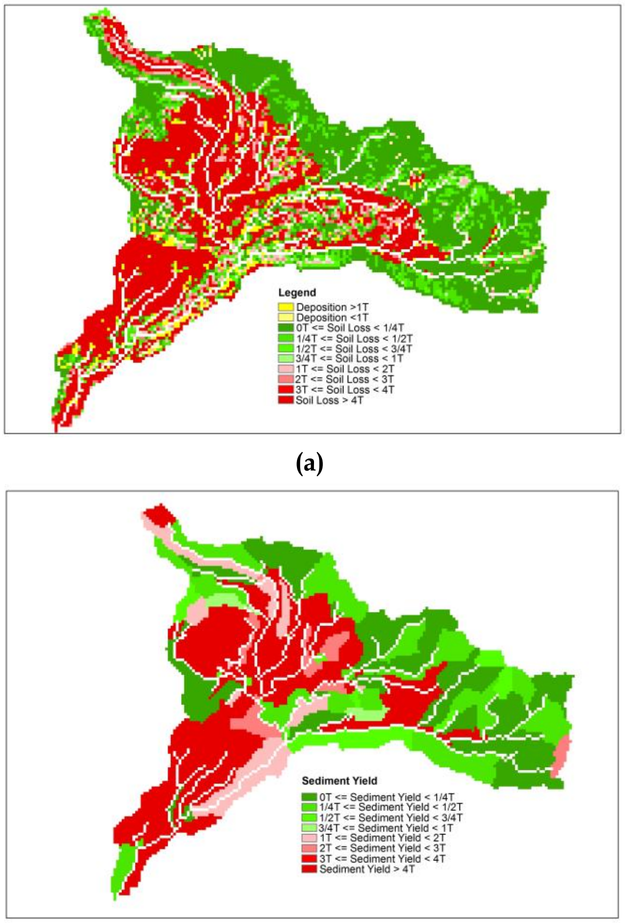
Table 3. *Characteristics of Runoff and Erosion in Cikapundung*

Parameter of Runoff and erosion	Value
Precipitation (mm)	2,093
Runoff depth (mm)	410
Total hillslope soil loss (tones/ha/year)	359
Total channel soil loss (tones/ha/year)	413
Sediment discharge from outlet (tones/year)	217
Sediment delivery ratio	0.28

Erosion component consist of hillslope and channel erosion. From Table 3, it is known that total hillslope soil loss is 87%, smaller than total channel soil loss. It happened because of the amount of channel erosion is a function of the incoming upstream load (from hillslope/channel), transportation and deposition by concentrated flow, and river flow ability in detach the channel bed material or soil particle [41]. The average hillslope soil loss and average channel soil loss are approximately 359 tons/ha/year and 413 tons/ha/year, respectively. The hillslope soil loss value is greater than tolerable soil loss (TSL) of Cikapundung watershed, reaching 24 tons/ha/year. Average sediment yield in watershed outlet is 217 tons/ha/year, with sediment delivery ratio at about 0.28. It means that approximately 28% of total erosion both from hillslope and channel occurs in the watershed outlet. Spatial distributions of hillslope soil loss and sediment yield under existing condition are presented in Fig. 10. Mapped soil erosion was generated from flowpath method (onsite study). Figure 10 shows that Cikapundung watershed are dominated by soil erosion class 0T until 1/4T (35% of watershed area) and soil erosion > 4T (34%). The highest soil erosion was dominantly produced from moor, residential-medium density, and plantation area approximately 68, 16, and 5%, respectively.

5.3 Scenario Simulation of Cikapundung watershed Management

Simulation of Cikapundung watershed management was done in order to reduce the hillslope soil loss below the TSL. Results from the scenarios are presented in Table 4. The total runoff under regional planning scenario (scenario 3) was decreasing to approximately 3% (Table 4). It was because the total conservation area in this scenario reaches 80% from total watershed area. He et al. [42] showed that the increases of forest area can reduce total runoff volume of 17.70% in Hei River basin, Shaanxi Province, China. Maalim et al. [43] also showed that utilization of surface residue in conservation area can reduce runoff volume by 14%. The regional planning scenario also reduced hillslope soil erosion, and sediment yield of 94, and 95%, respectively. The reduction is caused by the existence of conservation area both in forest area and agricultural land. Puno et al. [44], and Maalim et al. [43] also stated that conservation approach in catchment area can decrease soil erosion by 75.87%, and 78.5%, respectively. The total runoff volume under 2030 predicted land cover scenario was increase by 2%. This was allegedly because the change in land cover under 2030 prediction was not significant almost for all land cover type (<5%). But average of sediment yield under scenario 2 was increased approximately 1.27%.



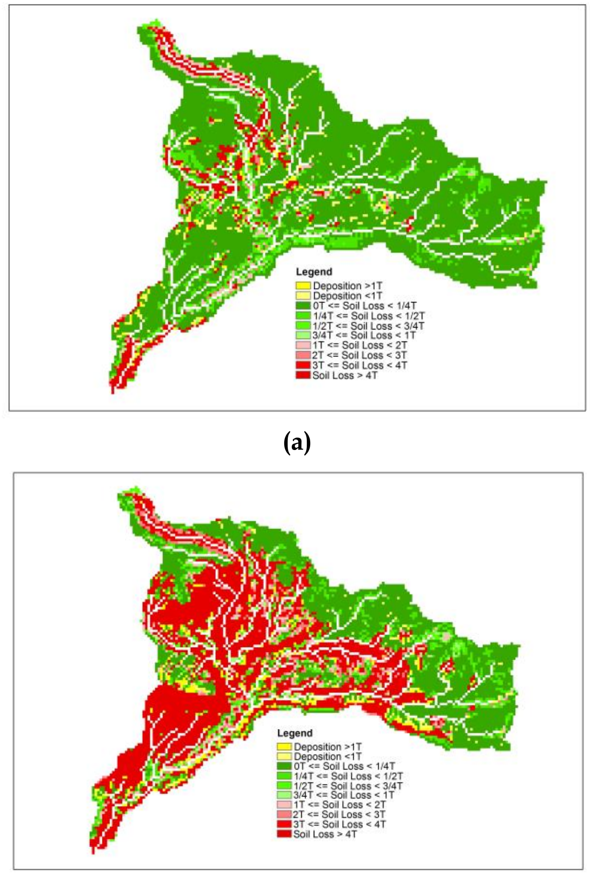
(b)

Fig. 10. *Spatial distribution of soil erosion (a) and sediment yield (b) under existing condition in Cikapundung watershed*

Spatial distribution of soil erosion for scenario 2 and 3 are presented in Fig. 11. The watershed was dominated by soil erosion more than 4T under scenario 2, approximately 38% of total watershed area, while the area with soil erosion between 0T until 1/4T was decreased by 8% compare to existing condition. This happened because the area with lowest erosion was distributed into highest soil erosion which is affected by increasing of moor area by 8% in 2030 predicted land cover scenario.

Table 4. *Scenario Simulation Result*

Results description	Scenarios		
	1	2	3
Rainfall (mm)	2,093	2,093	2,093
Runoff depth (mm)	410	420	399
Total hillslope soil loss (tones/ha/year)	359	352	21
Total channel soil loss (tones/ha/year)	413	927	46
Average of sediment yield (tones/ha/year)	217	219	10
Sediment delivery ratio	0.28	0.17	0.15



(b)

Fig. 11. *Spatial distribution of soil erosion under regional planning (a) and predicted land cover (b) scenario*

6 CONCLUSION

Simulation of total runoff, hillslope soil loss and sediment yield in Cikapundung watershed was gathered using watershed and flowpath method. The total runoff volume, hillslope soil loss, and sediment yield under existing condition were approximately 410 mm, 359 tons/ha/thn), and 217 ton/ha/thn), respectively. While regional planning scenario was produce total runoff, hillslope soil loss, and sediment yield of 399 mm, 21 tons/ha/year, and 10 tons/ha/year, respectively. The 2030 predicted land cover was generate the highest average sediment yield approximately 2190 tones/ha/year. The regional planning was the best scenario in reducing hillsope soil loss and sediment yield in Cikapundung watershed, approximately 94% and 95%, respectively.

ACKNOWLEDGMENT

The authors wish to thank Ministry of Education and Cultural-General Directorate of Higher Education, for supported in part by a grant from 2012 DIPA. And also thank to Southeast Asian Regional Centre for Tropical Biology, who was supported in part by a grant from 172-DIPARES-III-2016.

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