ISSN 1533-9211

DOI: 10.5281/zenodo.13832550

ECOSYSTEM-BASED DISASTER RISK REDUCTION SERVICES OF MANGROVE FOREST

RANDY A. QUITAIN *

College of Arts and Sciences, Mindoro State University, Oriental Mindoro Philippines 5211.
*Corresponding Author Email: randy.quitain@minsu.edu.ph

Abstract

Mangroves reduced the impact of catastrophic events through their functions, such as carbon sequestration and protection against upland flooding. Understanding the Ecosystem-based Disaster Risk Reduction (Eco-DRR) services provided by mangroves is essential for their conservation and protection. This study highlights a range of figures that illustrate the Disaster Risk Reduction (DRR) capacities of mangroves, with a specific focus on the hazards associated with climate change. There were 430 trees across six true mangrove species assessed in the Sukol River. The total estimated biomass of these mangroves was 5,905.88 $Mg \cdot Ha^{-1}$, AGB and BGB combined. The amount of their biomass resulted to 2,775.76 $Mg \cdot Ha^{-1}$ of carbon stock (equivalent to 10,187.05 $Mg \cdot Ha^{-1}$ of carbon dioxide). Meanwhile, the studied ecosystem reduced the velocity of flowing water under normal condition by 0.57 m/s, impacting the rate of discharge of the river to 190.12 m^3/s, resulting in a flow rate of 2691.64 cfs. The presence of mangroves along the coastal areas serves as a vital ecological asset, offering Eco-DRR services in terms of carbon sequestration that lessen the impact of greenhouse effect in the climate condition of earth. Moreover, their rigidity and complex physiological features made them effective in buffering the impact of flooding.

Keywords: Biomass; Carbon Sequestration; Ecosystem-Based Disaster Risk Reduction; Mangroves; Sukol River.

INTRODUCTION

Mangroves are halophyte trees flourishing the saline coastal environment. Beyond their ability to withstand high salinity levels they play vital ecological roles. One of the key features of mangroves is their pneumatophores, specialized roots that capture organic materials [1]. Their root systems are also designed to serve as fish spawning grounds, contributing to the biodiversity of the area. Moreover, these ecosystems serve as natural barriers, buffering coastal areas from hurricanes and tsunamis. Additionally, mangroves exhibit an intact zonation and host a diverse array of species that interact with other biotic factors. They support a rich variety of flora and fauna, and offer a range of valuable resources to nearby coastal communities, including food, fuel, and building materials. Furthermore, mangroves provide indirect benefits such as filtration and coastal protection for local communities [2–5].

Mangroves are essential for maintaining the health of coastal habitats as they trap and supply nutrients to adjacent ecosystems like seagrass beds and coral reefs. Meanwhile, tropical commercial fish species rely on mangroves at some stage of their life cycle. Additionally, mangroves hold cultural significance in indigenous communities that utilize native mangrove extracts for various purposes such as medicine and dye. These ecosystems were also valued for tourism and serve as productive fishing grounds. Due to their remarkable ability to sequester carbon, mangrove forests play a crucial role as carbon sinks in tropical regions [6]. They contribute in the ecological balance due to their diverse range of ecosystem services within

The Seybold Report
ISSN 1533-9211
DOI: 10.5281/zenodo.13832550

coastal zone. The abovementioned ecosystem services of mangroves are directly and indirectly supporting both humans and other biotic factors in facing natural hazards. Through their functions, specifically carbon sequestration and protection against upland flooding, they are reliable in reducing the impact of these catastrophic events. Understanding the Eco-DRR services of mangroves are essential for their conservation and protection [7,8]. Relative to this, the study provides a spectrum of figures to describe the Disaster Risk Reduction (DRR) capacities of mangroves focusing on natural hazards.

MATERIALS AND METHODS

Research Setting

The data collection was conducted at the river of Sukol, Municipality of Bongabong, Oriental Mindoro. The riverine and intertidal features of the study site include a variety of mangrove species, fostering exceptional biodiversity, and ecosystem services. The river water flows towards the beaches of K.I. and Aplaya. Meanwhile, Asiatic is at the left side of the main town where the river is passing through, displaying the interconnectedness of the environment and settlements in the studied ecosystem (Fig. 1).

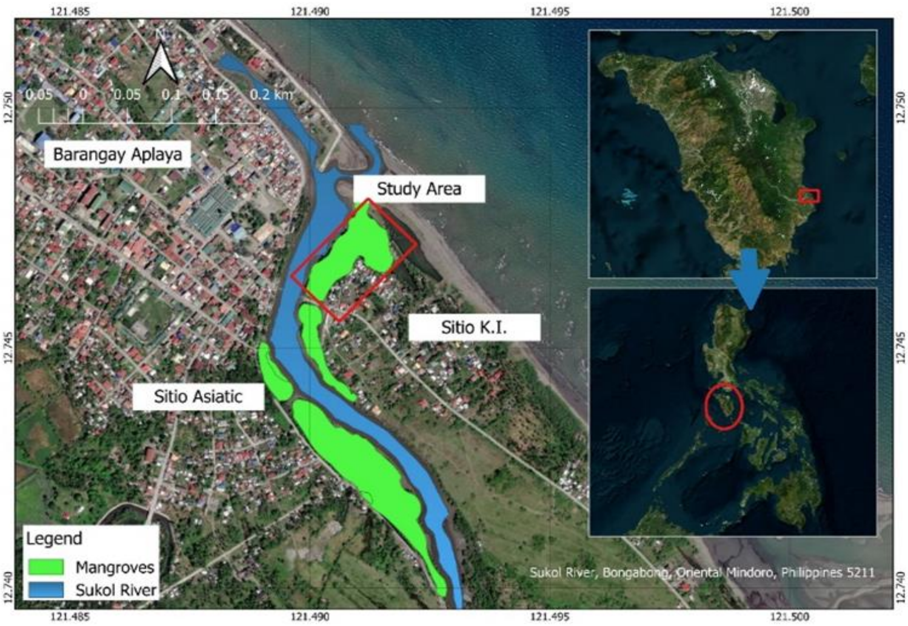

Figure 1: Map of Sukol River, Oriental Mindoro, Philippines

Data Collection and Processing

Acquiring the Biomass, Carbon stock, Carbon dioxide Equivalent of Mangroves

This study utilized the circular plot method by Kauffman and Donato (2012) [9] to assess mangrove allometry and equations for a deeper understanding of their biomass. To begin the allometric data collection, a 125m transect line was established to outline the sampling areas.

ISSN 1533-9211
DOI: 10.5281/zenodo.13832550

This transect line was secured at both ends using 22 mm PVC poles, allowing for a clear delineation of the sampling plots. Along this transect line, six circular plots with a 7m radius were strategically positioned. Each circular plot, overlaid on the transect line, maintains a 25m interval, starting from the zero point. Within these plots, mangrove trees outside the 2m radius were assessed based on allometry.

The allometric data collected consists of the Girth at Breast Height (GBH) and the height of the mangroves. GBH was measured using a tape measure, while the height of the trees was obtained with a modified meter pole. Additionally, a field guide was utilized to identify the mangrove species accurately, aiding in the selection of the appropriate wood density for biomass computation.

During fieldworks, allometric data were recorded on a slate to prevent fading in the humid conditions of the mangrove forest. Once collected, the data undergo processing to compute values such as Aboveground Biomass (AGB), Belowground Biomass (BGB), sequestered carbon including the Carbon dioxide Equivalent (CO_2-eq) using proven equations [10–12]. The study utilized the following equations to acquire the values for the abovementioned variables:

Aboveground Biomass (AGB) and Belowground Biomass (BGB)

$$AGB = 0.0509 * \rho * D^2 * H$$

$$BGB = 0.199 * \rho^{0.899} * D^{2.22}$$

(ρ= wood density; D= maximum tree diameter; H= maximum tree height)

* *refer to Kauffman and Donato (2012) p.22-23 wood density reference https://www.cifor-icraf.org/publications/pdf_files/WPapers/WP86CIFOR.pdf*

Carbon dioxide Equivalent (CO_2-eq)

Carbon stock= 0.47(carbon fraction) x biomass

$$CO_2\text{-}eq = \frac{\mathbf{44}\ \text{(relative molecular weight of Carbon dioxide)}}{\mathbf{12}\ \text{(relative atomic weight of carbon)}}\ x\ C\ sequestration$$

$$= 3.67\ x\ carbon\ sequestration$$

Acquiring Data to Estimate the Flood Buffering Capacity of Mangroves using Manning's n Roughness Coefficient

The Manning's *n* values were used by the study to estimate the velocity of flowing water entering the mangrove ecosystem of Sukol River. Procedures in acquiring the *n* values were assigning scores for each following variables; $n0$= bed material, $n1$= channel irregularities, $n2$= cross-sectional variations, $n3$= obstruction, $n4$= vegetation), and m= meander using Cowan's Method (1956) [13, 14] . Below is the equation of the abovementioned *n* values:

$$n\ value = m\ (n0 + n1 + n2 + n3 + n4)$$

After acquiring the Manning's *n* value, the Side Slope, Bed Width, and Depth of Flow were the key parameters determined for the estimates of the velocity of water when passing through

ISSN 1533-9211
DOI: 10.5281/zenodo.13832550

the mangroves of the study site. The Side Slope was determined by manually measuring the vertical and horizontal angles of the channel slope. Meanwhile, for the Bed Width, Google Earth Pro was utilized to calculate the width of the channel. Moreover, in measuring the Depth of Flow, a modified measuring pole was used to achieve the necessary data. This measurement helps in assessing the volume of water passing through the channel. In order to compute for the Area, Wetted Perimeter, and Hydraulic Radius, the equations below were utilized:

Area:

$$A = (B + my)y$$

Wetted Perimeter:

$$P = B + 2\sqrt{m^2 + 1y}$$

Hydraulic Radius:

$$R = \frac{A}{P}$$

Using a floating method the Flow Rate was determined. This method involves calculating the average flow rate by tracking an object as it floats from one point to another along the river. Through quantifying the width and depth of the downstream section, the Bed Slope was acquired using an improvised measuring pole. These measurements were crucial in understanding the dynamics of water flow in natural and man-made channels. The floating method was conducted in the mouth of the estuary considering that the study site has a straight path river.

Rate of Flow:

CF = A x V (A= area; V= velocity)

A= W (channel width) x D (depth of water)

V= DT (distance travelled) / t (travelled time)

Bed Slope:

$$S = \left(\frac{Qn}{1.49AR^{2/3}}\right)^2$$

In order to determine the discharge of the river water and velocity, the study utilized the data from initial tests. The equations below were utilized in analyzing the flow dynamics of the studied river channel, enabling the researcher to understand the interaction between water movement and the mangroves:

Velocity:

$$V = \frac{1}{n} R^{2/3} S_0^{1/2}$$

Discharge:

$$Q = A/V$$

The Seybold REPORT

ISSN 1533-9211

DOI: 10.5281/zenodo.13832550

RESULTS AND DISCUSSION

Mangroves as Carbon Sink to Mitigate Climate Change

Based on the results of the study, there were 430 trees across six true mangrove species assessed in the study site. The total estimated biomass of these mangroves was 5,905.88 Mg·Ha^{-1}, AGB and BGB combined. Among the different mangrove species assessed, *Sonneratia alba* stood out for its remarkable contribution to the mangrove biomass. This species exhibited the highest amount of AGB, totaling 5,087.36 Mg·Ha^{-1}, along with a substantial BGB of 19.4 Mg·Ha^{-1}. Conversely, *Bruguiera sexangula species* presented the lowest AGB, with only 2.79 Mg·Ha^{-1}. Additionally, its BGB was calculated to be 0.0106 Mg·Ha^{-1} (Table 1).

The biomass of mangrove trees is necessary in estimating the carbon stock content and sequestration potential of these ecosystems. The biomass is primarily carbon-based, by utilizing carbon data obtained through tree allometry, researchers can estimate the Carbon dioxide Equivalent (CO2-eq), the amount that can be released into the atmosphere [15].

Table 1: The data for the Aboveground and Belowground Biomass of Sukol River Mangroves

Mangrove Sampling Site	Species	Density	Aboveground Biomass (Mg·Ha^{-1})	Belowground Biomass (Mg·Ha-^{1})
1	*Sonneratia alba*	98	3,721.9	13.5
	Rhizophora mucronata	68	328.7	1.3
	Rhizophora apiculata	7	135.2	0.5
	Avicennia marina	14	29.4	0.3
	Avicennia officinalis	1	1.6	0
	Bruguiera sexangula	2	2.8	0
2	*Sonneratia alba*	48	895.9	3.6
	Rhizophora mucronata	14	22.8	0.1
	Rhizophora apiculata	38	81.2	0.4
	Avicennia marina	23	24.6	0.2
	Avicennia officinalis	9	104	0.4
3	*Sonneratia alba*	74	469.6	2.3
	Rhizophora mucronata	14	18.3	0.1
	Rhizophora apiculata	2	1.1	0
	Avicennia marina	15	40.1	0.3
	Avicennia officinalis	3	5.5	0.1
	Total	**23.89**	**5,882.7**	**23.1**

The estimated carbon stock of mangroves in the study site was 2,775.76 Mg·Ha^{-1} (equivalent to 10,187.05 Mg·Ha^{-1} of carbon dioxide). Noticeably, large girth trees of *Sonneratia alba* exhibit the highest biomass of 5,106.74 Mg·Ha-^{1}. Based on the amount of biomass per species, it confirms that mangroves can capture 1083 ± 378 MgC·Ha^{-1}, (Table 2) which was multiple times greater than terrestrial forests. The carbon stock of mangroves per species were used as basis to estimate the sum of carbon dioxide averted in reaching the atmosphere [16].

The Seybold Report
ISSN 1533-9211
DOI: 10.5281/zenodo.13832550

Table 2: The data for the total Biomass, Net Carbon Sequestration and Carbon dioxide Equivalent

Mangrove Species	Total Biomass ($Mg \cdot Ha^{-1}$)	Net Carbon Sequestration ($Mg \cdot Ha^{-1}$)	CO_2-Eq ($Mg \cdot Ha^{-1}$)
Sonneratia alba	5,106.74	2,400.17	8,808.62
Rhizophora mucronate	371.38	174.55	640.59
Rhizophora apiculate	218.46	102.68	376.83
Avicennia marina	94.91	44.61	163.7
Avicennia officinalis	111.59	52.45	192.48
Bruguiera sexangular	2.8	1.32	4.83
Total	**5,905.88**	**2,775.76**	**10,187.05**

Natural hazards such as abnormal temperatures, extreme rainfall, frequent strong typhoons, and prevalent droughts pose significant challenges in every region of the world. The impact of these phenomena was felt across various ecosystems, including mangrove forests. Mangroves are unique coastal ecosystems that fringed the coastal environment. They were characterized by their ability to capture carbon from the atmosphere, and store it in various components such as leaves, trunks, branches, below ground roots, and aerial roots. This process helps to reduce the concentration of carbon dioxide from different sources, thereby contributing to the mitigation of climate change. Numerical data on mangrove carbon stocks as presented in Table 2 provides compelling evidence of the effectiveness of these ecosystems in sequestering carbon. The data not only underscores the significance of mangroves in mitigating climate change but also serves as a valuable parameter in shaping policies, programs, and projects aimed at fostering the resilience of mangrove ecosystems. Mangroves contribute to climate change mitigation by acting as carbon sinks. Mangroves have the unique ability to sequester large amounts of carbon and store as biomass. This carbon sequestration process helps to offset the carbon dioxide emissions that contribute to global warming. Mangroves are critical in maintaining the amount of carbon that will reach the atmosphere as Greenhouse Gas. Mangroves are significant in reducing the impact of natural hazards, and mitigation of climate change [17–19]. Specifically, this ecosystem delivers coastal protection, biodiversity conservation, and the provision of livelihoods for local communities.

Mangroves as Natural Flood Barriers

The n values assigned to different channel conditions, as shown in Table 3 (n0= 0.26, n1= 0.010, n2= 0, n3= 0.004, n= 1.00, m: 1), were significant in estimating the abilities of the mangroves in Sukol to reduce the impact of flowing water. Through the compilation of data, a comprehensive n value of 0.374 was determined, aiding in the assessment of the river's ability to manage water flow dynamics (Table 3).

Table 3: Manning's *n* Roughness Coefficient data for Sukol River

Name of River Channel	Manning's Roughness Coefficient						
	m (Meander)	*n0* (Bed Material)	*n1* (Channel Irregularities)	*n2* (Cross-sectional variations)	*n3* (Obstruction)	*n4* (Vegetation)	Total
Sukol	1	0.26	0.010	0	0.004	0.100	0.374

The Seybold Report
ISSN 1533-9211
DOI: 10.5281/zenodo.13832550

In water flow analysis, hydraulic properties were significant in determining the behavior of the water movement in the studied channel. The results shown in **Table 4**, contributes uniquely to the overall dynamics of water current, influencing factors such as velocity, resistance, and efficiency within the channel.

Table 4: Data Set for Hydraulic Properties

Side Slope	Bed Width	Depth of Flow	Area	Wetted Perimeter	Hydraulic Radius
1.75: 1.50 m	141 m	2.3 m	333.558 m^2	149.623 m	2.229 m

The Sukol river mangroves ecosystem reduced the speed of flowing water as they decreased the velocity by 0.57 m/s under normal condition (considering that the study was conducted based on the day-to-day normal current of the selected site). The discharge rate of the river at this location was measured at 190.12 m^3/s, resulting in a flow rate of 2691.64 cfs (Table 5). This highlights the important function of mangroves in regulating the movement of water within a specific river channel.

Table 5: Summary of results for Velocity and Discharge

Flow Rate	Bed Slope	Velocity	Discharge
2691.64 cfs	0.01565	0.57 m/s	190.12 m^3/s

In many tropical and subtropical regions, mangroves are vital first line of defense against flooding. These protective benefits were achieved through a combination of factors such as bottom friction, the width of the forests along the shore, tree density, and their unique shapes.

The aerial roots of mangrove reduced the velocity of upland flooding including storm surge. Additionally, the roots, trunk, and canopy of mangroves serve to dissipate heavy floods which provides significant protection to coastal communities. Studies have indicated that mangroves can reduce as much as 66% of wave energy and high-rate flowing water within the initial 100 meters of forest width [20, 21].

CONCLUSIONS

In conclusion, the presence of mangroves along the coastal areas serves as a vital ecological asset, offering disaster risk reduction services in terms of carbon sequestration that lessen the impact of greenhouse effect on earth's climate conditions. Moreover, their rigidity and complex physiological features made them effective in buffering the impact of flooding.

Acknowledgments

The author would like to acknowledge the Mindoro State University- Research, Extension and Development (RED) Unit for the grant of internal funding to this research study.

Conflict of Interest

The authors declare no conflict of interest.

The Seybold Report
ISSN 1533-9211
DOI: 10.5281/zenodo.13832550

References and Notes

1) NIZAM A., MEERA S.P., KUMAR A. Genetic and molecular mechanisms underlying mangrove adaptations to intertidal environments, iScience [Internet]. **2022**; **25**(1):1–47. Available from: https://doi.org/10.1016/j.isci.

2) AKRAM H., HUSSAIN S., MAZUMDAR P., CHUA K.O., BUTT T.E., HARIKRISHNA J.A. Mangrove Health: A Review of Functions, Threats, and Challenges Associated with Mangrove Management Practices, Vol. **14**, Forests. Multidisciplinary Digital Publishing Institute (MDPI); **2023**.

3) AGUSTRIANI F., ISKANDAR I., YAZID M., FAUZIYAH. Economic Valuation of Mangrove Ecosystem Services in Sembilang National Park of South Sumatra, Indonesia, Journal of Hunan University Natural Sciences. **2023** Feb 28; **50**(1):66-156.

4) BIMRAH K., DASGUPTA R., HASHIMOTO S., SAIZEN I., DHYANI S. Ecosystem Services of Mangroves: A Systematic Review and Synthesis of Contemporary Scientific Literature, Vol. **14**, Sustainability (Switzerland). MDPI; **2022**.

5) FRIESS D.A. Ecosystem services and disservices of mangrove forests: Insights from historical colonial observations, Vol. 7, Forests. MDPI AG; 2016.

6) BRANDER M.L., WAGTENDONK J.A., HUSSAIN S.S., MCVITTIE A., VERBURG P.H., DE GROO R.S. Ecosystem service values for mangroves in Southeast Asia: A meta-analysis and value transfer application. Ecosyst Serv. 2012 Jul; 1(1):9-62.

7) MCVITTIE A., COLE L., WREFORD A., SGOBBI A., YORDI B. Ecosystem-based solutions for disaster risk reduction: Lessons from European applications of ecosystem-based adaptation measures, International Journal of Disaster Risk Reduction [Internet]. **2018; 32**:42–54. Available from: https://www.sciencedirect.com/science/article/pii/S2212420917302741

8) VAN ONSELEN V., BAYRAK M.M., LIN T.Y. Assessment of Ecosystem-Based Disaster Risk Reduction Strategies in Coastal Environments of Taiwan, J. of Dis. Res. **2023** Oct 1;**18**(7):7-700.

9) KAUFFMAN J.B., DONATO D.C. Working Paper Protocols for the measurement, monitoring and reporting of structure, biomass and carbon stocks in mangrove forests [Internet]. Bogor, Indonesia; **2012** [cited 2024 Mar 8]. Report No.: **86**. Available from: www.cifor.org

10) RAHMAN M., SIGIRO O.N. What is the true Carbon Fraction Value of Mangrove Biomass?, Malaysian Journal of Science [Internet]. **2023** Jun 28; **42**(2):67–72. Available from:https://mjs.um.edu.my/index.php/MJS/article/view/36905

11) MAULANA M.I., AULIAH N.L., ONRIZAL. Potential carbon storage of Indonesian mangroves. In: IOP Conference Series: Earth and Environmental Science. IOP Publishing Ltd; **2021**.

12) SCHÖNGART J., ARIEIRA J., FELFILI FORTES C., CEZARINE DE ARRUDA E., NUNES DA CUNHA, C. Age-related and stand-wise estimates of carbon stocks and sequestration in the aboveground coarse wood biomass of wetland forests in the northern Pantanal, Brazil, Biogeosciences. **2011; 8(**11):21-3407.

13) COON W. Estimation of Roughness Coefficients for Natural Stream Channels with Vegetated Banks, [Internet], Box 25286, Federal Center, Denver, CO 80225; **1998** [cited 2024 Mar 9]. Available from: https://pubs.usgs.gov › wsp › report

14) COWAN W.L. Estimating Hydraulic Roughness Coefficients. Vol. **37**, Agricultural Engineering. **1956**. p. 5-473.

15) MCCLAIN A.M, SHARKEY T.D. Triose phosphate utilization and beyond: from photosynthesis to end product synthesis, J Exp Bot [Internet]. **2019** Mar **27**;70(6):66-1755. Available from: https://doi.org/10.1093/jxb/erz058

ISSN 1533-9211

DOI: 10.5281/zenodo.13832550

16) MURDIYARSO D., PURBOPUSPITO J., KAUFFMAN J.B., WARREN M.W., SASMITO, S.D.,DONATO D.C. The potential of Indonesian mangrove forests for global climate change mitigation. Nat Clim Chang D.C., [Internet]. **2015;5**(12):92-1089. Available from: https://doi.org/10.1038/nclimate2734

17) CAMERON C., HUTLEY L.B., FRIESSD.A., BROWN B. High greenhouse gas emissions mitigation benefits from mangrove rehabilitation in Sulawesi, Indonesia, Ecosyst Serv [Internet]. **2019;40**:101035. Available from: https://www.sciencedirect.com/science/article/pii/S2212041619301561"

18) ADAME M.F., CHERIAN S., REEF R., STEWART-KOSTER B. Mangrove root biomass and the uncertainty of below ground carbon estimations. For Ecol Manage [Internet]. **2017**;**403**:52–60. Available from: https://www.sciencedirect.com/science/article/pii/S0378112717307156

19) ALONGI D.M. Carbon sequestration in mangrove forests. Carbon Manag [Internet]. **2012** Jun 1;**3**(3):22-313. Available from: https://doi.org/10.4155/cmt.12.20

20) VAN HESPEN R., HU Z., BORSJE B., DE DOMINICIS M., JEVREJEVA S., FRIESS D.A., KLEINHANS M., MAZA M., VAN BIJSTERVELDT C., VAN DER STOCKEN T., VAN WESENBEECK B., XIE D., BOUMA T. Mangrove forests as a nature-based solution for coastal flood protection: Biophysical and ecological considerations, Water Science and Engineering [Internet]. **2023;16**(1):1–13. Available from: https://www.sciencedirect.com/science/article/pii/S1674237022000874

21) MENÉNDEZ P., LOSADA I.J., TORRES-ORTEGA S., NARAYAN S., BECK M.W. The Global Flood Protection Benefits of Mangroves, Sci Rep [Internet]. **2020**;**10**(1):4404. Available from: https://doi.org/10.1038/s41598-020-61136-6