Assessing Livelihood Adaptation Indices and the Sustainability of Rice Farmers in Bangladesh’s Northwestern Region

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Climate change alters the impact of the environment on economies, and sustainable adaptation which may improve food security is embedded in the actualization of the 2030 United Nations Sustainable Development Goals (SDGs) 2, 13, and 14. Hence, this study contributes to the debate by measuring how farmers in the Northwestern region of Bangladesh adapt to climate change. A cross-sectional multistage random sampling is used to collect 500 data points by the face-to-face interview method. For robustness, the study demonstrates climate change adaptations, adaptation indices, and the sustainability indicators in social, economic, and environmental concepts using the composite indicator method. Also, Rasch analysis and marginal contribution were used to explain the adaptation indices. Finally, a trivariate Tobit regression is used to examine sustainability analyses of climate change adaptation strategies and explain how the climate change adaptations affect different dimensions of sustainability. The results showed that dominant male households, extended family, skilled farmers and food security influenced adaptation index as well as adaptation strategies like organic manure, changing planting dates, diseases tolerant varieties and irrigation. Though, most dominant strategies like irrigation and applying fertilizer are not sustainable. The study also found that farm size, credit access, and extension contact significantly affects sustainability. Moreover, off-farm activities, crop diversification, and using high-yield varieties are more sustainable adaptation strategies. Policy should be implemented on the basis of region and sustainable manner.

Keywords: adaptation, sustainability, rice farming, livelihood index, Rasch analysis, Tobit model

INTRODUCTION

The agricultural sector is burdened with the responsibility to tackle food security at the national and global levels (Schmidhuber and Tubiello, 2007; Barrett, 2010; FAOSTAT, 2015; Alam, 2016; Pandey et al., 2016; Adeleye et al., 2020; Osabohien et al., 2020). But food sustainability and security are hampered by the incidence of climate change. Though agriculture contributes the least to climate change, its adverse effect is felt due to the increase in the severity of the weather (Herring et al., 2014; Hulme, 2014; Adeleye et al., 2021), which adversely affects climate-related food productivity
RESEARCH DESIGN AND METHODOLOGY

Study Area, Description of Variables, Summary Statistics

During the 2017–18 production year, this study performed a cross-sectional pilot survey through a face-to-face interview process. The survey had 500 sample households of rice farmers to exclude missing data in the northwestern region of Bangladesh. The Northwestern region of Bangladesh is the most climate-sensitive and poorest area of Bangladesh (BBS, 2019). The region has experienced groundwater depletion and severe droughts (Alauddin and Sarker, 2014; Kabir et al., 2017). Two upazilas (sub-districts), Ishwardi in Pabna and Lalpur in Natore, were selected and assumed to be representative of the Northwestern region of Bangladesh. Figure 1 shows the study area, in which 79.85% of the people in the survey have their livelihood on agriculture. Moreover, Ishwardi Upazila and Lalpur Upazila reach their peak vulnerability from the intensity and frequent drought (Alauddin and Sarker, 2014; Eyasmin et al., 2017). The survey questionnaire included the 14 adaptation strategies such as irrigation, chemical fertilizer application, organic manure application, restructure cash flow and debt, crop rotation, off-farm activities, diseases tolerant varieties, changing planting dates, drought tolerance rice varieties, and crop diversification, which were identified in different studies in the drought-prone area (Ghosh et al., 2016; Eyasmin et al., 2017; Kabir et al., 2017). Table 1 shows the description of the variables.

Rasch Analysis

Assessing all the adaptation strategies is quite difficult due to their heterogeneous characteristics (Wheeler et al., 2013). To identify the most prioritized strategies by transitive rank, Rasch analysis was used. The model can be explained as,

$$\Pr(A_{ni} = A) = \frac{\exp(A(\beta_n - \delta_i))}{\gamma_{ni}}$$  \hspace{1cm} (1)

where, $A_{ni}$ = the Adaptation strategies $A \in (0,1)$

$\beta_n$ = parameters of nth households

$\delta_i$ = Parameters of ith region at same continuum.

And $\gamma_{ni} = 1 + \exp(\beta_n - \delta_i)$ indicates the normalizing factor to ensure that the sum of two probabilities in Equation (1) is equal to zero.

Livelihood-Based Adaptation Index

The livelihood-based adaptation index (LAI) was developed to evaluate the determinants of adaptation by assessing the weights of adaptation strategies on the basis of their marginal contribution to household livelihood. Ordinary least square (OLS) is used to measure the index which contributes to aggravate poverty:

$$L_i = \sum_{j=1}^{j} \beta_j(A_i) A_j + \varepsilon_i$$  \hspace{1cm} (2)

where,

$L_i$ = Livelihood based adaptation index of ith household which is weighted by their marginal contribution
TABLE 1 Descriptive statistics of the variables used in the study.

| Variables                        | Description of variables                                              | Mean  | St. dev. |
|----------------------------------|------------------------------------------------------------------------|-------|----------|
| Social sustainability            | Aggregation of scale of social indicators and components               | 41    | 10.28    |
| Environmental sustainability     | Aggregation of scale of environmental indicators and components        | 38    | 11.82    |
| Economical sustainability        | Aggregation of score of economic indicators and components             | 45    | 10.92    |
| Age                              | Years                                                                  | 41.32 | 10.85    |
| Gender                           | 1 if household head (HH) is male and 0 if female                       | 0.78  | 0.42     |
| Farming experience               | Years                                                                  | 25.49 | 12.12    |
| Education                        | Years of schooling                                                     | 8.05  | 5.01     |
| Farm size                        | Decimals                                                               | 138.59| 170.61   |
| Access to extension              | 1 if HH access extension services, 0 if otherwise                      | 0.78  | 0.40     |
| Credit accessibility             | 1 if HH access credit, 0 if otherwise                                  | 0.71  | 0.38     |
| Adaptation strategies            |                                                                        |       |          |
| Using formal irrigation          | 1 if HH choose irrigation, 0 if otherwise                              | 0.89  | 0.47     |
| Use of chemical fertilizer       | 1 if HH apply chemical fertilizer, 0 if otherwise                      | 0.69  | 0.38     |
| Organic manure application       | 1 if HH apply organic manure, 0 if otherwise                           | 0.58  | 0.28     |
| Restructure cash flow and debt   | 1 if HH restructure cash flow and debt, 0 if otherwise                 | 0.41  | 0.39     |
| Crop rotation                    | 1 if HH adopt crop rotation, 0 if otherwise                            | 0.51  | 0.70     |
| Planting disease tolerance variety | 1 if HH plant disease tolerance variety, 0 if otherwise               | 0.40  | 0.19     |
| Off-farm income                  | 1 if HH has off-farm income, 0 if otherwise                            | 0.59  | 0.29     |
| Changing planting dates          | 1 if HH has changed planting dates, 0 if otherwise                     | 0.61  | 0.30     |
| Add new technology               | 1 if HH add technology, 0 if otherwise                                 | 0.31  | 0.12     |
| Intercropping                    | 1 if HH choose intercropping, 0 if otherwise                           | 0.07  | 0.005    |
| Use drought tolerance rice variety | 1 if HH use drought tolerant rice variety, 0 if otherwise             | 0.055 | 0.025    |
| Implement edge of field conservation practice | 1 if HH implement edge of field conservation practices, 0 if otherwise | 0.12  | 0.21     |
| Intensive or expand cultivated area | 1 if HH use intensive or expand cultivated area, 0 if otherwise     | 0.02  | 0.001    |
| Testing new crop                 | 1 if HH test new crop, 0 if otherwise                                 | 0.05  | 0.001    |

Source: Authors’ Calculation from household survey data 2018.
A_{ij} = j\text{th adaptation strategy are undertaken by ith household} \\
β_j = \text{parameter explained as poverty line unit, a more obvious interpretation of the result.}

However, LAI \text{<} 1 \text{ indicates the household below the poverty line and otherwise.}

**Model of Sustainability Analysis**

The sustainability of climate change adaptation strategies is measured by the socio-economic characteristics and the adjustment practices as well.

This assumption can be expressed as follows:

\[
S = f(Z, A) 
\]

where,

\(S\) = household’s sustainability level,

\(Z\) = household’s socio-economic characteristics

\(A\) = Adaptation strategies prioritize by the Rasch analysis.

The level of sustainability is estimated in economic, environmental, and social dimensions. As such, sustainability \(S\) is assessed by the \(n\)th household’s socio-economic characteristics and \(m\)th adaptation strategies. So, Equation (3) may be written as:

\[
S_j = f(Z_n, A_m). 
\]

As there are only three dimensions of sustainability, \(j = 3\).

The extension of Equation (4) is as follows:

\[
S_{ji} = \alpha_j + \sum_n \gamma_{nj}Z_{ni} + \sum_m \rho_{mj}A_{mi} + u_{ji} 
\]

where,

\(\alpha\) = constant terms, \(\gamma\) and \(\rho\) are the parameters, and \(u\) is the error term.

Due to the barrier of implementing OLS to multidimensional variables, a multivariate Tobit model is applied to sustainability which is limited between 0 and 100. Moreover, the Tobit model is advanced with its feature estimation of \(M\) equations together. Their sustainability is derived from their coefficient and level of significance. The specification of the sustainability Equation (5) is derived as follows:

\[
\begin{align*}
S_{1i} &= \alpha_1 + \sum_n \lambda_{n1}Z_{ni} + \sum_m \rho_{m1}A_{mi} + u_{1i} \\
S_{2i} &= \alpha_2 + \sum_n \lambda_{n2}Z_{ni} + \sum_m \rho_{m2}A_{mi} + u_{2i} \\
S_{3i} &= \alpha_3 + \sum_n \lambda_{n3}Z_{ni} + \sum_m \rho_{m3}A_{mi} + u_{3i}
\end{align*}
\]

The sustainability score measures from 0 to 100 in scale. All sustainability indicators and components are scaled by the agriculture extension officer and farmers (Yegbemey et al., 2017).

### RESULTS AND DISCUSSIONS

**Descriptive Statistics of Households in the Study Area**

Table 1 shows the summary statistics of the variables included in the study. The variables included dependent and independent variables such as sustainability in three dimensions, age, sex, farming experience, education, farm size, access to extension services, credit accessibility, and 14 adaptation strategies.

**Rasch Analysis Results**

The goodness-of-fit of the model is assessed by using strategies and individual fits residuals to rank the adaptation strategies from easiest to challenging (Bond and Fox, 2001). The selected range is between ±2.5. All other outer practices from the range are dropped down for further analysis (Bond and Fox, 2001).

Differential item functioning (DIF) further found that each strategy is unbiased at a 10% significance level. Table 2 shows the results from the Rasch analysis.

**Livelihood-Based Adaptation Index**

Tables 3, 4 show the influence of adaptability to climate change through household features via the OLS method and the marginal contribution of each adaptation strategy, i.e., the adaptation index. Before interpreting the results, the diagnostics reveal that the errors are normally distributed, and the White test
for heteroscedasticity cannot reject the null hypothesis of homoscedasticity. For multicollinearity, the variance inflation factor (VIF) ranges between 1.87 and 5.23; indicating the absence of multicollinearity. Lastly, the Durbin Watson statistic indicates no autocorrelation.

Table 3 shows a higher adaptation index for a male head of household with a larger family and more rice farming experience. Food accessibility and credit accessibility influence the adaptation index positively. Households with a male head and larger families are more likely to adjust to climate change by applying organic manure, chemical fertilizer, irrigation, and changing sowing dates.

A positive relationship for the size of the family, and the tendency to implement irrigation, chemical fertilizer, and changing planting dates have been established by Eyasmin et al. (2017) and Yasin and Ghosh (2019).

Food security lifted the adaptation index, which stimulates the probability of adjusting through organic manure application, changing planting dates, and disease-resistant varieties. This revelation proposes that farmers’ hunger and struggle to adapt become obstacles to adjust effective adaptation and decisive adjustment for improving the sustenance food security. Kristjanson et al. (2012) have found that families with food stressed are more inactive to adaptive systems.

It was more likely that highly skilled farmers would apply chemical fertilizers, crop rotation, and shifting planting dates which promote the adaptation index. Shikuku et al. (2017) noted that the chance of using chemical fertilizer, crop rotation, and changing planting dates was more likely higher among experienced farmers. However, the continuing climate change demotivates the farmer from applying adjustment practices that force the adaptation index to be lower following the study (Bryan et al., 2009; Deressa et al., 2009, 2011).

### Sustainability Analysis

The analysis of the multivariate Tobit model of sustainability is displayed in Table 5. The results reveal that the overall sustainability is 45. The results indicated that about 50% of farmers’ farming systems and adaptation strategies were sustainable in the social, economic, and environmental dimensions. The likelihood ratio of sustainability of 167.0234 indicates a significant level at 1%. Moreover, the likelihood ratio statistic of 173.71, 176.24, and 174.74 in the economic, environmental, and social aspects of sustainability are statistically significant at the 1% level. The results reveal the connection of the equations in the model and the significance of at least one covariance in the error terms. Hence, the estimated coefficients in the model present major driving forces on the sustainability dimension through adequate goodness of fit. Additionally, the corresponding coefficients indicated how rice farmers’ socio-economic characteristics and climate change adaptation strategies related to social, economic, and environmental sustainability.

### Sustainability of Socio-Economic Characteristics

Socio-economic characteristics such as level of education, farm size, credit access, and extension service access significantly impact sustainability dimensions. Education has a positive and significant effect that stimulates adaption with climate-friendly strategies as well as sustainable farming. However, the results show it to be an insignificant tool ($p > 0.10$) in both economic and social sustainability but a significant ($p < 0.10$) tool in environmental sustainability. However, significant environmental sustainability has a negative impact with a level of significance of 10%. It is shown to be an unsuitable tool to promote the sustainability of rice farming. Farm size is statistically significant and positively linked with sustainability, similar to other studies (Sarker et al., 2013; Ren et al., 2019). Therefore, farm size positively affects economic and environmental sustainability as expected at 10% probability but 1% at social sustainability. This reflects that land fragmentations reduce rice productivity and affect economic development, urbanization, and technological development as shown in Hung et al. (2007) and Adamopoulos and Restuccia (2014). Other variables such as accessing credit positively affect economic, environmental, and social sustainability at 5, 1, and 1% probability levels. Farmers who can access more credit adopt a more sustainable farming culture than those who access less. Sarker et al. (2013), Eyasmin et al. (2017), Linh et al. (2019), and Adeleye et al. (2020) also found a positive and statistically significant relationship between accessing credit and sustainable agricultural production. In all three dimensions of economic, environmental, and social sustainability, the relation between extended contacts and production sustainability is highly significant at a 1% significance level, though receiving higher extension services will result in higher social and environmental sustainability than economic sustainability as extension contacts become environmentally viable such as soil conservation, minimizing pesticides use, and organic farming. However, the traditional farming technique negatively affects sustainability and extension contact in the study area.

### Table 3 | Livelihood based adaptation index through OLS.

| Explanatory variables                  | Coefficient | Standard errors |
|----------------------------------------|-------------|-----------------|
| Household head is male                 | 0.0101*     | 0.070           |
| Formal education                       | 0.127       | 0.023           |
| Household size                         | 0.013***    | 0.015           |
| Experience                             | 0.68**      | 0.002           |
| Farm size                              | 0.008791    | 0.018           |
| Off-farm activities                    | 0.15        | 0.019           |
| Having food shortage                   | 0.165***    | 0.004           |
| Access credit for farming              | 0.089*      | 0.030           |
| Access to extension service            | 0.025       | 0.023           |
| Farmer’s perception of climate change  | 0.006***    | 0.031           |
| Adjustment practices to cope with this weather | 0.0138*** | 0.001           |
| Sample                                 | 500         |                 |
| Adjusted R-square                      | 0.31        |                 |
| F stat                                 | 16.11***    |                 |

Source: Authors’ Calculations.

*p < 0.1; **p < 0.05; ***p < 0.01.
**TABLE 4** Marginal effects from Tobit analysis of climate change adaptation strategies.

| Explanatory variables | Marginal effects |
|-----------------------|------------------|
|                       | OMA  | CFERT | RCFD | IRGTN | CR  | PDTV | GFJSFI | CPD  | ANT  |
| Sex (male) (1/0)      | 0.0134 | 0.2181** | −0.1185 | 0.0832* | −0.0315 | 0.1361* | −0.020 | 0.105 | −0.20 |
| Household size        | 0.022*** | 0.035*** | −0.0065 | −0.00655* | 0.0103 | 0.000532 | 0.006 | 0.71** | 0.380 |
| Experience            | 0.00217 | 0.00043* | −0.00034 | 0.00258 | −0.0005* | −0.000257 | 0.218 | 0.123*** | 0.95 |
| Education             | −0.0067 | 0.04580* | 0.005256 | 0.0075946 | −0.0014 | 0.0008488 | 0.556 | 0.11* | −0.94 |
| Farm size (decimals)  | −0.0004 | 0.00071*** | −0.00024 | 0.534E-02* | −0.00094 | 0.0000012 | 0.03 | −0.40 | 0.410*** |
| Extension contact (1/0) | 0.0997 | 0.08815 | 0.00371 | 0.00865 | 0.1192 | 0.06342 | 0.06** | −0.54 | −0.49* |
| Credit access (1/0)   | 0.049 | 0.165762 | −0.1139 | 0.021564 | 0.0305 | −0.03986 | 0.13 | 0.29 | 0.564 |
| Food shortage         | −0.009** | 0.006 | −0.003 | 0.012* | 0.556 | −0.002* | 0.001 | 0.007 | −0.001* |
| Off farm activities   | 0.094 | −0.148 | −0.023 | −0.067 | 0.224*** | −0.016 | −0.293** | 0.238 | 0.130 |
| Farmer’s perception of climate change | 0.235*** | 0.017 | 0.269*** | 0.234*** | 0.019 | 0.157*** | 0.183*** | 0.131*** | −0.131*** |
| Adjustment practices to cope with this weather | 0.019** | 0.004 | −0.009 | −0.022*** | 0.006 | −0.025*** | −0.007 | −0.010 | 0.006 |

OMA, organic manure application; CHEMFERT, chemical fertilizer; RCFD, restructure cash flow and debt; CR, crop rotation; PDTV, planting disease tolerance variety; IRGTN, irrigation; GFJSFI, get an off-farm job to supplement farm income; CPD, changing planting dates; ANT, add new technology. OMA is the base category.

(b) $\frac{\partial y}{\partial x}$ is for discrete change of dummy variables from 0 to 1.

Authors’ Computations from Field Level Data, 2018.

***, **, *: significant at 1, 5, and 10% level, respectively.

**TABLE 5** Determinants of agricultural sustainability of climate change adaptations.

| Variables | Economic sustainability | Environmental sustainability | Social sustainability |
|-----------|-------------------------|-----------------------------|----------------------|
|           | Cof. | Std. error | P > |Z| | Cof. | Std. error | P > |Z| | Cof. | Std. error | P > |Z| |
| Socio-economic variables | | | | | | | | | | | | | |
| Age       | 0.109 | 0.091 | 0.329 | 0.050 | 0.122 | 0.681 | 0.0891 | 0.119 | 0.457 |
| Level of education | −0.157 | −0.087 | 0.274 | 0.294* | 0.097 | 0.091 | 0.253 | 0.922 | 0.573 |
| Rice farming experience | 0.002 | 0.009 | 0.840 | 0.007 | 0.011 | 0.512 | 0.002 | 0.010 | 0.779 |
| Farm size | 0.019* | 0.007 | 0.010 | 0.011* | 0.008 | 0.012 | 0.102 | 0.012** | 0.008 | 0.047 |
| Access credit (0/1) | 1.186** | 0.260 | 0.05 | 1.233*** | 0.286 | 0.000 | 1.082*** | 0.251 | 0.000 |
| Extension service | −1.977*** | 0.416 | 0.000 | −2.252*** | 0.469 | 0.000 | −2.122*** | 0.452 | 0.000 |
| Adaptation strategies | | | | | | | | | | | | | |
| Using fertilizer | 0.1720 | 0.423 | 0.672 | −0.449 | 0.472 | 0.308 | 0.372 | 0.430 | 0.388 |
| Formal irrigation | −0.1790 | 0.180 | 0.319 | −0.135 | 0.197 | 0.495 | −0.114 | 0.194 | 0.556 |
| Off-farm activities | 1.199** | 0.526 | 0.024 | 1.879*** | 0.604 | 0.000 | 0.991* | 0.563 | 0.080 |
| Crop diversification | 0.505*** | 0.193 | 0.009 | 0.449*** | 0.214 | 0.003 | 0.157 | 0.157 | 0.345 |
| Using HYV | 0.383** | 0.255 | 0.101 | 0.625*** | 0.282 | 0.002 | 0.565* | 0.274 | 0.040 |
| Constant | 0.252 | 0.196 | 0.130 | 0.014 | 0.222 | 0.579 | 0.060* | 0.214 | 0.479 |
| Parameters | 11 | 11 | 11 |
| Prob > χ² | 0.000 | 0.000 | 0.000 | 0.000 |
| Log-likelihood | −173.70514 | −176.23566 | −175.74 |
| Pesudo R² | 0.1705 | 0.1450 | 0.15 |

Source: Authors’ Computations.

***, **, *: significant at 1, 5, and 10% level, respectively.

**Sustainability Analysis of Climate Change Adaptations**

Crop diversification, off-farm activities, and hybrid varieties for rice production significantly correlate with all three sustainability dimensions. Sustainability is highly related to off-farm activities at the 5, 1, and 10% significance levels in the economic, environmental, and social dimensions. Since it is challenging to manage the high cost of rice farming, farmers tend to do other off-farm activities like rickshaw pulling, plowing by machine, shopkeeping, day labor on other farms, and selling storage
rice production off-season (Al-Amin and Hossain, 2019). The positive coefficients with significant probability indicate more sustainability of another source of income. Several studies (Coelli and Fleming, 2004; Chavas et al., 2005; Gonzalez’lez and Lo’pez, 2007) have concluded the positive relationship between off-farm income and higher agricultural production. Other sources of income might boost investment in rice production and help cope with the impact of climate change in three dimensions of sustainability (Zhang et al., 2014; Alamgir et al., 2018; Chen and Mueller, 2018; Rahman et al., 2019). Crop diversification helps to minimize mono-crop losses and enhances sustainability at a 1% probability level in both economic and environment. Therefore, farmers have tried enhancing economic performance to lead to better social status. However, a negative and insignificant ($p > 0.10$) relation was shown in terms of social sustainability. High-yield seeds help a farmer gain higher economic return (i.e., higher yield, income, and maybe higher technical efficiency) and are more environmentally viable (i.e., remove biological constraints). In the study area, high yielding seeds (HYV) significantly affect rice productivity in the economic ($p < 0.05$), environmental ($p < 0.01$), and social ($p < 0.05$) dimensions. The most common and dominating adaptation strategies are using chemical fertilizer and irrigation, which has no significant impact on sustainability with probability $p > 0.10$. The efficiency of irrigation depends on the availability of fresh water on both ground and surface, and chemical fertilizer limits the quality of the soil. Depleting groundwater and soil degradation might cause being not sustainable (Selvaraju et al., 2006).

CONCLUSION AND POLICY IMPLICATIONS

This study aligns with the 2030 United Nations Sustainable Development Goals (SDGs) 2, 13, and 14 to evaluate the relationship between climate change strategies and rice farming sustainability in the northwestern region of Bangladesh. The study focuses on the leading climate change adaptation strategies and their implementation through the adaptation index and sustainability in economic, social, and environmental dimensions. Significant findings reveal that using adaptation strategies was not sustainable in social, economic, and environmental dimensions. The study showed a greater tendency to implement irrigation, chemical fertilizer, and changing planting dates in larger families, while organic manure application, changing planting dates, and disease-resistant varieties were related to food security and rice farming experience. In the case of sustainability analysis, the study found that farm size, credit access, and extension contact significantly affect sustainability.

Moreover, off-farm activities, crop diversification, and using high-yielding varieties are more sustainable adaptation strategies. Policymakers should try to organize agricultural training on crop diversification and high-yield rice varieties with a promotion that improves food security and the supply chain. Since education has a significant relation to sustainable agriculture, existing education, vocational training, and vocational education should be linked to sustainable agriculture by helping farmers preserve rainwater, limit the use of chemical fertilizer, and utilize adaptation strategies. Extension services should be more explored so that farmers can gather knowledge about undertaking climate change adaptation and the harmful impact of their overuse. New technologies should be developed and made available and affordable so that farmers can adapt easily. As the different regions have different weather conditions, regional policy to strengthen qualitative research needs to be pursued, and focus on the farmers who have decided to implement or expand the utilization of more adaption strategies.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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