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Satellite-based assessment of water quality and associate land cover changes of selected five Villus in Wilpattu National Park, Sri Lanka

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ABSTRACT

This study was conducted in relation to Sri Lanka's distinctive Villu ecosystem, situated within the expansive Wilpattu National Park (WNP), a Ramsar site. Villus are natural lakes which are filled with fresh or brackish water. Remote sensing techniques assessed water quality parameters and analyzed vegetation and land cover changes from 2019 to 2023. The incorporation of ground data enhanced the study's comprehensiveness. Fifteen sites across five villus within the WNP were strategically selected for mapping and spectral analysis. Precise distinctions in land use were achieved using the Normalized Difference Vegetation Index (NDVI), Normalize Difference Water Index (NDWI), and supervised classification. NDWI analysis highlighted pronounced water level fluctuations, peaking from November to December (Borupan Villu-3.09%, Kokkare Villu-19.41%, Mhapatessa Villu-8.59%, Kumbuk Villu-3.87%, and LunuVila Villu-7.09%) and sharply declining from July to August (Borupan Villu-0.80%, Kokkare Villu-8.89%, Mhapatessa Villu-4.00%, Kumbuk Villu-1.31%, and LunuWila Villu-3.74%). NDVI revealed the highest presence of sparse vegetation from March to April (Borupan Villu-64.94%, Kokkare Villu- 57.35%, Kumbuk Villu- 47.84%, LunuVila Villu- 67.91%, Mahapatessa Villu-68.53%), whereas the lowest occurred from July to August (Borupan Villu-6.39%, Kokkare Villu - 9.96%, Kumbuk Villu- 6.81%, LunuVila Villu - 6.45%, Mahapatessa Villu-6.41%). Conversely, dense vegetation exhibited an opposite seasonal pattern compared to sparse vegetation. Water quality parameters, assessed by Moran's Index, displayed distinct spatial clusters independent of Villus' proximity. All parameters, except nitrate concentration, exhibited significant spatial disparities among the five villus during both periods. Kokkare Villu showed high salinity, while others ranged from slightly saline to freshwater. Total phosphate concentration and pH exceeded aquatic life's ambient limits during rainy and dry periods. Intriguingly, changes in Villu-associated shrub and grassland areas were not recorded as a significant relationship with any water quality parameter. This study underscores the importance of incorporating satellite-based analysis for ongoing wetland management, serving as an invaluable tool for monitoring water areas and associated vegetation.

KEYWORDS: *Wilpattu National Park, Normalize Difference Vegetation Index, Normalize Difference Water Index, water quality, Land cover*

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1. INTRODUCTION

Sri Lanka, renowned for its exceptional biodiversity and breathtaking natural landscapes, contains seven Ramsar sites encompassing a total surface area of 1981.72 km^2, designated as wetlands of international importance. These are Bundala Wetland, Kumana Wetland, Annaiwilundawa Wetland, Madu Ganga Wetland, Vankalai Wetland, Colombo City Wetlands, and Wilpattu Wetland/ Wilpattu National Park (Hathurusinghe et al., 2020). Wilpattu National Park (WNP) and its adjacent protected areas earned Ramsar status in 2013 due to unique Villu and wetland ecosystems (Bandara et al., 2019). WNP stands out among Sri Lanka's Ramsar sites because of its extensive biodiversity, extensive coverage, cultural and historical significance, popularity as a tourist destination, and unique Villu ecosystems. The park derives its name from the numerous natural lakes or "Villu" that contain fresh or brackish water (Weerakoon and Goonatilleke, 2007). The term "Villu" denotes shallow water holes with grassland habitats. According to the Department of Wildlife Conservation (2019), WNP contains a cluster of 40 large and small Villus, typically found in shallow saucer-shaped depressions. The sevillus are circular to oval, with a semi-permanent or periodical hydroperiod. A gentle gradient from the periphery to the center often does not exceed 10 degrees. Distinct vegetation belts or associated grassland zones have been established in response to fluctuating water levels. These belts encompass occasionally flooded edge forests, occasionally flooded grasslands, seasonally flooded damp grasslands, swamp communities, marsh communities, and lentic communities (Bambaradeniya et al., 2009). Stronach et al. (2021) and Weerakoon and Goonatilleke (2007) studied avifaunal diversity in the Villu ecosystem within WNP, identifying endemic and migratory species. Wilson (2014) examined the villus and found that despite variations among individual villus, most exhibit similar patterns of water level fluctuations. These villus play a significant role in maintaining biodiversity and providing habitats for specially adapted plant and animal species. According to the Department of Wildlife Conservation (2007), WNP is home to 21 endemic and 30 nationally threatened faunal species, 27 endemic plant species, and 21 threatened plant species. While WNP encompasses four river catchments (Mei Oya, Kala Oya, Modaragam Aru, and Aruvi Aru), the central and northern coastal sections of

WNP predominantly rely on Villu ecosystems (Eisenberg and Lockhart, 1972). These shallow wetlands receive water primarily from rainfall in their limited catchment areas or a combination of rainfall and groundwater. Some Villus are seasonal, most are surrounded by grassland, and they serve as crucial feeding grounds for terrestrial herbivores such as elephants, sambar, and spotted deer, which prefer the associated grasslands and water bodies in WNP (Kotagama and Bambaradeniya, 2006). Many of these Villus experience seasonal drying, primarily due to water loss through evaporation, leading to drought in some years. This results in the drying out of water holes and Villu ecosystems, leading to the mortality of water-dependent wildlife. To address this issue, park management has constructed numerous small concrete-lined ponds to provide water for wildlife during droughts. It is thus vital to research water quality parameters, associated vegetation changes, and land cover change patterns in WNP to identify villus suitable for wildlife consumption and locations where food scarcity may impact herbivores due to limited grassland availability and changing patterns for future predictions. Ensuring the sustainable management of these unique Villu ecosystems within WNP necessitates a comprehensive understanding of their characteristics and potential impacts. This knowledge enables policymakers and stakeholders to develop and implement effective policies, legislation, and management systems that balance utilizing Villu resources for economic gain and preserving biodiversity and natural habitats (Piyankarage, 2004). However, acquiring this knowledge presents challenges as the villus are located within WNP, and access to some areas is limited. Navigating these regions requires safari jeeps, making daily monitoring and assessment a formidable task, particularly considering the economic crisis in Sri Lanka. Nevertheless, it remains crucial to enhance our understanding of the physical, chemical, and biological processes influencing Villu ecosystems and the historical and ongoing changes to the sensitive habitats of resident animal species. One potential solution to the challenge of limited access is remote sensing technology. Remote sensing can serve as a cost-effective method for decision-making in environmental ecosystems, offering insights at both temporal and spatial scales. As highlighted by Gholizadeh et al. (2016), remotely sensed data can enhance the ability of water resources for researchers and decision-makers to monitor water bodies effectively. In recent decades, remote sensing techniques have been widely employed to measure qualitative parameters. Notably, there is a shortage of previous studies focusing on remote sensing-based water quality assessment in the wetlands in the WNP. Consequently, the present study was conducted in the Villu ecosystems in the WNP to assess the suitability of remote sensing-based water quality assessment methods to study variations in water quality, vegetation, and land cover. Additionally, in-situ and laboratory analyses were carried out to provide comprehensive insights into the dynamics and changes in water quality parameters occurring within the Villu ecosystems. Satellite-based assessments for forests that have difficulties to access are very effective.

2 MATERIALS AND METHODS

2.1 Study area

For this study, 15 locations were selected for water sampling, focusing on five villus close to Kokkare Villu. These five villus are located centrally within the park and form a cluster. During the selection process, accessibility and salinity variations were considered to ensure a representative sample. Figure 1 displays the map of the study area and study sites, which were created using ArcGIS software, Sentinel-2 image ID: L1C_T44PLQ_A024283_20200215T051451 was obtained from the United States Geographical Surveys (USGS).

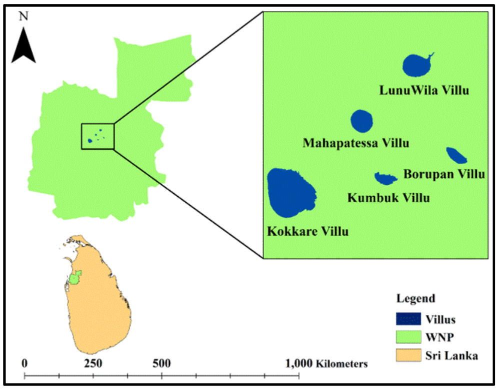


Fig. 1. Map of the WNP and selected five Villus

2.2 Data collection

Satellite imagery data spanning from 2019 to 2023, at two-month intervals, was acquired from https://earthexplorer.usgs.gov/. Rainfall records from 2015 to 2022 were compiled for three stations – Vanathavillu, Nochchiyagama, and Ranoruwewa- from the Meteorological Department of Sri Lanka. Temperature, salinity, Total Dissolved Solid (TDS), Dissolved Oxygen (DO), conductivity, and pH values were obtained through on-site analysis. Laboratory analysis was used to obtain chlorophyll concentration, nitrate concentration, phosphate concentration, and Biochemical Oxygen Demand (BOD) data from water samples collected during both dry (May and September) and rainy (March and December) periods for two years at the study sites.

2.3 Rainfall data analysis

Monthly mean values of daily rainfall data from the year 2015 to the year 2022 collected from three stations were calculated and graphed against the months of the year. Rainfall analysis was done to identify the patterns of rainfall change throughout the year.

2.4 Land cover analysis using satellite remote sensing technique

The shapes of five villus were individually extracted from Google Earth, and 1km distance buffer zones were created for each, using ArcMap. Satellite imagery data was processed to remove the Villu areas and buffer zones. Algorithms were employed to calculate the Normalized Difference Index (NDVI) and Normalize Difference Water Index (NDWI)

2.4.1 NDVI

One of the most commonly used vegetation indices is the NDVI, as defined by Rouse et al. (1974). NDVI was calculated for each Villu with a buffer zone extracted from the satellite image. The following equation was used for NDVI calculation.

$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{RED})}{(\mathrm{NIR} + \mathrm{RED})}$$

This index is based on the difference between the maximum absorption of radiation in the red due to chlorophyll pigments and the ultimate reflection of radiation in the Near Infrared (NIR) due to the leaf cellular structure. NDVI measures vegetation health and vigor, with values ranging from -1 to +1 (Chauhan et al., 2021). NDVI images were classified into five major classes: water, sand and soil, shrub and grassland, sparse vegetation, and dense vegetation, based on NDVI threshold values described by Akbar et al. (2019) and Mansourmoghaddam et al. (2022). The area of each class in each Villu was calculated using the attribute table in ArcGIS. Changes in the area of each category were analyzed from 2019 to 2022 within two-month intervals. The percentage value of the area in each Villu for each class was calculated, and graphs were plotted to display the changing patterns of vegetation and water area. The graphs show each class's mean percentage area values plotted against months, allowing for easy identification of trends or shifts in the vegetation and water areas throughout the year.

2.4.2 NDWI

Although NDVI is more accurate for vegetation, NDWI was also used to analyze water area changes as it is more accurate for water, as noted by Szabo et al. (2016). NDWI was calculated for each Villu with a buffer area using the following equation defined by McFeeters (1996).

$$\mathrm{NDWI} = \frac{(\mathrm{Green} - \mathrm{NIR})}{(\mathrm{Green} + \mathrm{NIR})}$$

The values from NDWI range from +1 to -1, with a value of more than 0 theoretically considered as water in the NDWI image (Garg et al., 2020). Resultant NDWI values were classified into two classes: water area and non-water area. Utilizing the attribute table within ArcGIS, the area of water within each Villu was computed spanning from 2019 to 2022, delineated by two-month intervals annually. Subsequently, mean values of water area were derived for these two-month intervals across the three years. Mean percentage water area values were plotted against months to identify the changing patterns of water areas throughout the year.

2.5 Water quality parameters

The multi-parameter (HACH/Model: HQ40d) was used to measure the in-situ water quality parameters (pH, DO, TDS, temperature, salinity, and conductivity). Three readings were taken from each study site for each water quality parameter and averaged to obtain the mean value for each parameter. The same calibrated multi-parameter instrument was used at all sampling events. Nitrate concentration, phosphorus concentration, BOD, and chlorophyll-a concentration in water were analyzed in the laboratory according to the standard methods described by APHA (1998).

2.6 Spatial and temporal variations of water quality parameters

Physical and chemical water quality parameters were utilized to create distribution maps via geostatistical interpolation methods in ArcGIS. Spatial distribution patterns of these parameters were evaluated using Moran's Index (Hongfei et al., 2007) ranging from -1 to +1. Positive values indicate the clustering of similar values, while negative values signify the dispersion of dissimilar values; a Moran's I value of 0 denotes perfect randomness (Wijeyaratne and Nanayakkara, 2020). The spatial variability of water quality parameters within the five villus during the dry and rainy seasons was analyzed using ANOVA and Tukey's pairwise comparison. Pearson correlation analysis was used to identify the relationships between water quality parameters.

2.7 Relationship between shrub and grassland vegetation changes with water quality parameters

The correlation between shrub and grassland vegetation changes in five villus and water quality parameters was investigated. Shrub and grassland percentages were derived from satellite imagery taken during the same periods as water sample collection and analysis. Pearson correlation analysis assessed the relationships between changes in shrub and grassland areas and individual water parameters.

3 RESULTS & DISCUSSION

3.1 Rainfall analysis

The 8-year rainfall analysis indicated a unique rainfall changing pattern throughout the year in the study area. The first is a minor rainy season, extending from March to May, while a more substantial rainy season spans from September to December. Consistent with prior research by Dombois (1968), the WNP experiences a brief drought period in January and February, followed by rainy spells from September to December and March to April. This study underscores the resilience of WNP's rain pattern, with minimal variations. Notably, in 2017, this study observed a significant reduction in April's rainfall, marking the lowest recorded precipitation for that year.

3.2 Satellite image analysis

Research by Sandamali et al. (2018), Bandara et al. (2019), and Dilini et al. (2013) employed satellite image analysis to assess forest cover in the WNP. However, no prior studies have utilized satellite imagery to analyze changes in villus and associated vegetation. Therefore, this study aimed to examine water level variations and associated land cover changes in the WNP using satellite images from 2019 to 2022. This research revealed consistent water level fluctuations among closely located villus, aligning with Wilson's (2014) and Rajapaksha et al. (2022) observations. These uniform water level fluctuation patterns were evident across all five villus. NDWI analysis unveiled consistent seasonal water area patterns (Figure 2), with the highest water area percentages occurring from November to December and the lowest from July to August. Remarkably, despite a brief dry period in January and February, water levels remained higher than from March to April, characterized by lower rainfall. This analysis suggests that factors beyond precipitation, such as groundwater interaction, evaporation, vegetation cover, and climate changes, play a significant role in determining Villu water levels. Rainfall during the rainy season replenishes shallow aquifers, with water gradually seeping into the lakes during subsequent dry periods, as noted by Maggirwar and Umrikar (2011). NDVI classification revealed four land cover classes surrounding the Villu throughout the year: soil and sand area, shrub and grassland, sparse vegetation, and dense vegetation. Table 1 presents the percentage area of each class throughout the year. Sparse and dense vegetation displayed a consistent pattern across all five villus. However, sand and soil areas, along with shrub and grassland, exhibited distinct variations among the five villus. Sparse vegetation peaked in March – April and reached its lowest point in July – August, while dense vegetation followed an opposing trend, with the highest density observed in July to August and the lowest in March to April. The changes in sand and soil area throughout the year for five Villu did not exhibit any discernible significant pattern (Table 1). This lack of pattern may be attributed to the variations in the open area surrounding each Villu. Sparse vegetation exhibited a significant pattern across all five Villu ecosystems. From July to August, they consistently displayed the lowest coverage of sparse vegetation in all the villus, coinciding with a no-table drought in the study area. This prolonged dry period may have caused the drying out of sparse vegetation surrounding the Villus, resulting in a more level terrain.

Conversely, the highest coverage of sparse vegetation was observed from March to April in all Villu ecosystems. This increase in vegetation coincides with the heavy rain period, particularly in December, when grass seeds and dried vegetation start to reemerge. During January and February, when water levels in the Villus were high, the emerged plants had ample water supply. Furthermore, January and February constituted a short drought period, which helped the plants receive sufficient sunlight. These favorable conditions may have contributed to plant growth during this period. Throughout

March and April, sparse vegetation exhibited continuous growth and reached its peak level. Dense vegetation displayed a pattern opposite to the pattern of sparse vegetation. While sparse vegetation exhibited the highest percentage of the mean cover area from March to April, dense vegetation cover showed the lowest coverage during this period.

Furthermore, from July to August, sparse vegetation cover showed the lowest percentage of coverage, while dense vegetation exhibited the highest coverage rate. Gunarathne and Perera (2014) indicated leaf fall in many tropical plant species occurs during the dry period. In contrast, leaf bud breaking and the formation of young foliage occur during high rainfall. However, the observed highest dense vegetation cover during the dry period of July to August in the study area suggested that the species in the WNP may be able to tolerate prolonged drought conditions. Additionally, the flowering and fruiting in dry forest species occur during the rainy season (Gunarathne and Perera, 2014). The lowest dense vegetation cover observed from March to April can be attributed to the replacement of flowers and fruits in these species, which reduces leaf coverage. However, specific studies on leaf falling and flowering patterns of species in the dry zone forests have not yet been conducted. Therefore, further investigation into this phenomenon is required to enhance the knowledge about plant species in the dry zone forest in Sri Lanka.

3.3 Water quality parameters

Tables 2 and 3 show the spatial variability of water quality parameters within the five villus during the dry and rainy seasons. Notably, all water quality parameters, except nitrate concentration, displayed significant spatial disparities among the five Villu during both periods (ANOVA, Tukey's pairwise comparison, $p < 0.05$). Kokkare Villu and Mahapatessa Villu consistently exhibited higher surface water temperatures than the other villus. This observation holds significant implications for various ecological aspects, including lake water quality and the growth and reproduction of aquatic organisms, as highlighted by Peng et al. (2022). Factors such as solar radiation, water depth, surface area, and vegetation cover contribute to these temperature variations. Intriguingly, Kokkare Villu, despite its considerable distance from the sea, exhibited the highest salinity levels throughout dry and rainy periods. This finding is remarkable since salinity levels in the region are generally influenced by proximity to the sea. Water in the Kokkare Villu can be classified as highly saline, surpassing the threshold values: freshwater < 1 g/L, slightly saline water – (1-2) g/L, moderately saline water > 2 g/L and highly saline water > 3g/L (Nahian et al., 2018). The Mahapatessa Villu and Kumbuk Villu showed slightly saline water levels during dry and rainy periods. LunuVila Villu and Borupan Villu, while slightly saline during the dry period, transitioned to freshwater conditions during the rainy season (Table 2 and Table 3). It is essential to recognize that villus are closed ecosystems with no external water inflow, and Katz (1975) attributed their salinity to underlying limestone. Thus, the observed decrease in salinity during the rainy season (Kokkare Villu salinity reduction percentage - 16.28%, LunuWila Villu salinity reduction percentage – 40.00%, Borupan Villu salinity reduction percentage – 55.56%, Kumbuk Villu salinity reduction percentage – 21.43%, and Mahapatessa Villu salinity reduction percentage – 21.43%) can be attributed to the dilution of sodium chloride within the villus. Moreover, Kokkare Villu exhibited significantly higher pH (dry period - 9.3±0.4, rainy period- 9.5±0.029), Dissolved Oxygen (DO) (dry period - 7.2±0.7 mg/L, rainy period – 11.1±1.0 mg/L), conductivity (dry period - 7845±479 μS/cm, rainy period – 7062±79 μS/cm), and salinity (dry period - 4.3±0.2 ppt, rainy period - 3.6±0.01 ppt) levels than the other villus during dry and rainy periods (Table 2 and Table 3). Across all five villus, water temperature, conductivity, and salinity exhibited a decrease. At the same time, DO, total phosphate concentration, and chlorophyll concentration increased during the rainy period compared to the dry period (Table 2 and Table 3, ANOVA, Tukey's pairwise comparison, $p < 0.05$).

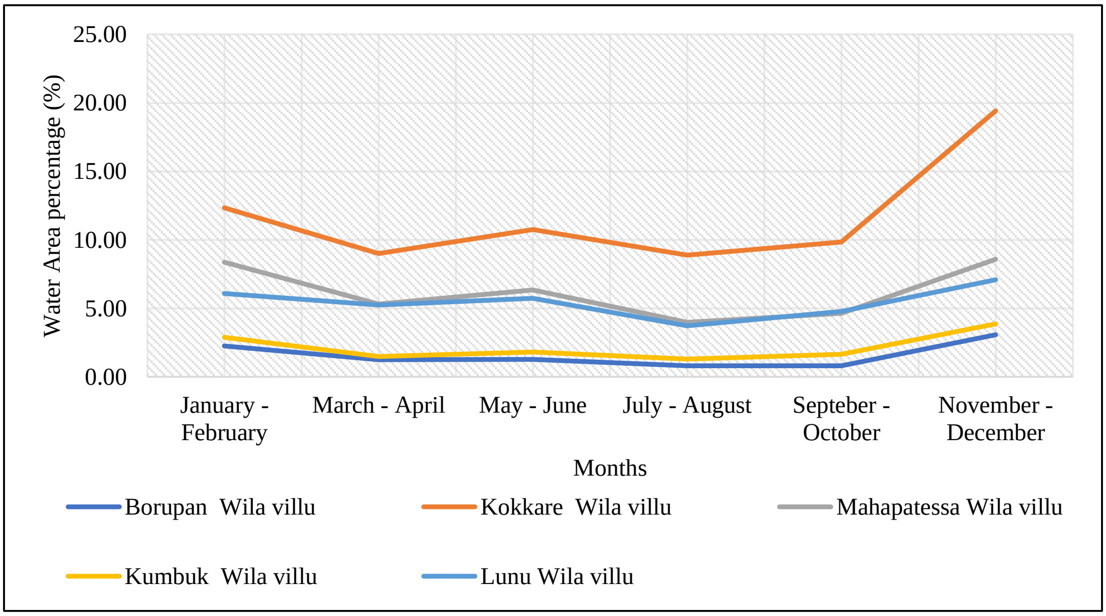


Fig. 2. Water area percentage variation in selected five villus

Table 1. Percentage area values of the four classes of NDVI, which were recorded for each Villu during each period

Villu	**January - February**	**March – April**	**May – June**	**July - August**	**September - October**
Sand and Soil area percentage					
Borupan Villu	1.74	1.31	2.52	0.74	2.12
Kokkare Villu	1.11	6.65	1.15	1.01	1.18
Kumbuk Villu	2.08	1.30	2.61	0.60	1.67
LunuVila Villu	3.72	4.16	3.26	2.81	1.88
Mahapatessa Villu	3.41	3.79	3.86	2.54	3.65
Shrub and grassland area percentage					
Borupan Villu	2.43	4.23	6.20	3.45	4.54
Kokkare Villu	1.71	2.74	2.70	2.62	3.62
Kumbuk Villu	1.98	3.66	4.53	2.50	4.60
LunuVila Villu	1.85	4.59	3.33	1.68	3.65
Mahapatessa Villu	2.15	4.25	3.53	3.76	7.90
Sparse vegetation area percentage					
Borupan Villu	27.37	64.94	33.90	6.39	18.09
Kokkare Villu	25.03	57.35	32.42	9.96	13.43

Kumbuk Villu	25.81	47.84	8.91	6.81	20.97
LunuVila Villu	25.68	67.91	36.11	6.45	11.84
Mahapatessa Villu	24.60	68.53	32.55	6.41	13.19
Dense vegetation area percentage					
Borupan Villu	67.87	29.41	57.02	89.14	74.70
Kokkare Villu	60.48	27.71	52.39	75.89	71.48
Kumbuk Villu	67.33	25.28	55.24	89.16	72.38
LunuVila Villu	65.32	21.59	54.37	86.35	79.22
Mahapatessa Villu	65.44	20.70	57.22	84.83	72.61

In adherence to the water quality standards stipulated by the Central Environmental Authority (2019) of Sri Lanka for inland waters conducive to aquatic life, the following criteria must be satisfied: total nitrate concentration ≤10 mg/L, total phosphorous (TP) concentration ≤0.4 mg/L, dissolved oxygen content ≥5 mg/L, BOD ≤ 4 mg/L, and pH within the range of 6 - 8.5 (Central Environmental Authority, 2019). The findings of this research reveal that total phosphate concentration values consistently exceeded the prescribed limits across all five villus during both dry and rainy seasons. However, the nitrate concentration remained within acceptable limits. Dissolved oxygen concentration during the rainy period exceeded the minimum requirements in all five Villus (Kokkare Villu – 11.1 mg/L, LunuVila Villu – 5.3 mg/L, Borupan Villu – 8.6 mg/L, Kumbuk Villu – 7.3 mg/L, Mahapatessa Villu – 9.6 mg/L). However, during the dry season, it fell below the stipulated threshold in LunuVila Villu, Borupan Villu, and Kumbuk Villu.BOD levels, in compliance with the standards varied among the villus. Borupan Villu, Kumbuk Villu, and Mahapatessa Villu consistently adhered to the prescribed limits in rainy and dry periods. However, LunuVila Villu exceeded the limits for BOD concentration during both seasons, and Kokkare Villu did so specifically during the rainy period (Table 2 and Table 3).

3.4 Geostatistical Analysis and Moran's Index

Tables 4 and 5 provide Moran's I statistic values for the examined water quality parameters during the dry and rainy periods. The interpolated maps for the variation of water quality parameters during the rainy and dry periods are given in Figures 3,4,5,6,7,8,9,10, and 11.

According to the distribution patterns inferred from Moran's I statistic, all water quality parameters exhibited a positive Moran's I statistic, indicating a clustered distribution pattern. The observed variations in the interpolated maps (Fig 3, Fig 4, Fig 5, Fig 6, Fig 7, Fig 8, Fig 9, Fig 10, Fig 11, Table 4, and Table 5) align with the distribution patterns elucidated by the Moran's I statistic. Higher Moran's I statistic values indicate more pronounced clustering patterns (Weerasinghe and Handapangoda, 2019). The findings of this study show that parameters with elevated Moran's I statistic values exhibit substantial clustering in the interpolation maps. The interpolated prediction maps for water quality trends encompass various parameters, with Fig. 11, Fig. 10, and Fig. 9 specifically illustrating Chlorophyll-a, total dissolved phosphorous concentration, and nitrate concentrations. Additionally, Fig. 3, Fig 4, Fig 5, Fig 6, Fig 7, and Fig 8 depict the interpolated prediction maps for Temperature, pH, Salinity, TDS, Conductivity, and BOD. These maps collectively highlight discernible patterns in water quality trends across the studied villus. Notably, Kokkare Villu consistently exhibits higher values for pH, conductivity, salinity, temperature, and TDS, as depicted in Figures 4, Fig 7, Fig 5, Fig 3, and 6. However, when focusing on eutrophication-related water quality parameters, Mahapatessa Villu emerges with a higher distribution trend of Chlorophyll-a during the dry period, while Borupan Villu (Fig 11) displays this trend during the rainy season. Total dissolved phosphorous concentration demonstrates an elevated presence in Kumbuk Villu during the dry period, whereas LunuVila Villu exhibits a similar trend during the rainy season. Nitrate concentration was higher in Borupan Villu compared to other villus during both periods, as depicted in Fig 9.

Table 2. Spatial variation of mean ± standard deviation of water quality

Parameter	Kokkare Villu	LunuVila	Borupan Villu	KumbukVila	Mahapatessa Villu
Water temperature (°C)	36.1±0.9^{a}	29.2±0.7^{bc}	27.2±0.5^{c}	31.2±0.1^{b}	36.3±0.3^{a}
pH	9.3±0.2^{a}	9.1±0.1^{a}	8.7±0.7^{b}	9.0±0.2^{a}	9.2±0.1^{a}
DO (mg/L)	7.2±0.9^{a}	3.5±0.8^{b}	2.2±0.5^{bc}	0.01±0.5^{c}	6.4±0.5^{a}
Conductivity (µS/cm)	7845.0±392.3^{a}	2922.0±117.6^{b}	3369.0±337.2^{b}	2692.8±39.6^{b}	2763.0±45.6^{b}

Salinity (g/L)	4.3±0.2^{a}	1.5±0.1^{b}	1.8±0.2^{b}	1.4±0.02^{b}	1.4±0.1^{b}
BOD (mg/L)	3.2±0.2^{b}	5.1±0.3^{a}	2.7±0.3^{b}	0.8±0.1^{c}	3.3±0.2^{b}
Nitrate concentration (mg/L)	1.0±0.5^{a}	1.0±0.2^{a}	1.7±0.1^{a}	0.9±0.3^{a}	0.9±0.2^{a}
Dissolve Phosphate concentration (mg/L)	1.6±0.1^{b}	2.1±0.3^{ab}	0.5±0.1^{c}	2.7±0.4^{a}	1.2±0.1^{bc}
Chlorophyll-a concentration (mg/L)	0.4±0.1^{b}	1.2±0.1^{b}	1.2±1.2^{a}	1.4±0.2^{b}	0.4±0.1^{b}
Water temperature (°C)	36.1±0.9^{a}	29.2±0.7^{bc}	27.2±0.49^{c}	31.2±0.1^{b}	36.3±0.3^{a}

Table 3. Spatial variation of mean ± standard deviation of water quality parameters at each Villu during the rainy period. For each parameter, mean values indicated by different superscript letters at each row are significantly different from each other (ANOVA, Tukey's pairwise comparison; n = 6).

Parameter	Kokkare Villu	LunuVila	Borupan Villu	KumbukVila	Mahapatessa Villu
Water temperature (°C)	28.4±1.2a	26.2±0.4^{a}	27.5±0.7^{a}	27.8±0.1^{a}	27.8±0.3^{a}
pH	9.5±0.01a	8.2±0.3^{c}	9.2±0.2^{ab}	8.8±0.1^{bc}	9.0±0.02^{ab}
DO (mg/L)	11.1±1.2a	5.3±0.4^{c}	8.6±0.5^{abc}	7.3±0.9^{bc}	9.6±0.7^{ab}
Conductivity (µS/cm)	7062.0±172.3^{a}	1980.0±101.7b	1759.5±62.5b	2181.2±55.2b	2131.8±74.1b
Salinity (g/L)	3.6±0.03a	0.9±0.09^{b}	0.8±0.2^{b}	1.1±0.01^{b}	1.1±0.02^{b}
BOD (mg/L)	6.9±0.4a	1.2±0.1^{c}	2.8±0.5^{b}	1.1±0.2^{c}	1.2±0.1^{c}
Nitrate concentration (mg/L)	1.4±0.3a	0.7±0.1^{a}	1.4±0.4^{a}	1.2±0.3^{a}	0.9±0.2^{a}
Dissolve Phosphate concentration (mg/L)	3.6±0.1b	6.3±0.8^{a}	4.1±0.5^{a}	3.8±0.4^{a}	4±0.3^{a}
Chlorophyll-a concentration (mg/L)	7.0±0.3b	3.5±1.1^{a}	24.1±5.6^{b}	2±0.7^{b}	6.8±2.8^{b}
Water température (°C)	28.4±1.2a	26.2±0.4^{a}	27.5±0.7^{a}	27.8±0.1^{a}	27.8±0.3^{a}
Total Dissolve Solid (mg/L)	9.5±0.01a	8.2±0.3^{c}	9.2±0.2^{ab}	8.8±0.09^{bc}	9±0.02^{ab}

Table 4. Variation of Moran's Index for each water quality parameter during the dry season in the study period

Parameter	Moran's Index	Expected Index	Variance	Z Score	P value	Distribution type
Water temperature	0.954042	-0.000546	0.000279	57.157357	0.000000	Clustered
pH	0.944872	-0.000546	0.000279	56.649575	0.000000	Clustered
Salinity	0.946702	-0.000546	0.000279	56.758044	0.000000	Clustered
TDS	0.944872	-0.000546	0.000279	56.649575	0.000000	Clustered
Conductivity	0.942884	-0.000546	0.000279	56.531446	0.000000	Clustered
BOD5	0.932348	-0.000546	0.000279	55.862626	0.000000	Clustered
Nitrate	0.919359	-0.000546	0.000279	55.081156	0.000000	Clustered
Phosphate	0.921337	-0.000546	0.000279	55.210918	0.000000	Clustered
Chlorophyll a	0.935036	-0.000546	0.000278	56.071687	0.000000	Clustered
DO	0.945316	-0.000546	0.000279	56.646208	0.000000	Clustered

Table 5. Variation of Moran's Index for water quality parameter during the rainy season in the study period

Parameter	Moran's Index	Expected Index	Variance	Z Score	P value	Distribution type
Water temperature	0.93827	-0.000546	0.000279	56.22779	0.0000	Clustered
pH	0.950987	-0.000546	0.000279	56.983382	0.0000	Clustered
Salinity	0.938488	-0.000546	0.000279	56.265971	0.0000	Clustered
TDS	0.942409	-0.000546	0.000279	56.502539	0.0000	Clustered
Conductivity	0.940414	-0.000546	0.000279	56.382712	0.0000	Clustered
BOD5	0.953603	-0.000546	0.000279	57.160676	0.0000	Clustered
Nitrate	0.923132	-0.000546	0.000279	55.318623	0.0000	Clustered
Phosphate	0.942887	-0.000546	0.000279	56.496493	0.0000	Clustered
Chlorophyll a	0.93584	-0.000546	0.000278	56.11026	0.0000	Clustered
DO	0.926435	-0.000546	0.000279	55.509434	0.0000	Clustered

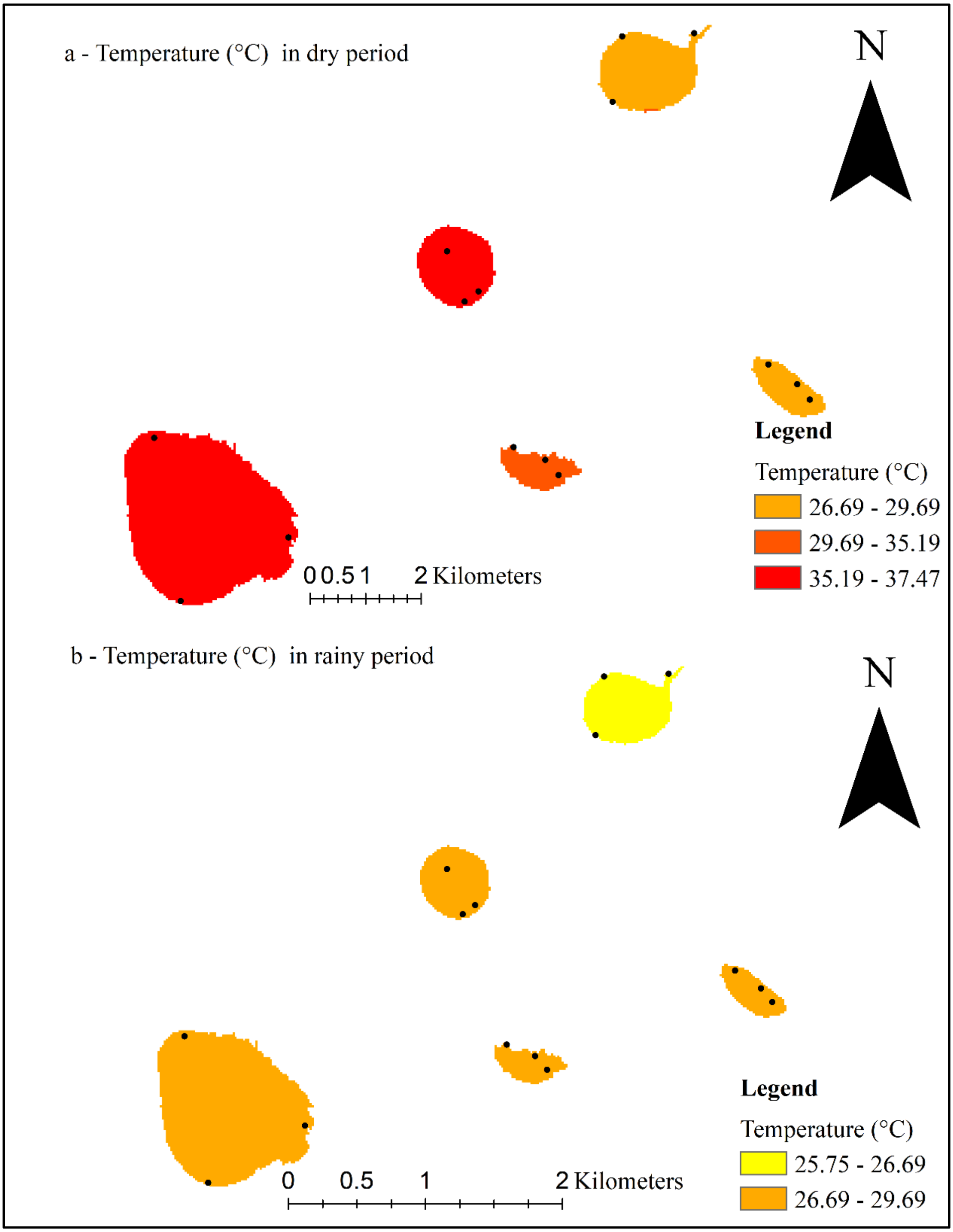


Fig. 3. Spatial and temporal variations of water temperature °C in selected five villus

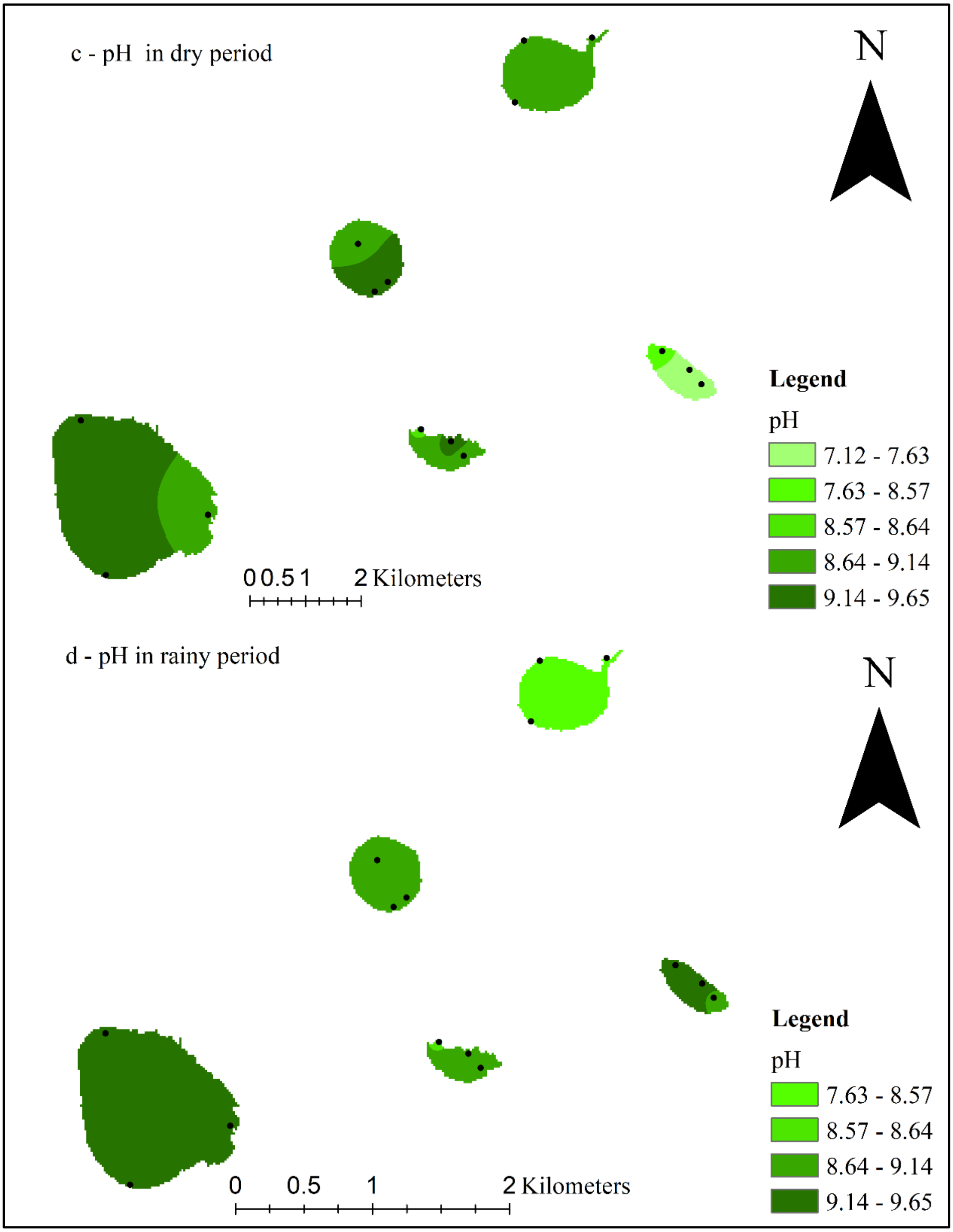


Fig. 4. Spatial and temporal variations of water pH in selected five Villus

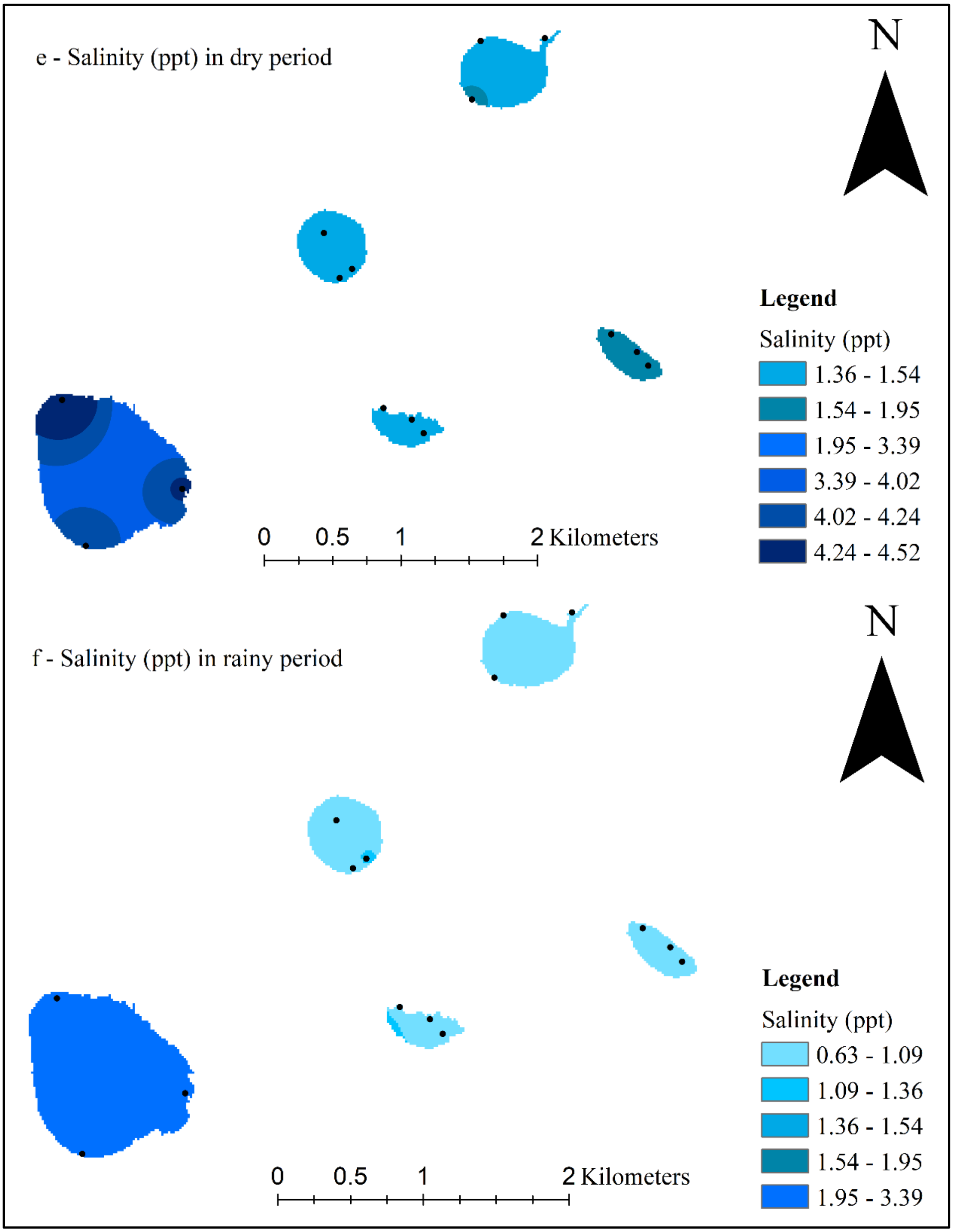


Fig. 5. Spatial and temporal variations of salinity (ppt) in selected five Villus

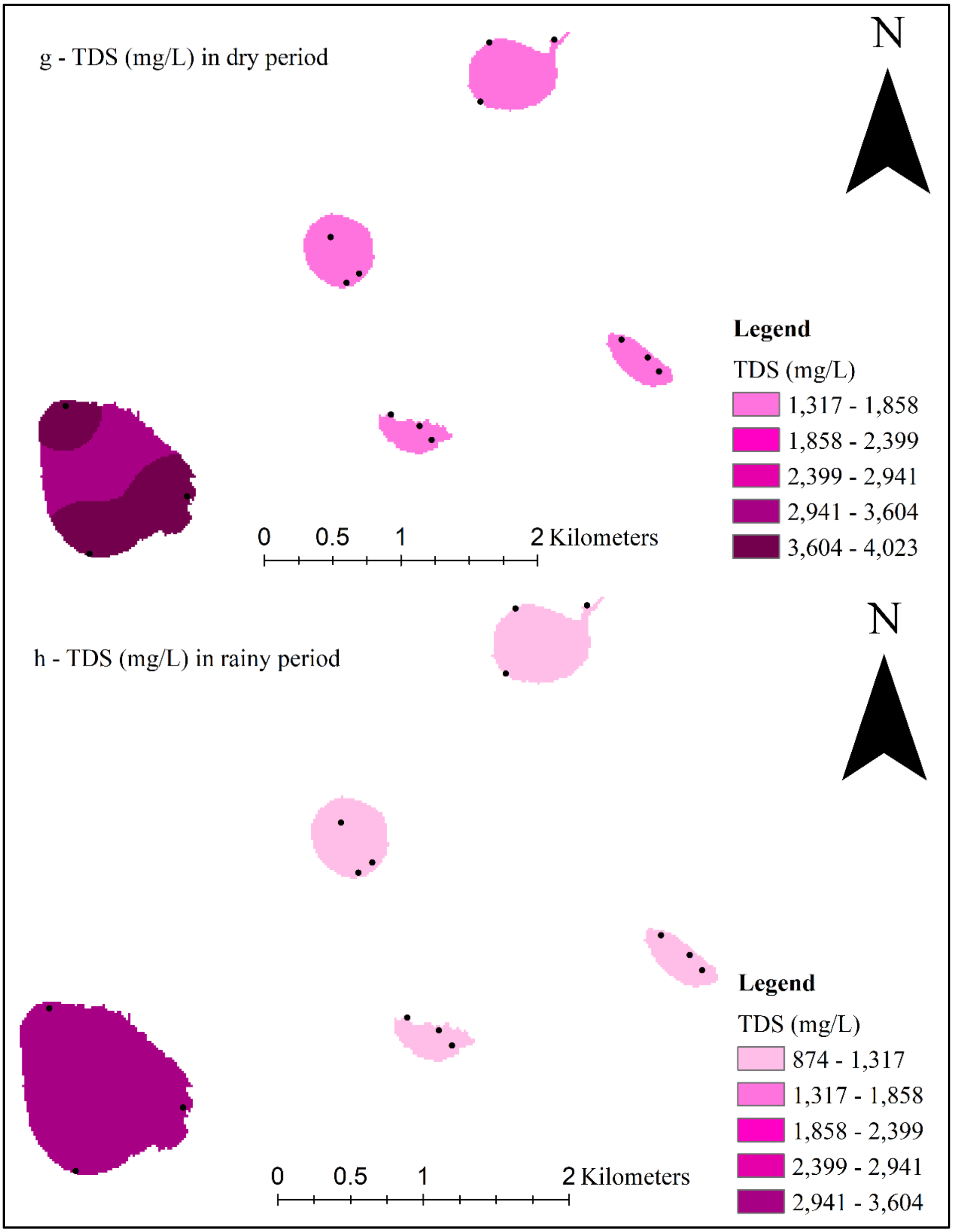


Fig. 6. Spatial and temporal variations of TDS (mg/L) in selected five villus

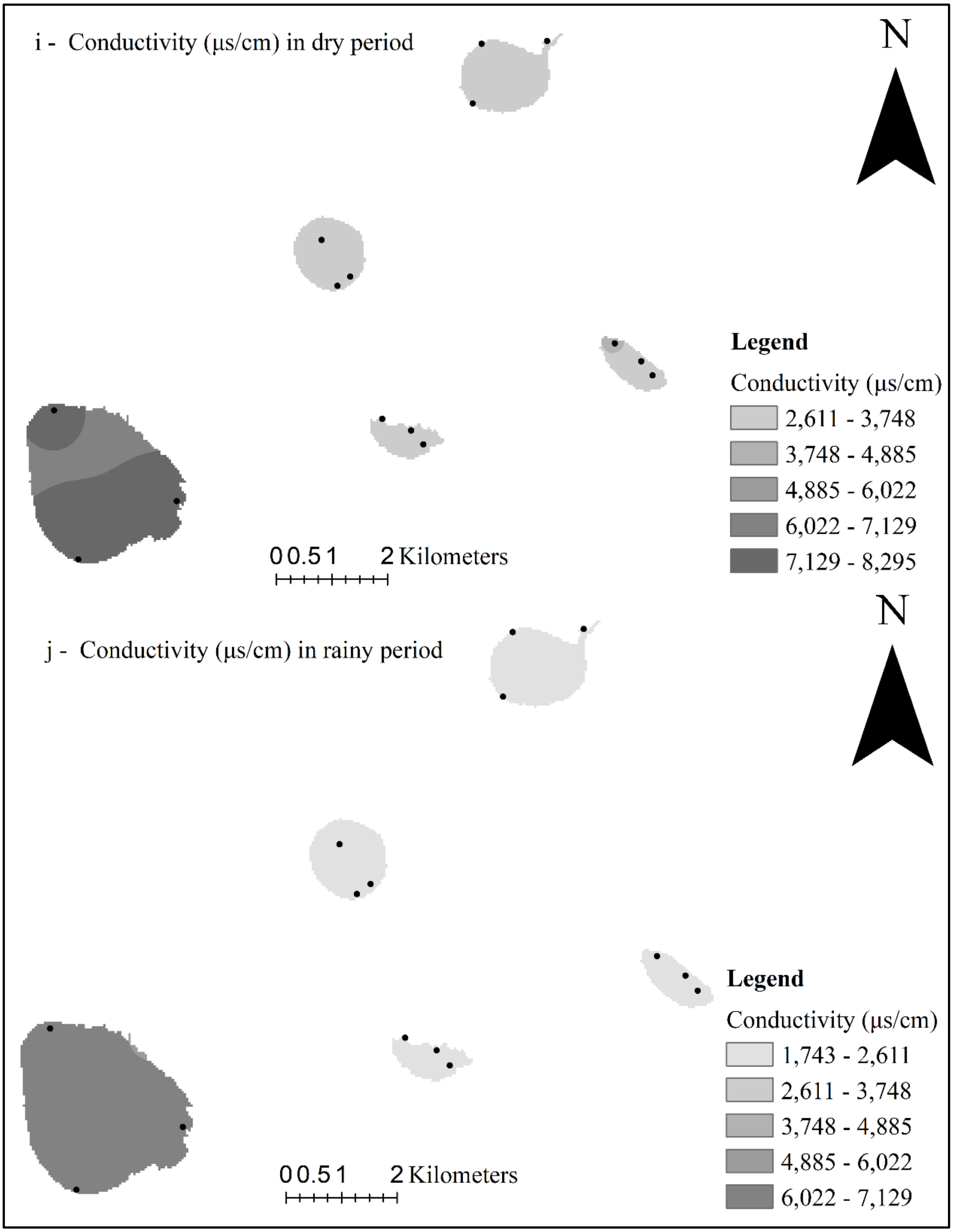


Fig. 7. Spatial and temporal variations of conductivity (µs/cm) in selected five villus

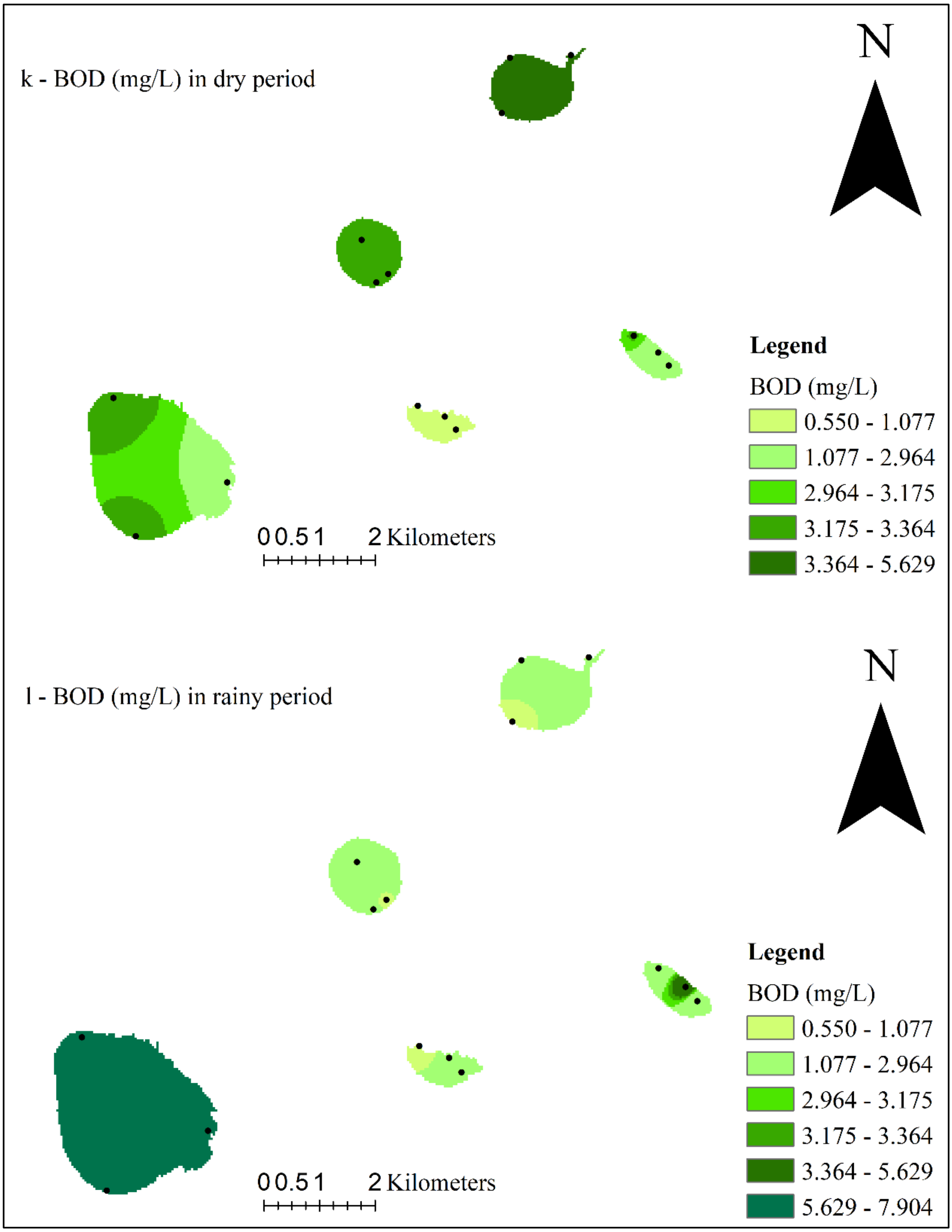


Fig. 8. Spatial and temporal variations of BOD (mg/L) in selected five Villus

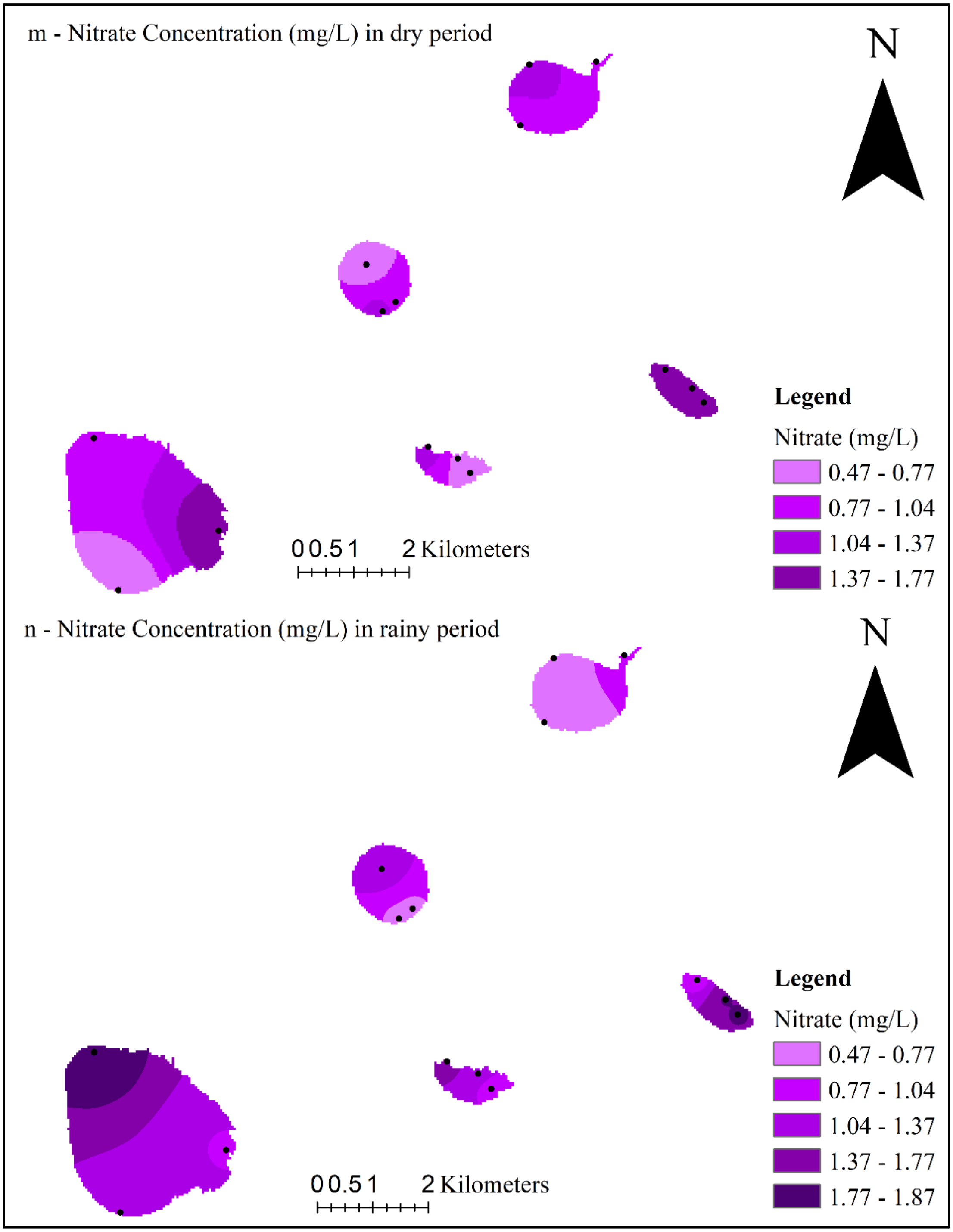
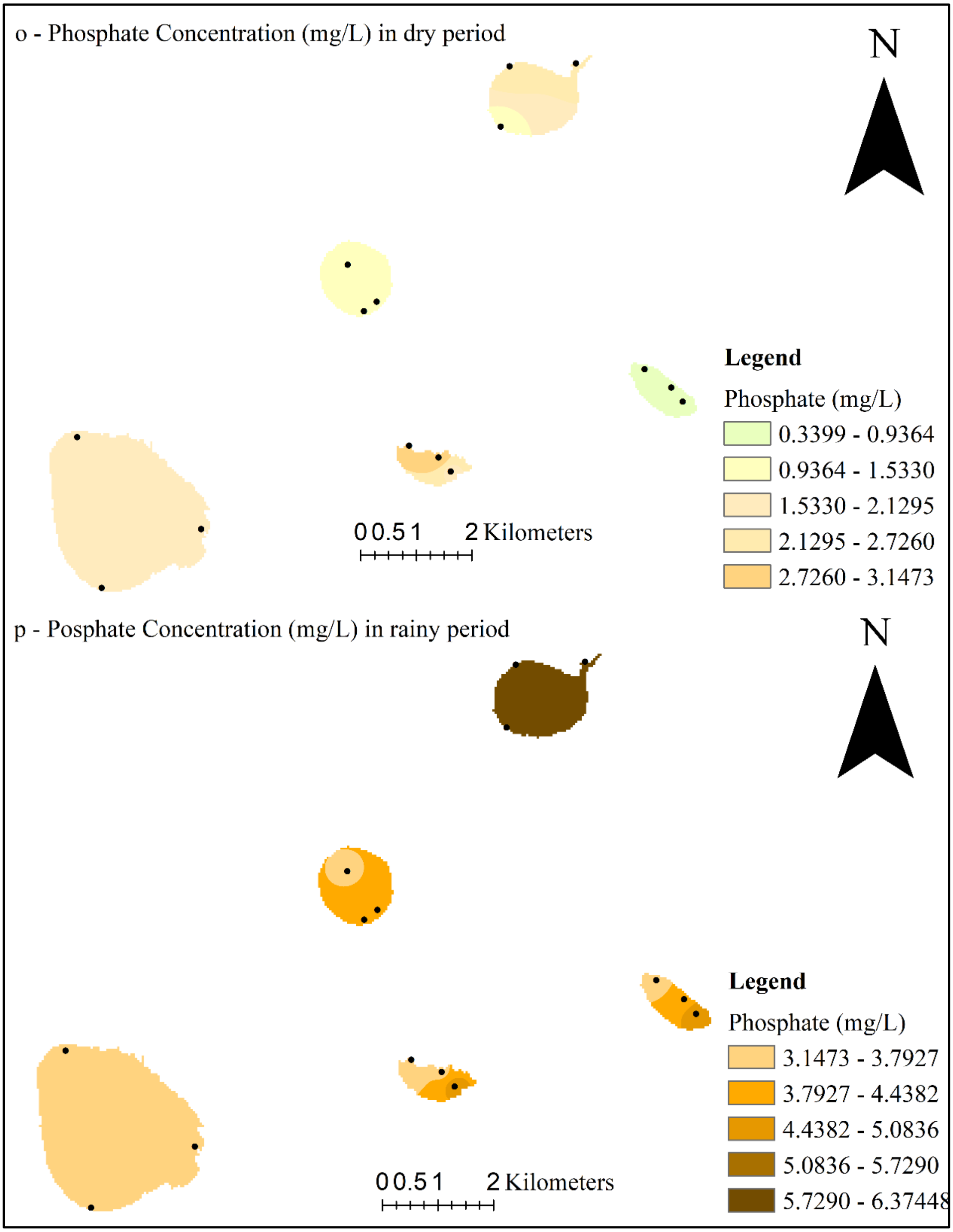


Fig. 9. Spatial and temporal variations of nitrate concentration (mg/L) in selected five Villus



o - Phosphate Concentration (mg/L) in dry period

p - Posphate Concentration (mg/L) in rainy period

Fig. 10. Spatial and temporal variations of phosphate concentration (mg/L) in selected five Villus

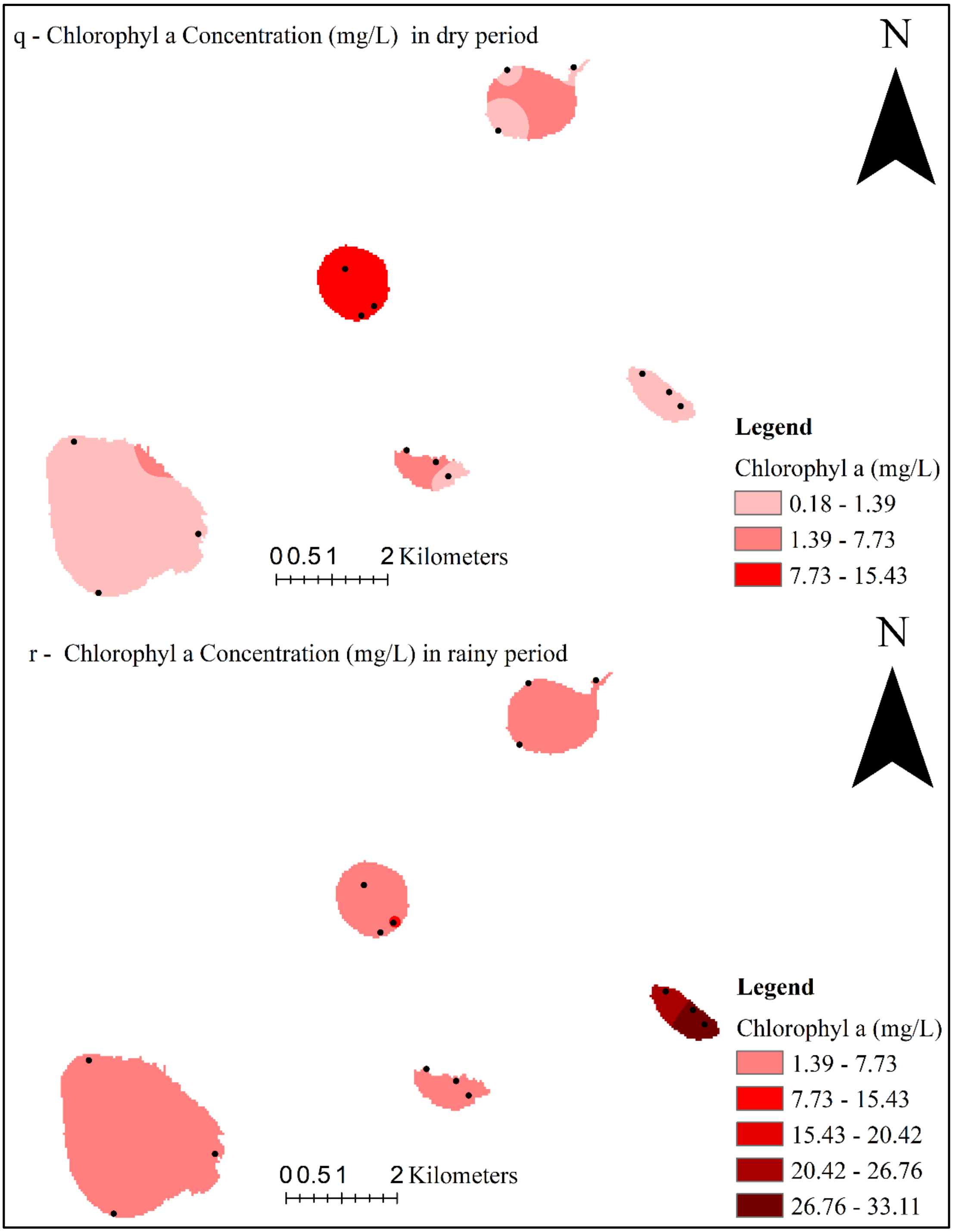


Fig. 11. Spatial and temporal variations of chlorophyll a concentration (mg/L) in selected five Villus

3.5 Relationship between shrub and grassland vegetation changes with water quality parameters

The water quality parameters exhibited no significant correlation (Table 6) with changes in associated grassland areas (Pearson Correlation, $p > 0.05$). This correlation suggests that additional factors, such as soil conditions, nutrient availability, and air temperature, may influence changes in the grassland areas.

Table 6. Correlation between water quality parameters and grass area percentage values (n=10)

Parameter	**Dry period**		**Rainy period**	
	Pearson's correlation	**P - value**	**Pearson's correlation**	**P - value**
Water temperature (°C)	-0.116	0.749	0.337	0.340
pH	-0.185	0.609	0.132	0.716
DO (mg/L)	0.153	0.674	0.199	0.582
Conductivity (µS/cm)	-0.202	0.577	-0.109	0.763
Salinity (g/L)	-0.291	0.415	-0.154	0.670
BOD (mg/L)	-0.586	0.075	-0.258	0.472
Nitrate concentration (mg/L)	0.610	0.061	0.458	0.148
TDS (mg/L)	-0.490	0.150	-0.004	0.991
Dissolve Phosphate concentration (mg/L)	-0.236	0.512	-0.509	0.133
Chlorophyll-a concentration (mg/L)	-0.081	0.823	0.187	0.605

4 CONCLUSION & RECOMMENDATIONS

This study delves into the unique Villu ecosystem within Sri Lanka's Wilpattu National Park, a designated Ramsar site. Through a combination of remote sensing techniques and ground data, it comprehensively examines water quality, vegetation dynamics, and land cover changes from 2019 to 2023. Key findings reveal significant seasonal fluctuations in water levels and vegetation density across the villus, as evidenced by NDVI and NDWI analyses. Spatial assessment using Moran's Index highlights distinct clusters of water quality parameters, with Kokkare Villu demonstrating elevated salinity levels. Notably, shifts in Villu-associated vegetation show no significant correlation with water quality parameters. The study underscores the utility of satellite-based analysis for effective wetland management and emphasizes its pivotal role in monitoring water areas and associated vegetation dynamics.

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