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ENVIRONMENTAL PARAMETERS AND PHYTOPLANKTON COMMUNITY QUALITY: IMPLICATIONS FOR FOOD SAFETY IN COASTAL COMMUNITIES

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ABSTRACT

This study aimed to evaluate environmental parameters and phytoplankton quality as well as the implications for the food safety of seafood-consuming coastal communities. The study was conducted in coastal waters of South Sulawesi, Indonesia at four sites (three stations/site): Pangkep (PK), Kuri (KR), Maros (MR), and Tallo (TL) during June, August, and October 2020. Observations formed three spatial clusters: MR1, PK; MR2, MR3, TL; KR (92.5 % similarity), and two temporal clusters: June 2020; August and October 2020 (87.9 % similarity). PCA showed parameters most strongly characterizing TL, KR, and MR (except MR1) were high levels of salinity, nitrate, nitrite, ammonium, silicate, temperature, pH, and abundance of both phytoplankton that can form harmful algal blooms (HABs) and non-HAB forming phytoplankton (non-HABs), with low current velocity. PK was characterized by high current velocity, non-HABs, orthophosphate, ammonium, nitrite, and turbidity with low nitrate and HABs. Main characterizing parameters in the temporal PCA were high current velocity and HABs with low orthophosphate in June 2020; high nitrate, ammonium, orthophosphate, and non-HABs with even lower HABs in August 2020; high turbidity, temperature, and salinity with low pH, nitrite, silicate, and HABs in October 2020. Current velocity (low at TL, KR, MR and high at PK) influenced both non-HABs and HABs. The results indicate that faster currents may have impeded HABs development so that the phytoplankton quality was still good. Therefore, the fish from these waters can be considered safe for human consumption, thereby contributing to maintaining the health of coastal communities.

Keywords: *Environmental, phytoplankton, HABs, seafood safety, coastal communities*

INTRODUCTION

From a marine management perspective, coastal waters have always been a major focus of attention (Khoshravan *et al.*, 2019). The reason is simple; coastal ecosystems are rich in many diverse organisms of economic value (Gaylard *et al.*, 2020; Melet *et al.*, 2020; Mehvar *et al.*, 2018). These resources are a source of income and food security for people living along the coast. In line with population growth and socio-economic development, human activities and resource use in coastal zones are continually increasing (Mylona, 2020), involving increasingly diverse interests and resulting in the emergence of a growing range of problems and influences on the management of coastal areas (Stronkhorst *et al*., 2018).

Various human activities in the coastal zone can create problems in coastal waters, including those associated with aquaculture (Trottet *et al.*, 2021), brackish water ponds (Ahmed *et al.*, 2020), and agriculture (Gopalakrishnan *et* *al.*, 2019). In particular, these activities produce organic and inorganic waste (Abdelfattah, 2021) which eventually reaches the sea through rivers or run-off from land along the coast. The entry of organic and inorganic materials into coastal waters can support ecosystem productivity (St Pierre *et al.*, 2021) or result in pollution and degraded ecosystems (Adyasari *et al.*, 2021), depending on the amount and nature of the input load (Paczkowska *et al.*, 2020) as well as oceanographic (Cuevas *et al.*, 2019). The productive system paradigm will apply if the waters can assimilate or disperse the nutrients and other materials so that levels remain within the tolerance limits of the organisms living there. However, if the assimilation or carrying capacity of the waters is exceeded, a logical consequence will be a shift towards a system degraded by pollution, with negative impacts on the biotic community living in the coastal waters (Tambaru *et al.*, 2021b).

The ongoing accumulation of organic and inorganic materials entering any water body will lead to changes in the physical, chemical, and biological character of the waters in question (Rustiah *et al.*, 2019). Such conditions can be exacerbated by many anthropogenic activities, including the loading and unloading of ships (I Khedr *et al.*, 2019) and mining (Mavraganis *et al.*, 2020) that do not comply with environmental ethics. Coastal abrasion can also have a negative impact on coastal waters (Istijono *et al.*, 2018). Such situations can affect the lives and livelihoods of people living in coastal communities, especially fishers who depend on the harvest of marine resources.

Organic matter that has entered coastal waters then undergoes decomposition processes which ultimately affect the concentration of inorganic materials, including nutrients such as nitrogen (N), phosphorus (P), and silica (Si) which play an important role in stimulating the growth of photosynthetic organisms (Tambaru *et al.*, 2021b). In addition, both organic and inorganic matter also influences light penetration, reducing the depth to which each wavelength can penetrate; while the effect on primary production from photosynthesis can be negative, it can also be positive when harmful ultraviolet (UV) radiation is blocked (Häder and Gao, 2015).

Any decline in the quality of coastal waters can affect living marine resources and may reduce the abundance of key organisms, including phytoplankton which forms the basis of many marine food webs (Lu *et al.*, 2018). Polluted water conditions and imbalances in nutrient concentrations can also promote the growth of dangerous types of phytoplankton, including those that can form harmful algal blooms or HABs (Glibert and Burford, 2017). Harmful phytoplankton includes species that can produce toxins capable of attacking various key systems in humans including the nervous system (Paralytic Shellfish Poisoning, PSP), respiratory system (Amnesic Shellfish Poisoning, ASP), and digestive system (Diarrhetic Shellfish Poisoning, DSP) (Sarkar, 2018). Health problems (poisoning) mostly occur when phytoplankton containing these toxins are consumed (directly or through the food chain) by fish or invertebrates which are then caught and consumed by humans (Abo-Taleb, 2019).

From a public health viewpoint, it is therefore important to monitor the water quality and phytoplankton community composition in coastal waters to ensure the safety of seafood caught in areas where toxic phytoplankton could occur. The purpose of this research was to evaluate the condition of coastal waters in the study area and the implications for the consumption of seafood (fish and invertebrates) on human health through analyzing environmental parameters and the phytoplankton present.

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MATERIALS AND METHODS

Study site and timeframe

The study was conducted in the coastal waters of South Sulawesi, Indonesia. Data on phytoplankton communities and environmental parameters were collected at bimonthly intervals in June, August and October 2020 at four sites along the Makassar Strait coast. These sites were: Tallo (TL), in the northern part of Makassar City; Kuri (KR) and Maros (MR) in Maros Regency; and an area in Pangkep Regency (PK) (Figure 1). At each site the study area was divided into 3 zones, based on distance from the Sulawesi mainland: inner zone (Station 1: 0.5-1 km from shore); middle zone (Station 2: up to 1 km seawards from the inner zone); and outer zone (Station 3: more than 1 km seawards from the inner zone). Laboratory analyses were conducted in the Environmental Chemistry Laboratory, Department of Marine Science, Faculty of Marine Science and Fisheries, Universitas Hasanuddin in Makassar.

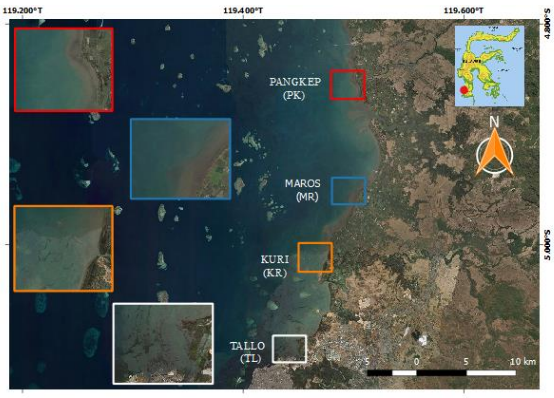


Figure 1. Map of the study sites in South Sulawesi, Indonesia (satellite image source: Google Maps)

Parameters recorded

The parameters recorded included phytoplankton community characteristics and environmental parameters. The former included phytoplankton abundance, overall and by type or taxonomic group. The latter were physical and chemical seawater parameters including nitrate, nitrite, ammonium, orthophosphate, and silicate concentrations; temperature, pH, salinity, turbidity and current speed.

Water sample collection

Seawater samples (2 L) were collected at each station during each sampling period using a Horizontal Water Sampler (Apha Van Dorn model LVHA-420) at a depth of 30-50 cm below the sea surface. The water samples were placed in sterile sample bottles and packed in a coolbox filled with ice for transport to the laboratory. The nitrate, nitrite, ammonium, orthophosphate, and silicate concentrations were measured using 250 ml subsamples, while 100 ml subsamples were used to measure turbidity (100ml) and for the phytoplankton analysis (100 ml).

In Situ and *ex situ* water quality parameter measurements

Environmental parameters measured *in situ* at each sampling station were current speed, measured using the Euler method (m/s, calibrated drogue); temperature (^{o}C, thermometer), and salinity (refractometer, ppt). The remaining parameters were measured in the laboratory. The pH and turbidity were measured using the potentiometric and nephelometric methods, respectively, following Strickland and Parsons (1972). The nutrient concentrations were measured following APHA (1989): nitrate with the brucine method, nitrite with the sulphanilamide method, ammonium with the phenate method, orthophosphate with the stannous chloride method, and silicate with the molybdosilicate method.

Phytoplankton abundance and identification

Seawater samples for estimating phytoplankton were prepared following the sedimentation method developed by Uthermol (Vadrucci *et al.*, 2018). Seawater samples (100 ml) to which 5 ml of 1 %

Lugol solution had been added as a preservative (on arrival at the laboratory) were placed in a measuring beaker (with 100 ml graduation) and left for a 7 day settlement period. The supernatant was then siphoned out of the beaker to leave the deposited material or sediment (volume 10 ml) which was placed in a 30 ml sample tube to which 5 drops of Lugol 1% solution were added.

Phytoplankton were counted by placing 1 ml of the deposited sediment in a Sedgwig Rafter Cell (SRC) (Wildlife Supply Company, 1801-G20) using a measuring pipette. The SRC was placed under a binocular microscope (Olympus CX21) at a magnification of 10x10. Phytoplankton abundance was estimated using the sweep method (census) (Rocha et al., 2015). Phytoplankton were identified based on references (e.g. Castellani and Edwards, 2017; Tomas, 1997).

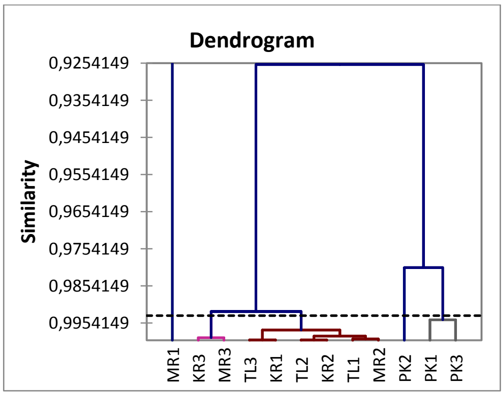
Data analysis

Cluster analysis (Stewart *et al.*, 2012) was used to group the observations into spatial and temporal clusters based on the values of the parameters measured. Principal component analysis (PCA) was used to determine the main parameters characterizing the spatial and temporal clusters (Jollife and Cadima, 2016). The analyses were performed in Microsoft XLStat 2015.

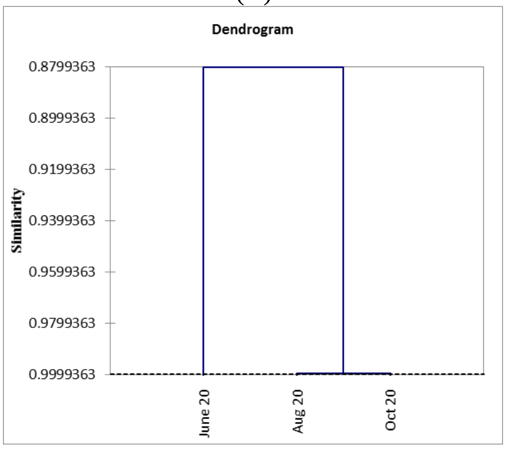
RESULTS

The spatial cluster analyses resulted in three clades with an overall similarity of 92.5 % (Figure 2A), while temporal cluster analysis formed two clades with an overall similarity of 87.9 % (Figure 2B).

The first spatial clade comprised one station at the Maros site (MR1): the second comprised the three Pangkep (PK) stations; and the third clade comprised all three Tallo (TL) and Kuri (KR) stations and the other two Maros (MR) stations. The first temporal cluster comprised observations from June 2020, and the second cluster comprised observations from August and October 2020.



(A)



(B)

Figure 2. Cluster analysis dendrograms based on spasial (A) and temporal (B)

The spatial principle components analysis (PCA) produced four axes with the first four axes representing 83% of the between-station variability in the dataset (Table 1). The temporal PCA produced two axes, representing all (100%) of the between-sampling period variability in the dataset (Table 2).

Table 1. The first four spatial PCA axis eigenvalues and proportion (%) of variability explained

	F1	F2	F3	F4
Eigenvalue	3.868	2.946	1.882	1.285
Variability (%)	32.229	24.553	15.679	10.708
Cumulative %	32.229	56.782	72.462	83.170

The PCA plots based on the four major axes (Table 1) are shown in Figure 3 (spatial PCA). The first two axes described just over half (56.8 %) of the spatial variation, while a considerable proportion (nearly 17 %) of the variation was not described by any of the first four PCA axes.

Table 2. The two temporal PCA axis eigenvalues and proportion (%) of variability explained

	F1	F2
Eigenvalue	7.920	5.080
Variability (%)	60.921	39.079
Cumulative %	60.921	100.000

The main parameters characterizing stations in Tallo, Kuri, and two of the Maros stations (MR2 and MR3) were high salinity, nitrate, nitrite, ammonium, silicate, temperature, pH, and phytoplankton (non-HABs and HABs), with low current velocity. At the Pangkep site, the dominant parameters were high current speed, non-HABs, orthophosphate, ammonium, nitrite, and turbidity, with low nitrate and HABs. One of the three Maros stations (MR1) had characteristics that differed from all other sites with comparatively high current speed, turbidity, nitrate, orthophosphate, non-HABs, pH, and temperature, with relatively low HABs. This station had a higher similarity with the Pangkep (PK) stations than with the other two Maros stations, in particular with regards to the relatively high current speed and turbidity coupled with comparatively low HABs.

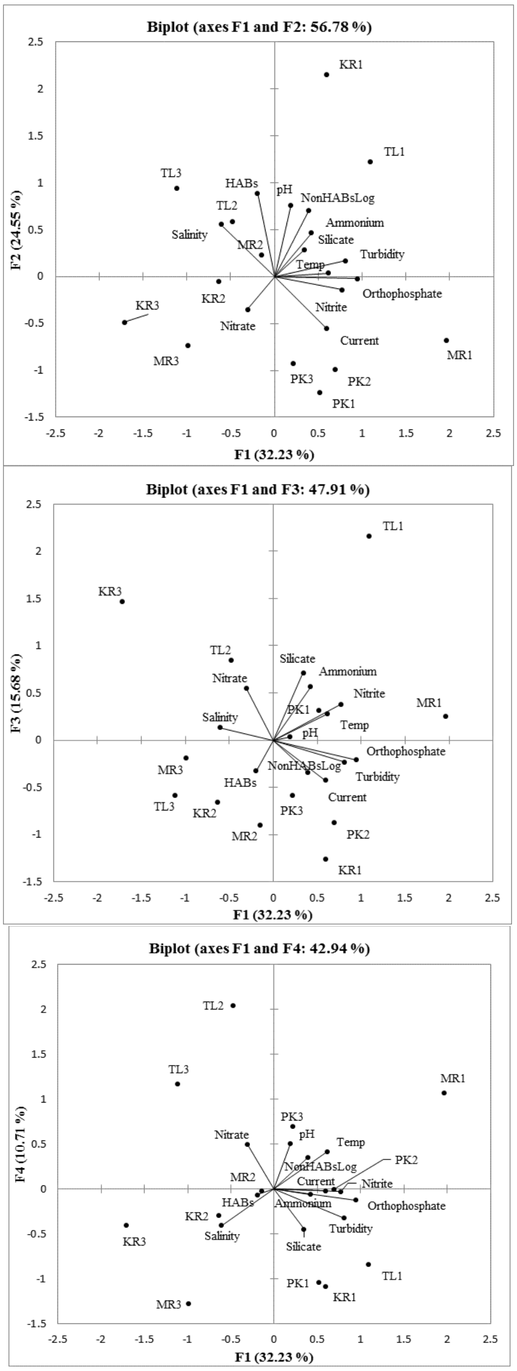
The temporal PCA analysis resulted in two main axes (Table 2) which explained 100% of the variability (Figure 4). In June, the most prominent parameters were relatively high current speed and higher HABs with lower orthophosphate concentrations. August was distinguished by low HABs with high nitrate, ammonium, orthophosphate, and high non-HABs. October 2020 was distinguished by comparatively high turbidity, temperature, and salinity, with relatively low pH, nitrite, and silicate.

DISCUSSION

The similarity was less than 95 % for both spatial and temporal cluster analyses, indicating considerable differences in the environmental parameters measured between sites and between the sampling periods. For the spatial cluster analysis, there is a strong contrast between the two main clusters or clades in the values of some of the main defining parameters. For example, the current velocity was typically weaker than average in the Tallo, Kuri, and Maros (MR2 & MR3) cluster, but stronger than average in the Pangkep cluster, as well as in the singleton cluster MR1. Conversely, phytoplankton abundance, especially for non-HABs, was higher in the Tallo, Kuri, and Maros (MR2 & MR3) cluster than in the Pangkep cluster. This indicates that the stronger current may have hampered phytoplankton growth, especially that of HABs.

Concerning the temporal analysis, the data show that HABs did not become abundant or bloom during any of the observation periods. Even though the June observations were characterized by comparatively higher HABs compared to the August and October observations, the abundances remained low, well below the levels at which dangerous HABs can be formed. While it is possible that coastal seawater conditions in June may have been more conducive to the growth of HABs, it is also possible that the higher abundances of these taxa could have been due to fluctuations in the phytoplankton brought to the area by the prevailing ocean currents (Barlow *et al.*, 2020).

Spatial and temporal variations in current velocity, a key physical parameter in aquatic environments, can have significant effects on the distribution and abundance of marine organisms (Kuhn *et al.*, 2019).



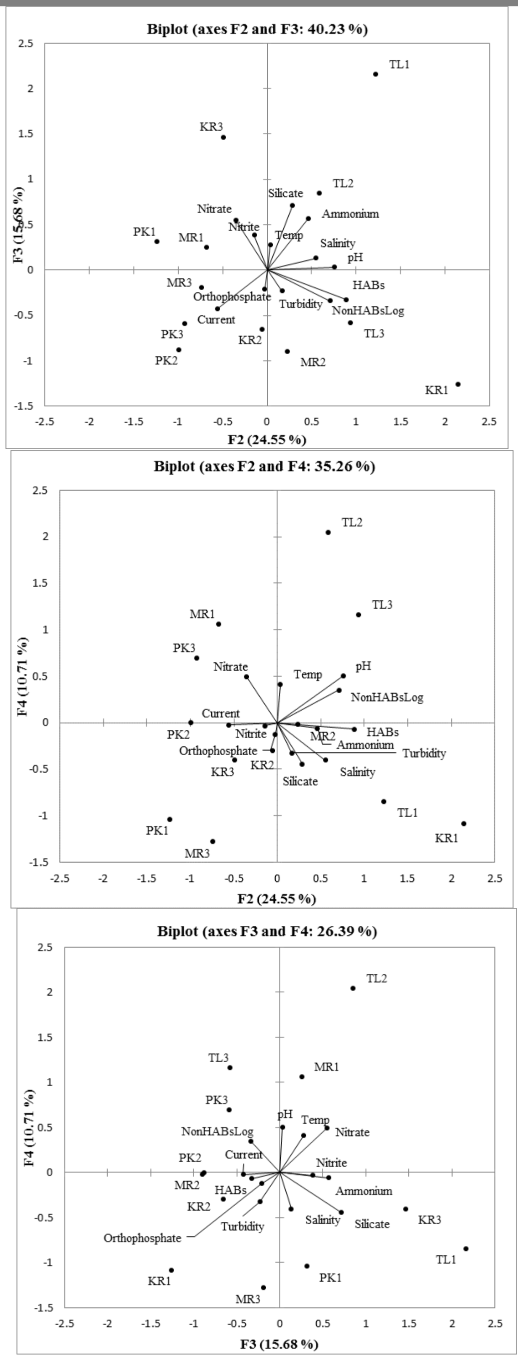


Figure 3. Spatial-based PCA biplot of water quality parameters (F1 to F4)

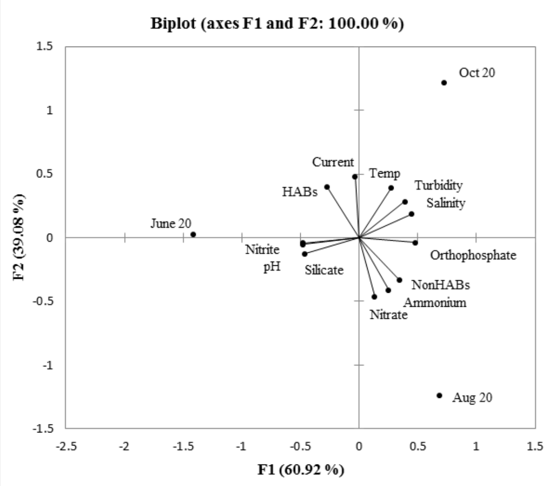


Figure 4. Temporal-based PCA biplot of water quality parameters (Axes F1 and F2)

Currents are part of ocean dynamics and can bring changes as water masses flow into or out of a given area, together with the various materials they carry, including nutrients and biomass, including various types of phytoplankton (Lu *et al*., 2018). The results of this study are consonant with the concept proposed by Cadier *et al*. (2017) and others (e.g Li et *al.*, 2022) that current velocity is a parameter that can become a limiting factor for the development of phytoplankton, especially HABs.

Current velocity is an environmental parameter that affects phytoplankton. According to Chen *et al*., (2021), current velocity is very clearly its effect on phytoplankton distribus, not just nutrients, temperature and salinity. The movement of water masses due to currents certainly has an impact on the number of phytoplankton communities that are carried from one water to another. However, the presence of strong currents does not provide an opportunity for phytoplankton to develop properly due to water conditions that are too turbulent (Xu *et al.*, 2021).

Taking a closer look at some of the characterizing parameters in August 2020 provides insight into the lack of growth of HABs. In addition to the current speed, the results may indicate a paradoxical inability of the HABs to absorb nutrients such as nitrate, ammonium, and orthophosphate which were present in relatively high concentrations. While it is possible that the ability to absorb nutrients was limited due to water movement associated with the high current velocity, the results indicate that the comparatively high nutrient concentrations had a positive impact reflected in the comparatively high of non-HABs which was the strongest characterizing parameter in August 2020. The apparent inability of HABs to develop was most likely further exacerbated at the time of the October observations by the comparatively high turbidity, another defining parameter associated with low HABs (Aslam *et al.*, 2020), and a factor that may have contributed to the prevention of HABs development during the study.

Despite these variations, this study ascertained that, based on the environmental parameters measured, the water quality did not change very much in the study area over the study period. Furthermore, conditions in the coastal waters of northwestern South Sulawesi can still support relatively high of non-HABs; conversely, the abundance of HABs was low (Tambaru *et al.*, 2021a). Of course, it affects the phytoplankton community which still has good quality. These conditions should be conducive to maintaining other marine organisms, including fish and other fisheries commodities (Andrews *et al.*, 2021).

The low level of potentially toxic HABs means that the fish caught by fishermen should be of good quality and safe for human consumption and therefore capable of supporting the nutritional health of coastal communities. However, although the abundance of HABs is still low, observations of waters need to be improved. This is so that the development of HABs can be detected at any time. Its presence is an early warning that the waters are always monitored on an ongoing basis so that the quality of phytoplankton and the food safety of coastal communities are maintained.

CONCLUSION

The Tallo, Kuri, and most of the Maros sites have similar main characteristics, with comparatively high salinity, nitrate, nitrite, ammonium, silicate, temperature, pH, and phytoplankton abundance (mainly non-HABs but also some HABs), with relatively low current velocity. The main characteristics of the Pangkep location were comparatively high current velocity, non-HABs, orthophosphate, ammonium, nitrite, and turbidity, with comparatively low nitrate and HABs.

The typically higher phytoplankton abundance at the Tallo, Kuri and Maros sites compared to the Pangkep site was thought likely to be related to the water movements associated with the stronger currents in Pangkep which could have had a negative impact on phytoplankton growth. This difference was especially marked in potentially HABs.

Arguably the key finding from this study is that the relative and absolute abundance of HABs remained low. This has an impact on the quality of the phytoplankton which is still good. These results mean that fish and other seafood harvested by fishermen should be safe from contamination by HABs and the toxins they produce, thereby supporting the nutritional health of people living in and around the study area.

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