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Monitoring the Billion Trees Afforestation Project in Khyber Pakhtunkhwa, Pakistan through Remote Sensing

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Abstract: The utilization of remote sensing (RS) techniques plays a crucial role in the efficient planning and monitoring of afforestation projects within constrained timeframes. This study evaluates the progress of the Billion Trees Afforestation Project (BTAP) in Dera Ismail Khan (DIK), Khyber Pakhtunkhwa, Pakistan, using RS technology. Geographical positioning systems were employed to delineate the boundaries of the plantation areas, and two temporal Sentinel-2 images from 2016 (the commencement of the plantation) and 2018 were analyzed to calculate the normalized difference vegetation index (NDVI). The results revealed that the survival rate of plantations varied between 37.39% and 85.15%, while the area of unstocked regions ranged from 14.84% to 62.60%. Overall, in 2016, the survival rate was determined to be 61.28%, with 38.72% of the area remaining unstocked. The NDVI values in 2016 ranged from -1 to -0.43, whereas in 2018, they spanned from -0.43 to 0.80, indicating significant progress in plantation growth and a substantial reduction in unstocked areas. The RS-based assessment proved to be highly effective, suggesting its adoption for the rapid detection and evaluation of plantation efforts. It is recommended to use high-resolution satellite images and drone technology to enhance accuracy further. Additionally, measures such as the establishment of closures, pit sowing, appropriate site and species selection, and effective soil and water conservation techniques are essential to maximizing the survival rate of plantations.

Keywords: Billion Trees Afforestation Project; Remote sensing; Plantation assessment; Sentinel-2 images; Normalized difference vegetation index

1 Introduction

Forestry plays an important role in the economy of the country by providing firewood, timber and non-timber forest products. Besides, trees produce oxygen, absorb carbon dioxide, provide a habitat for a large number of wildlife, regulate the supply of water and contribute to the conservation of soil fertility [1, 2]. Forests are recognized as the most cost-effective instruments for achieving the United Nations (UN) Sustainable Development Goals (SDGs) 13 and 15, which pertain to climate change mitigation and biodiversity conservation. Apart from the global measures on the conservation of natural forests for climate change mitigation and biodiversity conservation, the establishment of new plantations has gained significant importance [3]. These plantation projects are now core components of international policies and politics and are gaining strength and momentum globally [4]. Under the umbrella of the Bonn Challenge and the New York Declaration on Forests, political leaders, member countries, multilateral, governmental and non-governmental organizations, and the private sector have been making great progress in achieving the targets [3]. Commitment at national and regional levels has been made to design plantation strategies and policies and many countries have launched massive conservation and restoration plantation projects [5].

These afforestation campaigns at sub-national, national and regional levels have greatly impacted the land cover dynamics and, therefore, their progress needs to be monitored. For this purpose, both inventory and cartographic data are available at national and sub-national levels [6]. However, questions were still raised and faced by the local forest department concerning the progress of these plantations. It is a well-known fact that tree plantation is very easy, but it needs continuous protection from various biotic and abiotic factors and the actual status and success of the plantation site are still questionable. To answer this question, regular field visits are needed physically to verify the situation on the ground, which is very difficult due to the limitations of resources and manpower. To overcome this problem, RS plays an important role in the planning and monitoring of the plantation status within a limited time frame [7–11]. RS represents a useful instrument to monitor the land cover dynamics associated with plantation projects. Both Landsat and Sentinel images are useful tools to monitor land cover trends globally. However, Sentinel images are preferred where high accuracy is needed because of their high resolutions [6]. Apart from land cover trends, RS also provides information on the scale of the success or failure of plantations through different bands of spectral data and can be summarized in the form of different spectral vegetation indices such as NDVI, Enhanced Vegetation Index (EVI) or Normalized Burn Ratio (NBR) [6].

To fulfill the Bonn Challenge commitment, Pakistan has taken different initiatives on the conservation and restoration of forests. As a matter of fact, Pakistan has very low forest cover, mainly due to large parts of the country falling into arid and semi-arid climatic zones. A major portion of the forest is located in the northern parts of the country, which comprise coniferous and scrub forest [12–14]. On the other side, the Pakistani population is continuously increasing beyond the carrying capacity of the forest and other natural resources [15]. In addition, due to low forest cover, Pakistan is at high climate-change risk and needs measures to combat the climate change associated with natural disasters like floods and droughts, etc. [16]. To cope with the very low forest cover and increase the forest cover recently, the government of Khyber Pakhtunkhwa, Pakistan, decided to plant one billion trees through a project called the BTAP to bring the total provincial forest cover from 17% to 22% [17]. The progress monitoring of this plantation project is essential for achieving the goal. Many studies have been carried out in Pakistan using RS-based sensors with various resolutions to assess land cover change dynamics. For instance, high-resolution SPOT-5 satellites were used for the forest cover assessment and other land use changes in the Hindu Kush Mountain ranges of northern Pakistan [13, 14, 18–20]. Similarly, many studies have been reported in Pakistan for quantifying forest cover and other land use changes using medium-resolution Landsat satellite images [21–24]. All the above-mentioned studies in Pakistan were conducted to quantify and assess changes in natural forests. However, status monitoring of ongoing plantation projects has not yet been documented, particularly in the arid or semi-arid climatic zones. Using field visits and RS data, the progress of plantations was assessed and detected in this study using Sentinel-2 satellite images. The main purpose of this study is to find out the current progress of the BTAP from 2016 (date of plantation) to 2018, with the DIK area as the study area of a case study, which is located in Khyber Pakhtunkhwa Province of Pakistan, using temporal Sentinel-2 satellite images. This study aims to assess the stocked and unstocked areas and detect changes in NDVI associated with plantations from 2016 to 2018.

2 Methodology

2.1 Study Sites

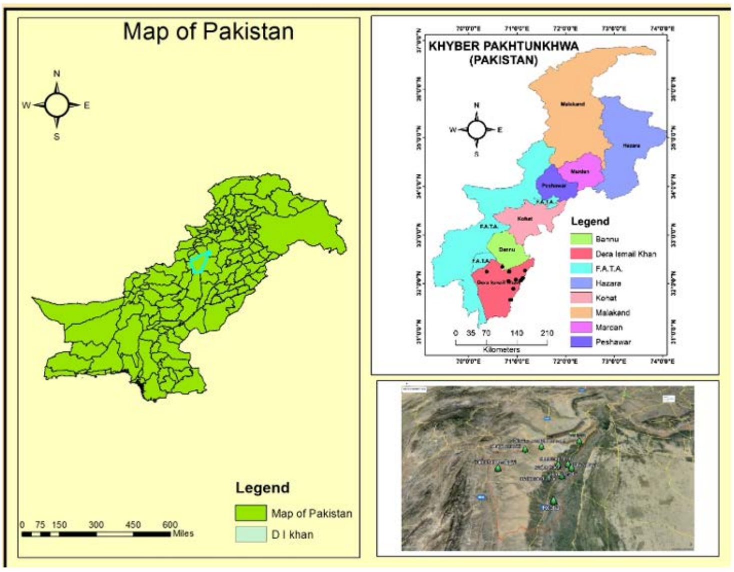


Figure 1. Location maps of plantation/study sites

The study sites are located in DIK, a district of Khyber Pakhtunkhwa Province, Pakistan. The elevation of DIK is about 600 m above sea level, with a total area of 0.7 million ha [25]. The mean temperature in winter varies from

4℃ to 20℃ and the mean summer temperature is from 25℃ to 30℃ [26]. The average annual precipitation of the study area is 268.8 mm. The major rocks in the area include dolomites, limestone and dolomitic limestone [27]. The major tree species of the area include Acacia modesta, Acacia nilotica, Ficus palmate, Monotheca buxifolia, Olea ferruginea, Phoneix dactylifera, Salvadora oleoidies and Zizophus mauritiana, while the major shrubs are Ziziphus nmuuleria, Phlomis satewartii and Dodonaea viscosa [28]. Three main tree species planted in the study area include Eucalyptus camaldulensis, Acacia nilotica, and Acacia modesta. The plantation of the BTAP was carried out in three phases, i.e., phase I (2014-15), phase II (2015-16), and phase III (2016-17). In this study, the phase III area during the period from January 2016 to June 2017 was selected. Ten sites from the total of 68 sites in the area under phase III were selected for this study Figure 1).

2.2 RS Data Acquisition and Processing

Temporal Sentinel-2 satellite images from 2016 to 2018 downloaded from the United States Geological Survey (USGS) website were used to assess the progress of the plantation. The Sentinel-2 satellite was launched in 2013 with a multispectral instrument with 13 spectral bands. The resolution of the bands varies from 10 to 60 m. Out of 13 spectral bands, only 4 bands with 10-m resolution were used in this study. Table 1 shows the details of the satellite images. The quality of the images was ensured by downloading cloud-free images in November. The map was scanned and processed using software. Image preprocessing is a crucial step before classification and change detection. The preprocessing consists of geometric correction (GC), radiometric correction (RC) and atmospheric correction (AC). The GC was performed for the topographic map and ground control point taken by the Global Positioning System (GPS) using ENVI 3.1. The RC and AC were performed through FLAASH and radiometric calibration tools in ENVI 3.1. In order to classify the study area into stocked and unstocked classes, the satellite data was first examined with pre-pixel signatures being given. Then different colors were assigned to each class and supervised classification was carried out through the maximum likelihood algorithm. The accuracy of each image was determined through a confusion matrix. In order to measure the success scale of plantations at respective sites, the NDVI of each site from 2016 to 2018 was also calculated. The four bands, i.e., 2 (blue), 3 (green), 4 (red), and 8 (near-infrared) with 10-m resolution, were stacked together using layer stacking tools in ERDAS IMAGINE software. The NDVI was calculated by using the following formula:

$$NDVI = Near\,Infrared - Red/Near - Infrared + RED \tag{1}$$

Finally, the NDVI difference was calculated by subtracting the NDVI of the image in 2018 from the NDVI of the image in 2016.

$$NDVI(Difference) = (NDVI\,2018 - NDVI\,2016) \tag{2}$$

The resultant difference map pixels with positive, zero, and/or negative values were found. The positive values represent an increased rate, while the zero or negative values show no change in the area. Finally, the percentage of increase or decrease in plantation area was calculated based on the number of pixels falling in positive, zero, or negative values (Table 2).

Table 1. Detailed analysis of RS data

Data	Year of Acquisition	Band Used	Resolution (m)	Source
Sentinel	2016 − 2018	2	10	USGS
		3	10	USGS
		4	10	USGS

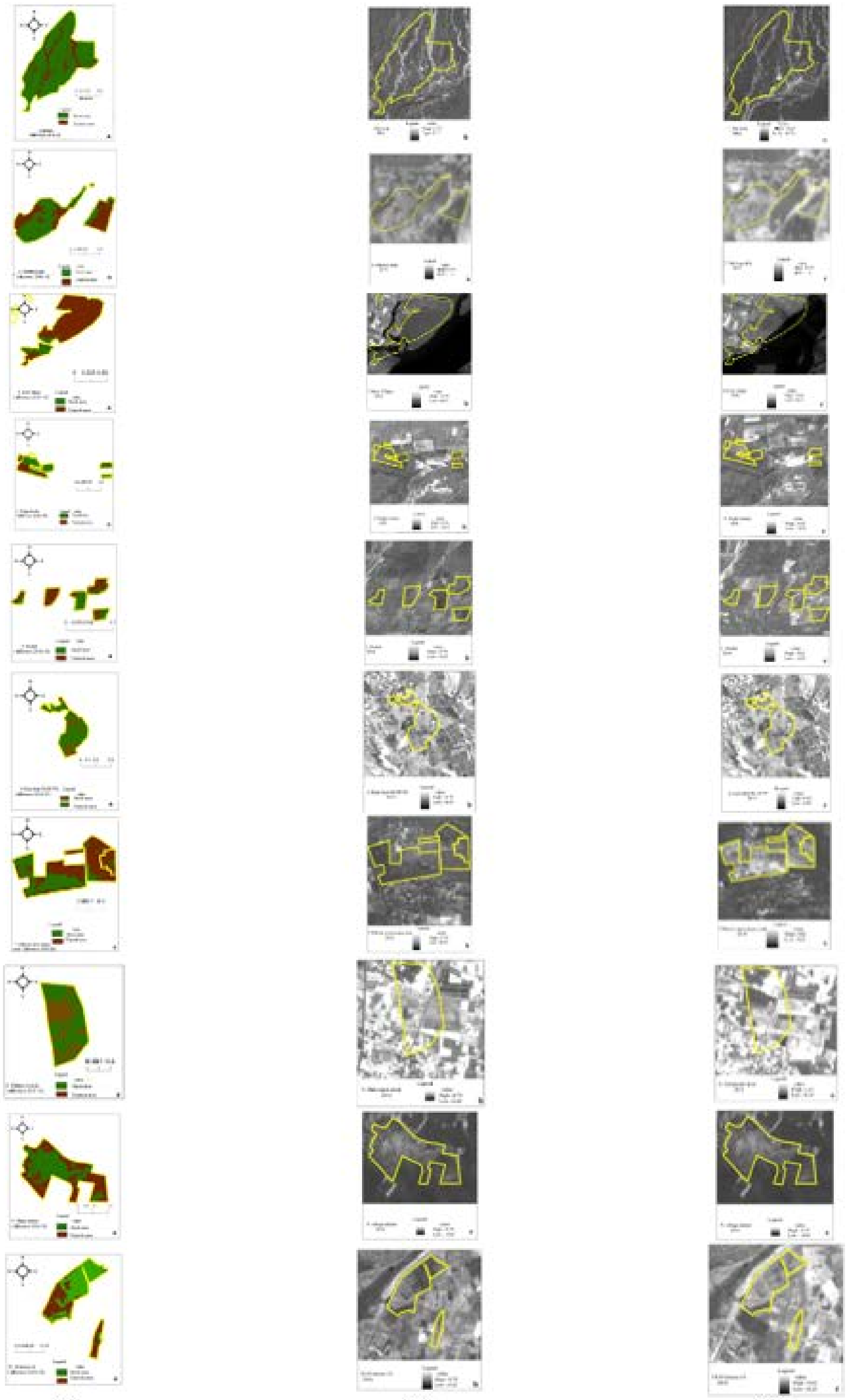
Table 2. Classified classes

Classes	Description	Increase or No Change
1	Increase	Increased ratio in plantation area
2	Decrease/zero	No change

3 Results

3.1 Stocked and Unstocked Areas

Site-wise details of stocked and unstocked areas are given in Table 3 and In the subgraph (a) of Figure 2. The overall results showed that among the different sites, the highest success in terms of stocking was found at the Paintara site, followed by Hote village and Wajho Kacha from 2015-16 to 2018. Similarly, over the period, the lowest success in terms of stocking was found in the Dilawar area of Bannu Road, followed by Rodha and Village Akabari. It can be seen from the table that at the Paintara site, out of the total planted area in 2016, the total stock area was about 85% and the unstocked area was about 14.8%. In Hote village and Wajho Kacha sites, of the total plantations in 2016, 66.33% and 65.58% were stocked in 2018, respectively, and the remainder was blank. The results of the table also show that in the Dilawar area of Bannu Road, the total unstocked or blank area was found to be 62.6%. In summary, of the total planted area in the region in 2016, about 61.28% was found to be stocked, and 38.72% was unstocked or blank.



(a) (b) (c)

Figure 2. Final maps of 10 plantation sites (a) difference of each site (2018-2016); (b) NDVI (2016); and (c) NDVI (2018)

Table 3. Details of the progress of plantation sites

No.	Name of the Plantation Site	Stocked Area (%)	Unstocked Area (%)	Year of Plantation
1	Paintara	85.15	14.84	2015 – 16
2	Mushtaq Shah	54.2	45.8	2015 – 16
3	Hote village	66.33	33.66	2015 – 16
4	Wajho Kacha	65.58	34.41	2015 – 16
5	Rodha	38.09	61.91	2015 – 16
6	Kari Shah madpowl	60.15	39.84	2015 – 16
7	Dilawar area of Bannu Road	37.39	62.60	2015 – 16
8	Mahmood Abad	57.25	42.74	2015 – 16
9	Village Akabari	44.40	55.59	2015 – 16
10	Al Moees I & II	47.09	52.90	2015 – 16
	Mean	61.28	38.71	2015 – 16

3.2 Scale of Plantation Success Based on NDVI

In order to measure the success of plantations at each study site, images of each site from 2016 to 2018 were analyzed using NDVI. the subgraph (b) of Figure 2 represents the NDVI results of each study site in 2016 and the subgraph (c) of Figure 2 represents the NDVI results for the year 2018. It can be seen from the figure that the NDVI value increased at each study site. A higher NDVI value at the Paintara site in 2018 indicates the success and scale of the plantation at this site. In 2016, the minimum NDVI value was found in the range of -0.22 to 0.59, while the maximum NDVI value was found in the range of 0.23 to 0.62. Compared to 2016, the minimum NDVI values varied from - 0.42 to 0.78 and the maximum NDVI value varied from -0.47 to 80 in 2018. Overall, the results of the higher values of NDVI in 2018 at all sites compared to 2016 show the progress of the plantation sites.

4 Discussions

Pakistan has a small forest cover, with about 5.1% of land covered by forest [29]. According to the Forestry Sector Master Plan (FSMP) [30] , Pakistan lost its natural forests at a rate of 27,000 ha (-0.7%) between 1990 and 2000. Khyber Pakhtunkhwa, Azad Jammu and Kashmir, and Gilgit Baltistan are the three regions of the country where the overall annual rate of change in forest cover is -0.38% [31]. In order to increase the forest area and conserve, protect and rehabilitate the existing forest, the government of Pakistan took some measures, such as the logging ban and Forestry Sector Master Plan(FSMP) in 1992, the Sarhad Conservation Strategy (1992), the Khyber Pakhtunkhwa Forest Ordinance in 2002 [14, 30]. Despite the reforms, no major shifts regarding forest conservation and restoration have been achieved. Most recently, the government of Khyber Pakhtunkhwa launched the Billion Trees Tsunami Afforestation Project (BTTAP), aiming at increasing forest area and cover, rehabilitation, restoring and conservation of degraded forests. The provincial government's political motivations led to the project, which received widespread acclaim on a national and international scale. The Worldwide Fund for Nature (WWF) presented the findings of its report after observing the project's implementation in 28 forests and 10 watershed divisions throughout the province for half a year [32]. Khyber Pakhtunkhwa Province was recognized as one of the world's ”forest restoration leaders” in 2015 at the UN Climate Change Conference in Paris [33]. The Bonn Challenge, which was established in 2011 with the aim of restoring 150 million ha of the world's degraded and deforested lands by 2020 and 350 million ha by 2030, has also recognized the BTTAP. At the Bonn Challenge, which has received responses from more than 20 nations, Khyber Pakhtunkhwa distinguished itself as the first subnational entity in the entire world. Under the Bonn Challenge, the BTTAP has committed to restoring 0.384 million ha of forest [32]. The implementation of BTAP has a substantial impact on the local community, household income, household livelihoods, and the provincial natural environment [34, 35].

The progress of the BTAP was monitored in this study using RS, with DIK, Pakistan, as a case study. Overall, the results of this study reveal that out of the total plantation area, 61.28% was found to be stocked and 38.71% was found unstocked from 2016 to 2018 (Figure 3). Paintara has the maximum survival or success rate in terms of stocking (85.15%), while Dilawar Road, located in the Bannu region of Khyber Pakhtunkhwa, Pakistan, has a minimum stocked area of 37.39%. The current survival rate of 61% in terms of stocking was found to be lower as compared to other regions such as Dir Upper, Dir Lower, Swat, Buner and Shangla, with survival rates of 92%, 84%, 83%, and 83%, respectively [3, 36]. However, the present findings are consistent with the survival rate of the Malakand and Alupr regions [36]. The relatively high survival rate is likely the result of the department's careful care as well as the species' choice and site selection. The high rate of survival is also attributed to careful maintenance, the establishment of closures and additional sowing in pits. Pit sowing has greatly increased the number of unsuccessful plants. Furthermore, the climatic condition and the availability of water are other key factors in a successful plantation. Although the 61% survival rate is encouraging in the study area, the establishment of closures, pit sowing, proper site and species selection and appropriate soil and water conservation techniques are required for the maximum survival rate. WWF Pakistan also monitored the progress of Phase II, BTAP, as a third party by visiting practically all the plantation sites in DIK, Khyber Pakhtunkhwa, Pakistan [37]. They reported a survival rate of 63.6% (farm forestry), followed by 81.27% (saline and waterlogged areas), 87.44% (roadside and canalside plantations), and 93.6% (multipurpose trees), for an overall average rate of 81.48% [37]. These differences might be attributed to the afterward failure of many plants. Those plants could not reach maturity level until 2018, as the WWF monitored the survival rate of the plantation in 2017. Apart from silviculture measures, legal and protective measures are also needed to ensure maximum survival. The Khyber Pakhtunkhwa government has, however, just recently created a unique division known as the forest patrol division. The unit has to patrol three to four times each day to keep any illegal activity under control and address it legally. The government also collaborates with local communities to more effectively meet the security requirement and assure the project's viability.

The NDVI results from the map of 2016 depict the actual forest area at that time, while the 2018 map illustrates the forest site's condition in 2018. The difference map (2018-2016) shows the actual increase, decrease, or no change in the selected forest site of the BTAP. The RS-based results obtained from NDVI differences using Sentinel-2 are slightly lower than those obtained by WWF. However, it is believed that due to the 10-meter spatial resolution of Sentinel-2 satellite images, many small plants could not be detected, and the results can be further improved by using high-resolution satellite images or aerial photographs [38]. The vegetation indices can detect land change patterns with high accuracy using multi-date Landsat data to identify forest change, and NDVI and NBR can all be used to monitor forest regeneration [38, 39]. Analysis of land use trajectories and NDVI differences was used to detect reforestation and describe various afforestation stages [3, 40–42]. Additionally, atmospheric factors have an impact on the NDVI [43–46].

Previous studies have indicated that community involvement, strict monitoring and law enforcement are required for the effective and viable implementation of such a project [30, 34]. BTAP is a green initiative not only for ecological and environmental purposes but also for the creation of rural jobs and the improvement of local livelihoods. This project aims at improving the natural and communal forests, growing forests on private lands, and developing agroforestry. Therefore, this project works in close collaboration with local communities and stockholders. The project also encourages the establishment of private nurseries and provides funds to local communities for raising nurseries. This greatly improved the socioeconomic condition of the local people. The BTAP-related activities in terms of the establishment of public and private nurseries, site preparation and plantation activities in the short term are positively linked to local socioeconomic development. The households that participate in BTAP activities hold about 35% more capital assets and 4% more income compared to those who are not part of such activities. Until now, BTAP-related activities in the plantation sites have also improved the air quality, controlled soil erosion, water logging and salinity, and protected crops from lodging, thus improving the social development index of the plantation sites [35]. Furthermore, the government has established task forces and monitoring squads to secure conservation and livelihood goals through law enforcement and extension services.

5 Conclusions and Outlook

Successful afforestation projects require regular monitoring of their progre ss. For this purpose, regular field inventory is needed. However, it is very costly, labor-intensive, and time-consuming, and many concerns about their accuracy have been raised. RS is a cost- and time-effective means to monitor the progress and success scale of plantation projects. Under the Bonn Challenge commitment, the Khyber Pakhtunkhwa Province launched a massive green initiative for the conservation and restoration of existing forests and the increase of forest area through plantations. Although the Khyber Pakhtunkhwa government assigned a third party (WWF) to monitor the success and status of plantations, there are doubts about the accuracy of the monitoring results. The results of this study reported a maximum survival rate of 85% at some sites and a minimum survival rate of 37%. The mean survival rate was found to be 61%. Compared to the success rate of 63% to 90% reported by WWF (on ground data), the estimates of this study provide slightly lower values, maybe because many plants failed afterward and could not reach maturity level until 2018. However, WWF monitored the survival rate of the plantation in 2017. The RS-based approach for assessing the progress of the plantation is very encouraging. Based on the conclusion of this study, the RS approach is highly recommended in the future for quick detection and assessment of any forestry plantation. It is also recommended that the results be further improved by using high-resolution satellite images, aerial photographs acquired from an airplane or unmanned aerial vehicle drones, and airborne laser scanning light detection and ranging technology. Apart from this, silviculture and legal policy measures are also recommended to improve the success rate. In this regard, soil and water conservation, rainwater harvesting, spreading pit sowing, careful maintenance, and the establishment of closures are suggested. Additionally. It is necessary to check, balance, and audit the project's funding and administration.

Author Contributions

"Conceptualization, investigation, methodology, formal analysis, writing original draft, S.U.U, F.K and A.I. software, visualization, project administration, S.U, M.Z; writing—original draft preparation, review and editing and supervision, A.A."

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Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

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Conflicts of Interest

The authors declare that they have no conflicts of interest.

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