A MACHINE LEARNING APPROACH FOR SPATIAL SUITABILITY MODELLING FOR COTTON CULTIVATION IN NORTH-EAST BALUCHISTAN-PAKISTAN

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ABSTRACT: Over the past few years, cotton cultivation in Pakistan has witnessed a decline, with farmers increasingly turning to sugarcane and maize. This shift has had detrimental effects on the local textile industry. To revive cotton farming in the region, this study sought to identify vacant, naturally available land suitable for cotton cultivation. The research focused on the suitability of cotton cultivation in Northeast Baluchistan, a challenging terrain characterized by extreme slopes and mountainous areas. The data were processed in Google Earth Engine (GEE) and for different parameters *i.e.* Land use and Landcover (LULC), Normalized Difference Vegetation Index (NDVI), and Normalized Difference Moisture Index (NDMI), Rainfall, Temperature, Geology, Slope, DEM, Soil pH and Soil texture. Different satellite data were used to measure the parameters in the study area. Then all the parameters were assigned different weights and the Weighted Overlay Method was applied from the Spatial Analyst tool in Arc Map and suitability modelling was done. The study revealed that Barkhan in Northeast Baluchistan exhibited the highest suitability for cotton cultivation, covering 0.71% of the area. On the other hand, approximately 47.86% of the region displayed suitability despite restrictions on cultivation, including well-furnished drainages and irrigation and important infrastructures. The remaining land was not suitable for cotton cultivation in the northeast of Baluchistan. Overall, this publication offers information on land suitability for cotton farming in Northeast Baluchistan and creates a path for the discovery of feasible cotton farming.

Keywords: GEE, Weighted Overlay, Spatial Analyst, Suitability Modelling, Cotton Cultivation.

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INTRODUCTION

Usually grown as annual row crops in mechanized production methods for commercial purposes, cotton plants have an unpredictable growth behavior. [Gwathmey and others, 2016]. Due to its adaptability and a vast range of applications, cotton, a valuable natural fiber generated from the seed capsules of plants in the Malvaceae family's *Gossypium genus,* is essential to many different businesses (Ioelovich *et al*., 2008). *Gossypium hirsutum L*., a well-known cotton species that is extensively grown for its fibre, is the subject of this study (Gwathmey etal.,2016). With almost 90% of the world's cotton produced, *Gossypium hirsutum* is the predominant species, followed by *Gossypium barbadense* (3–4%), *Gossypium arboreum*, and *Gossypium herbaceum* (2%) (Shan *et al*., 2016).

Cotton is a versatile raw material that serves as the basis for a diverse range of products, food additives, chemicals, papers, medical supplies, cosmetics, rubber, tire cord, reinforced plastics, among others. Although wood is the primary source of fibers for papermaking, cotton fibers also play a significant role in the industry. Cotton can be used to produce high-quality and specialized paper types, such as tissue paper, technical papers, drawing and printing papers, albums, banknotes, and document papers, among others (Cerchi and Tullio, 2006).

Cotton production leaders on a global scale are India, the United States, and China, with a growing emphasis on sustainable cotton production (Wright, S. 2020). Pakistan, a significant player in the cotton and textile industry, relies heavily on cotton for its economy (Economic Survey of Pakistan, 2017). Known as "white gold," cotton is pivotal to Pakistan's economy, contributing significantly to GDP and export earnings (Banuri, T. 1998).

Cotton cultivation has a long history in Pakistan, dating back to 3000 BC in the Indus Valley (Kirkby *et al*., 2012). Baluchistan, specifically Northeast Baluchistan, holds promise for cotton farming due to its vast expanse and climatic conditions (Brite, E., and Marston, J.M. 2013). Pakistan ranks fifth globally in both production and imports of cotton, which is regarded as a cash crop in that country. (Mehmood *et al*., 2021). When compared to other nations like the USA, China, and India, Pakistan's cotton production has been declining over time, and both the total area planted in cotton and the overall production have declined dramatically. In Pakistan, the total area under cultivation for cotton decreased to 2,200 thousand hectares in 2020–2021 from 2,700 thousand hectares in 2017–2018. Several factors, including the employment of antiquated agricultural methods, low-quality seeds, and the farmer community switching to cultivate other crops for greater profit, are to blame for the drop in Pakistan's cotton production. (Shahzad *et al*., 2022). The main objective of this study was to identify the most suitable location for cotton cultivation in North-East Baluchistan with the utilization of a machine learning algorithm and spatial suitability modeling. The research holds significance by providing valuable GIS-based data for agricultural planners and cotton growers, aiding in cotton area monitoring, and supporting initiatives to increase cotton production in Pakistan.

MATERIALS AND METHODS

Study Area: The research was carried out in the Balochistani districts of Kohlu, Barkhan, and Musakhel (figure 1). The region was chosen due to general observations that it can be more suitable, looking at climatic conditions, soil type, and available resources. One main reason is the vast area to cultivate. These three districts combined almost create Northeast Balochistan and cover an area of 17219 sq km. In Punjab, farmers are shifting their focus to sugarcane and maize, which would allow them to reconsider cotton and revive the country's once-lost cotton-growing roots. The study region is located between longitudes 68°05'48.73" and 70°14'45.13" east and latitudes 29°25'16.33" to 31°30'30.84" north. The region is bordered by the districts of Dera Ismail Khan in KPK in the north, Dera Ghazi Khan in Punjab in the east, Loralai, Zhob, and Sibi in the west, and Bolan in Balochistan in the south. In terms of demographics, the research area's population has increased in comparison to previous years.

In this study, different indices were applied along with the spatial suitability modeling in ArcGIS software. A machine learning approach has been utilized by using Google Earth Engine (Figure 2).

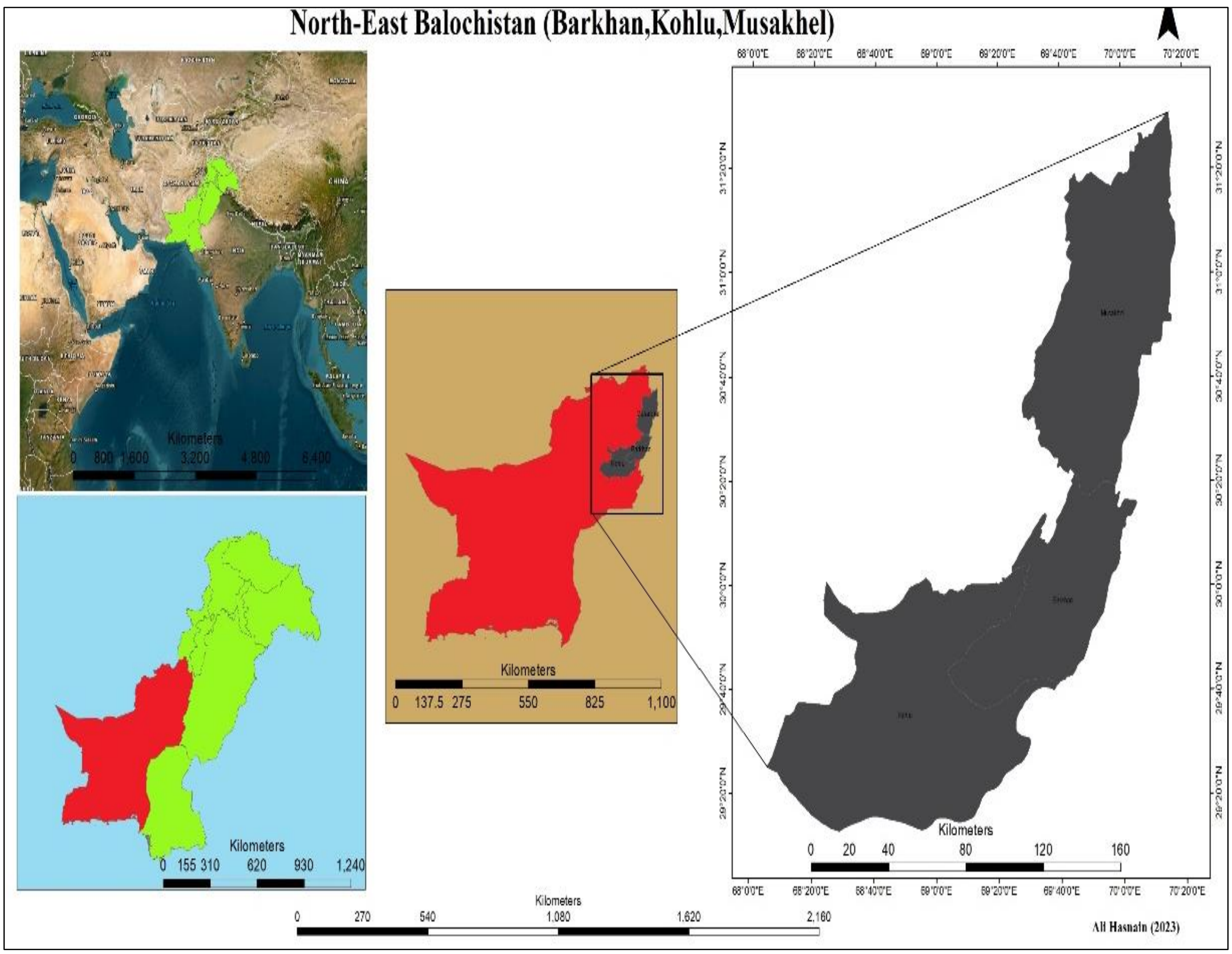

Figure 1: Map of Study Area (Northeast Balochistan)

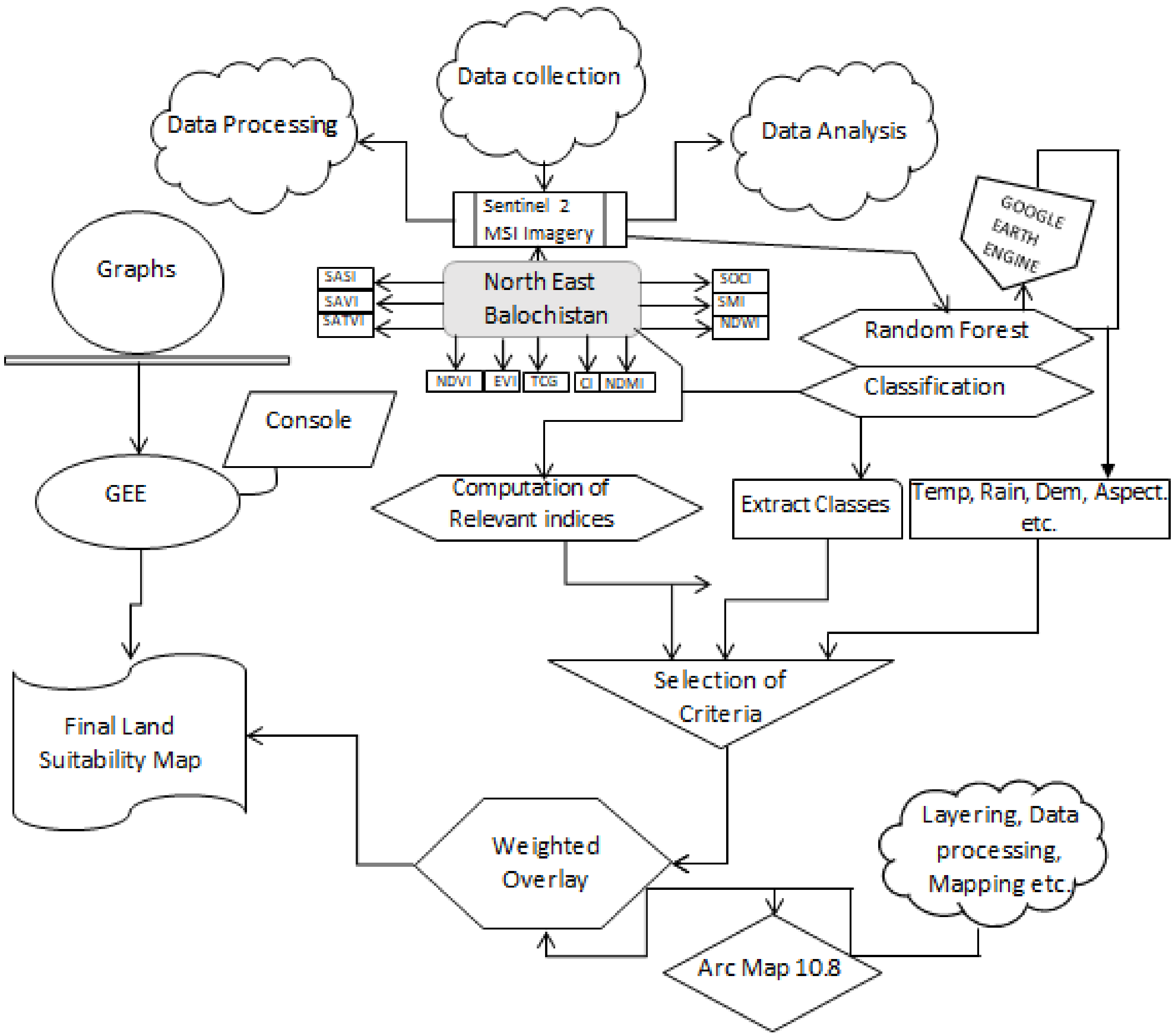

Figure 2: Methodology Framework

Data Collection:

Land use and Land cover (LULC): To create LULC the Sentinel-2 mission images have been used in GEE. To generate the LULC layer, the Sentinel-2 MSI 2022 imagery has been taken, and various filters to ensure the data accuracy of the data. In GEE random forest classifier has been trained and five classes were generated.

NDVI and NDMI: Two important indices, the Normalized Difference Vegetation Index (NDVI) and Normalized Difference Moisture Index (NDMI) using Sentinel-2 satellite imagery have been computed. To evaluate the health and density of the vegetation, NDVI has been implemented in the Google Earth Engine JavaScript API for the months of May and June in 2022. "The difference between the red and near-infrared (NIR) spectral bands can be divided by their sum to calculate the normalized difference vegetation index (NDVI): NDVI = (NIR - Red)/(NIR + Red)." Red is represented by Band 4 (B4) in Sentinel-2, whereas NIR (near-infrared) is represented by Band 8 (B8).

NDVI = (B8 – B4) / (B8 + B4)

Similarly, NDMI also applied for the year 2022 in GEE by using the following formula.

The formula for NDMI is:

NDMI = (NIR - SWIR) / (NIR + SWIR)

These indices helped us assess vegetation health and moisture content, critical factors for cotton cultivation.

Rainfall and Temperature: Precipitation data was taken from the Climate Hazards Group InfraRed Precipitation with Station Data (CHIRPS) dataset, while temperature data was taken from ERA5-Land Monthly Aggregated data. Both were calculated for months of May and June. Both variables were essential in evaluating the climate suitability for cotton farming.

Slope, Soil pH, Soil Texture, and Geology: Slope data was acquired from NASA's SRTM Digital Elevation dataset and soil-related information from various sources, including FAO global soil maps and geological data from USGS. These layers contributed to our land suitability analysis.

Data Processing: For this study, different tools were utilized such as mosaic to new raster, extract by mask, projection, resampling, and conversion to integer values to ensure compatibility and accuracy of the data and processing.

Spatial Suitability Modeling: The weighted overlay analysis from the spatial analyst tool was performed using ArcMap 10.8. Every layer has its cell size set to the same value for this reason. Nine characteristics were chosen to create a Land Suitability model for cotton agriculture. On the other hand, the expert knowledge determined the weight for every criterion. Expert knowledge for each parameter was used to determine the influence level for that parameter. To obtain output, the scale was set for each class after the weight influence was established. The normalized weight percentages are shown in Figure 3.

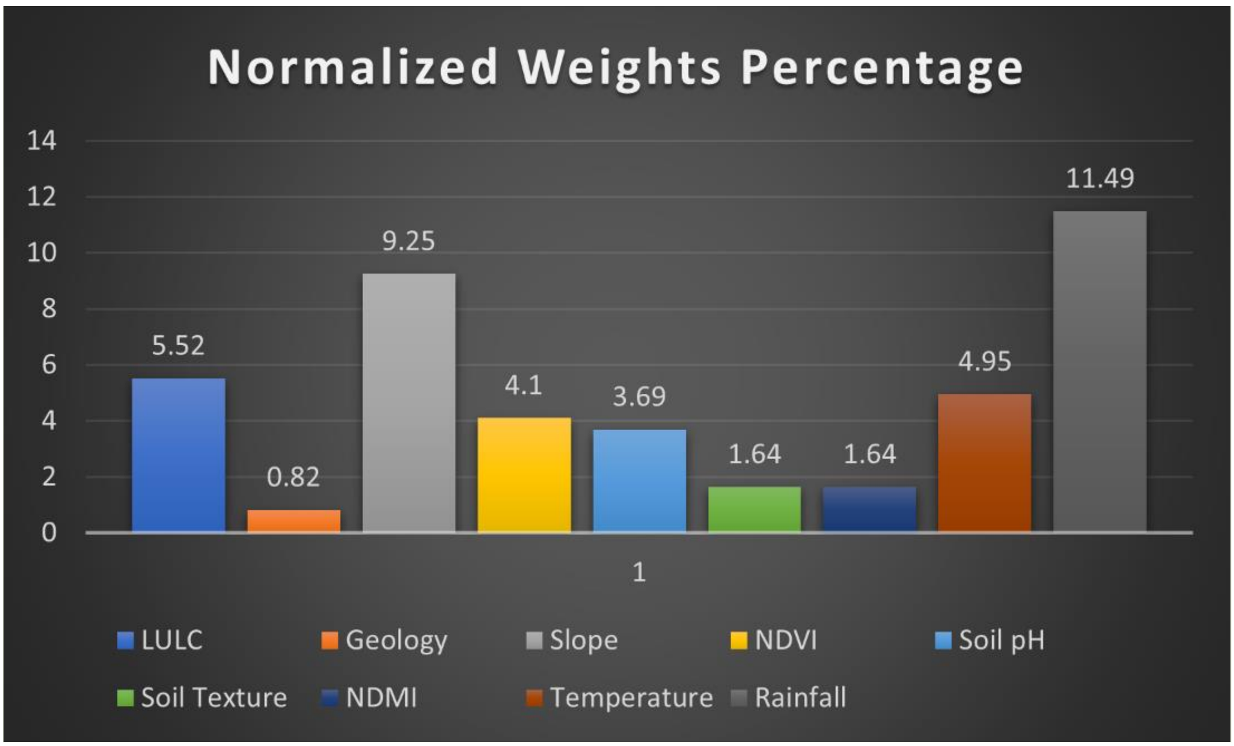

Figure 3: Suitability Percentages for Land of Northeast Balochistan.

RESULTS

Land Use Land Cover: In Figure 5 (A) LULC map, showcasing the northern region dominated by dense forests. This area primarily falls within Musa Khail district, characterized by mixed forest cover, highlighting its potential for cotton cultivation. The central area corresponds to Barkhan district, rich in agricultural activities. Kohlu, though hilly, possesses soil suitable for cotton cultivation and is well-endowed with water sources, such as the renowned Kohlu valley. Overall, Northeast Balochistan is sparsely populated, providing unique opportunities for agriculture and economic growth.

Rainfall: Figure 5 (B) Rainfall map sheds light on the rainfall patterns in Northeast Balochistan. Barkhan, district received relatively higher rainfall, particularly in the eastern region. However, proper water management is crucial to prevent waterlogging. Areas with 15 to 36 mm of rainfall may face water scarcity, necessitating supplemental irrigation. Other rainfall categories are generally favorable and subject to appropriate irrigation practices. The graphical representation also shows the increasing trend in rainfall, particularly in June 2022 (figure 4).

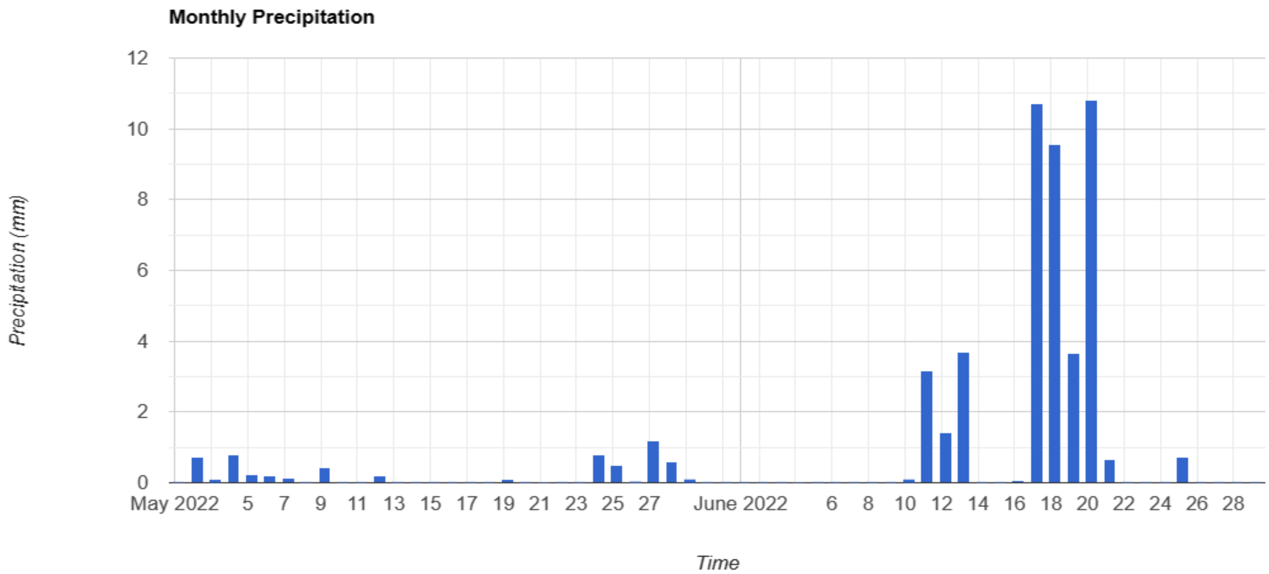

Figure 4: NEB May and June Rain 2022

Temperature: Cotton thrives in warm conditions. Figure 5 (C) shows the temperature range in Northeast Balochistan, with the optimal range for cotton growth falling around 25°C. Areas falling within this range, such as Musakhail and the western region of Barkhan, are particularly suitable for cotton cultivation. Higher temperature ranges may pose challenges, with crops more susceptible to heat stress and reduced yields.

Soil pH: Soil pH is crucial for nutrient availability and overall soil health. Cotton plants favor slightly acidic to neutral soils (pH 5.8-7.0). soil pH (Figure 5 (D) Soil Ph into Water) indicates that Musa Khail falls within this optimal range, while Barkhan and Kohlu have alkaline soils that may require fertilization.

Soil Texture: Soil texture influences water retention, nutrient management, and root development. Loam soils, comprising sand, silt, and clay particles, are ideal for cotton cultivation. Figure 5 (E) Lithology reveals that loam soil types are prevalent in Northeast Balochistan.

Geology: Geology provides insights into soil composition and suitability for agriculture. Although geology plays a minor role in our land suitability analysis, it contributes to our understanding of soil properties. Figure 5 (F) Geology Map displays the geological features of the region.

Slope: Slope influences soil erosion and water runoff. Figure 5(G) Slope classifies slopes into various categories, with flatter terrains being more favorable for cotton cultivation.

Normalized Difference Moisture Index (NDMI): NDMI indicates soil moisture content, critical for vegetation growth. Figure 5(H) NDMI illustrates the NDMI map, with the blue areas indicating high soil moisture content, ideal for lush vegetation and cotton cultivation. -0.1-0.04 range covered by most of the parts of the study area. While the northern part of the study area ranges between 0.02 to 0.3. Overall, the NDMI values show the dry conditions prevail in the study area.

Normalized Difference Vegetation Index (NDVI): NDVI measures vegetation density and health. Figure 5 (I) NDVI shows that northern Musakhail and eastern Barkhan have higher NDVI values, indicative of healthier vegetation, whereas Kohlu exhibits sparse or stressed vegetation. Most of the parts of the study area were between 0.009 to 0.046 while only a few parts ranged between0.19and0.57.

Figure 6 shows the Suitability Map for cotton cultivation in Northeast Balochistan, generated through weighted overlay analysis. The various grades on the map stand for varying degrees of appropriateness. Not Suitable: Based on a weighted examination of multiple characteristics, this class identifies regions that were deemed unsuitable for the growing of cotton. Kohlu belongs to the less suitable and somewhat suitable classes, as Figure 5 also shows, Less Suitable: In comparison to other classes, these places are less suitable for the cultivation of cotton. Their lesser appropriateness may be caused by elements like soil types, climates, or other constraints. Certain areas of Kohlu and Musakhail in the west and southwest are considered less appropriate areas. Moderately Suitable: The regions included in this class are somewhat suitable for growing cotton. With the right management techniques, they can nevertheless sustain cotton development even though they may have certain restrictions or less-than-ideal conditions. Cotton farming can be supported in Kohlu, but it will require appropriate management techniques. Greater appropriateness: When compared to the preceding groups, these regions show a greater degree of appropriateness for the cultivation of cotton. Their climate, soil quality, and other pertinent characteristics are all favorable. According to the land suitability chart, Barkhan and the area south of Musakhail are appropriate for growing cotton. Extremely Suitable: The class designated as highly suitable comprises regions that are most suited for growing cotton. These regions provide ideal growing conditions for cotton, including good soil, a temperate climate, and other supportive elements. Barkhan's highly suitable classes are concentrated in its east and north, with moderately suitable classes making up the remainder of the city. In Barkhan's center, there is only one somewhat adequate walkway.

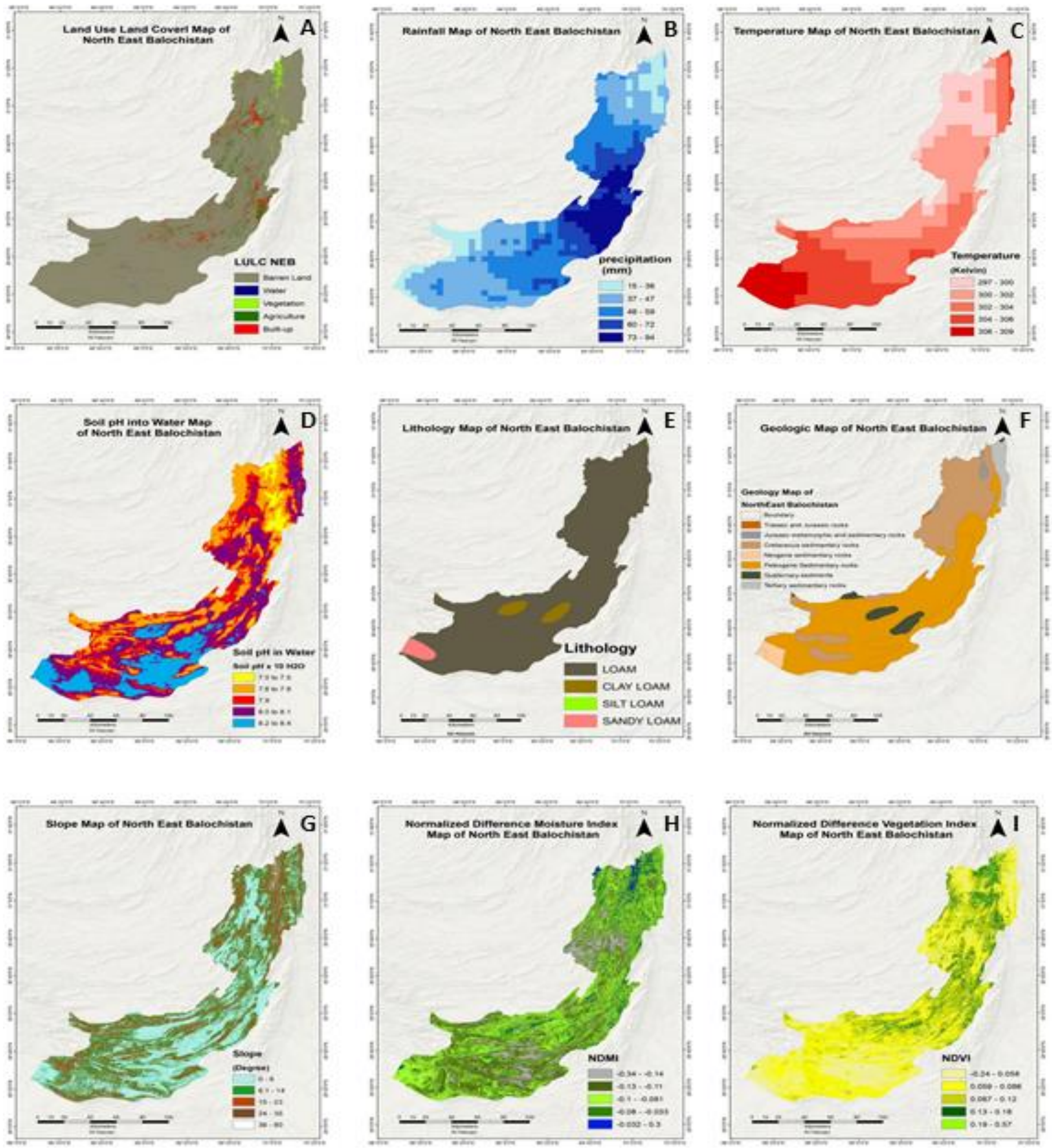

Figure 5: (A) Land Use Land Cover, (B) Rainfall, (C) Temperature, (D) Soil pH, (E) Lithology, (F) Geologic map, (G) Slope, (H) Normalized Difference Moisture Index and (I) Normalized Difference Vegetation Index

Spatial Suitability Modeling:

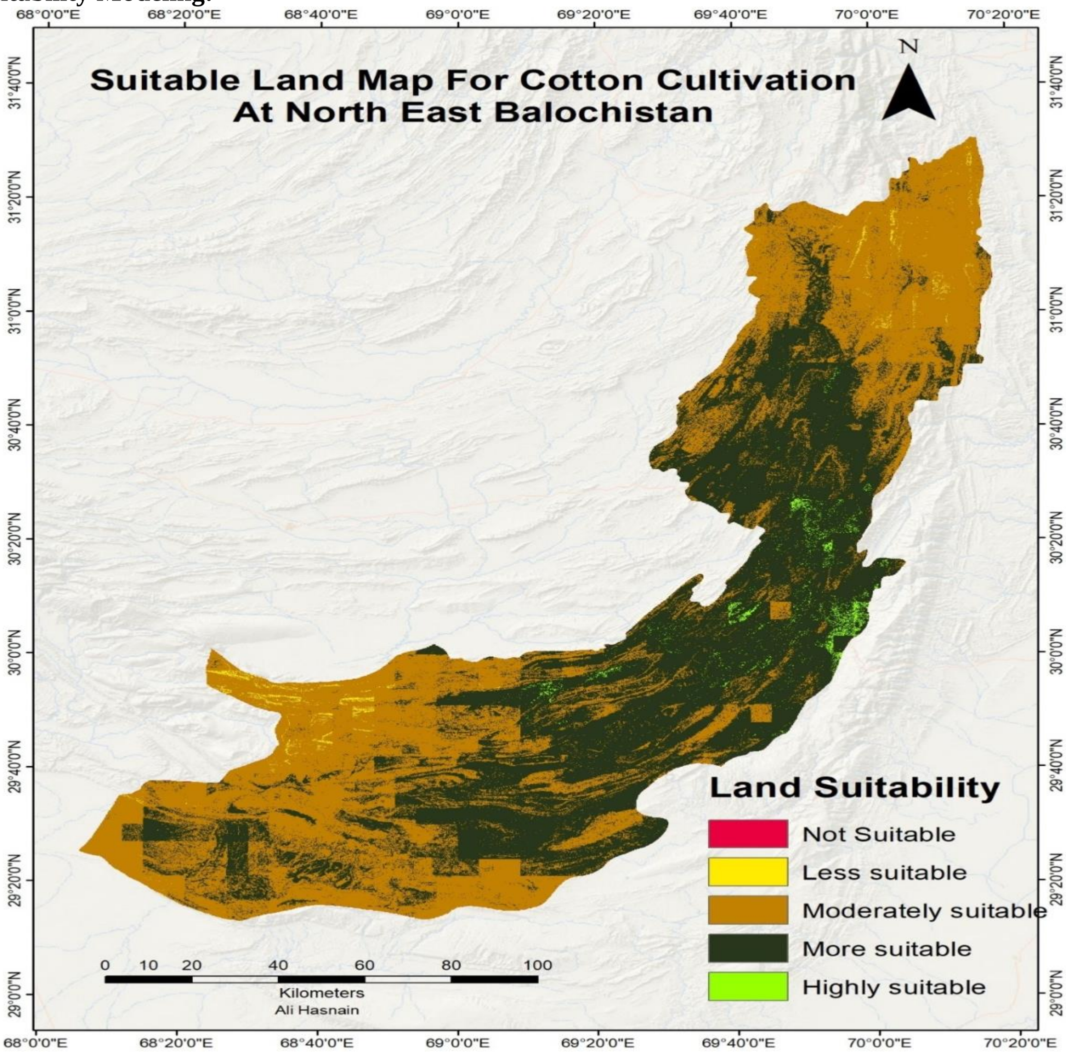

Figure 6: Suitability Map

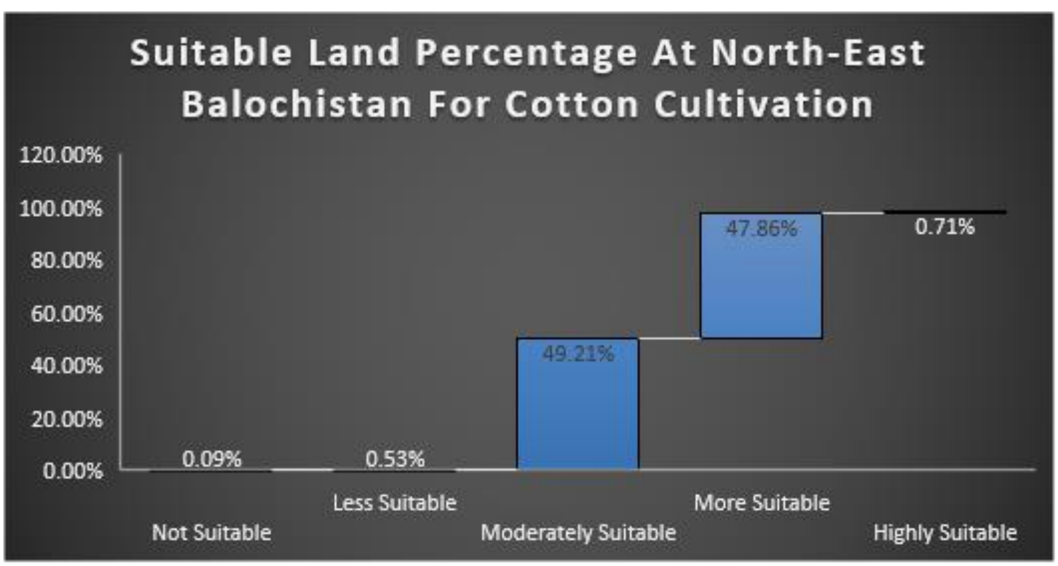

Figure 7: Land Suitability Percentage

Figure 7 demonstrates that in Northeastern Balochistan, 0.71% of the region was very appropriate and primarily falls under the Barkhan district. Barkhan District is generally quite conducive to the cultivation of cotton. Northeast Balochistan's 47.86% was ideal for supporting cotton production, yet it would also need additional elements like irrigation and other crucial procedures to enhance the quality of the vegetation. The Northeast has the highest percentage of reasonably appropriate areas, 49.21%, indicating that cotton can be grown there with the right irrigation and management techniques.

Northeastern Balochistan can be used to grow cotton, but some additional procedures will need to be taken into consideration. The fact that only 0.9% and 0.53% were less or not suitable is a positive indication that only a very small portion of the region is not suitable.

Northeast Balochistan exhibits varying degrees of land suitability for cotton cultivation. Barkhan emerges as a prime location, with other regions also showing promise, provided the right agricultural practices and irrigation systems are in place. This information is invaluable for stakeholders, farmers, and decision-makers seeking to optimize land use and crop planning in this unique region.

DISCUSSION

Promising results are obtained from the weighted overlay analysis carried out in Northeast Balochistan for cotton farming; a considerable section of the area is categorized as moderately to very suitable. According to a study conducted in Punjab, 65% of the land is extremely appropriate for growing cotton due to its favorable soil and climate conditions. The rest of the area needed some management techniques because it was somewhat suitable (Ali *et al*., 2015). While the number of extremely suitable areas is larger in Punjab (0.71%) than in Northeast Balochistan (0.71%), the proportion of moderately suitable areas is relatively similar. Both regions demonstrate that, with appropriate management, large-scale cotton farming is feasible. The difference in optimal locations may be attributed to Punjab's better soil quality and climate compared to Northeastern Balochistan (Ali *et al*., 2015). A study conducted in Maharashtra, India, found that about 30% of the state was highly suitable for growing cotton, 50% was deemed to be reasonably acceptable, and 20% was not so good due to limitations in soil and water (Patil *et al*., 2017).

Northeastern Balochistan has a higher proportion of fairly appropriate areas and a lesser percentage of extremely suitable areas when compared to Maharashtra. Both places have a substantial amount of land that requires management strategies to increase cotton production. Differences in soil types, climate, and water availability can account for variations in appropriateness classes. Forty percent of the land is very ideal for growing cotton, while the remaining twenty-five percent is less suitable due to water shortage and salinity of the soil, according to research on cotton suitability analysis done in Sudan (Elsheikh *et al*., 2013). Compared to Northeastern Balochistan, Sudan has a substantially higher percentage of extremely favorable sites. Conversely, Sudan has a lower proportion of suitable locations.

The climate and irrigation systems in Sudan are more favorable for growing cotton than in Northeastern Balochistan. In Texas, thirty percent of the land was deemed to be quite good for producing cotton, twenty percent was deemed inappropriate due to issues with water and soil erosion, and fifty percent of the land was found to be exceptionally suitable (Smith *et al*., 2018). There are more extremely appropriate areas in Texas than in Northeast Balochistan, which suggests that overall circumstances in Texas are superior for growing cotton. Improved soil management, cutting-edge farming practices, and Texas's favorable environment all contribute to higher adaptability ratings.

Several studies indicate that a sizable portion of land is often classified as fairly suitable, indicating that cotton production could be enhanced with appropriate management practices. This is consistent with the findings in Northeast Balochistan, where 49.21% of the land is moderately acceptable. Each location has a significantly different percentage of well-appropriate sites. Likely, the lower percentage in Northeast Balochistan compared to other regions like Punjab and Texas is due to less ideal soil and climate conditions.

The need for effective management practices, such as irrigation and soil augmentation, comes up time and time again in all the studies. This demonstrates how important agricultural interventions are to optimise the use of land for the production of cotton. The land suitability analysis for cotton production in Northeast Balochistan presents a scenario where the majority of the area is at least somewhat suited for cotton agriculture, which is consistent with findings in other locations. When these results are compared to those of other studies, it becomes clear that while Northeast Balochistan is capable of producing cotton, doing so will need addressing specific local problems like controlling the soil and water.

Conclusion: This study evaluated the "suitability of cotton cultivation in the northeastern region of Balochistan, Pakistan" by conducting a thorough investigation of several different characteristics. Rainfall, temperature, soil pH, soil texture, geology, slope, NDMI, and NDVI were among the factors taken into account. It has been investigated to use both platforms, such as GEE and ArcMap, in tandem. According to the analysis, the area receives moderate to heavy rainfall, which is necessary for growing cotton. The temperature ranges were ideal for cotton growth, meaning that the crop could flourish in a favorable environment. The soil's pH range was neutral to slightly alkaline, making it ideal for growing cotton.

Furthermore, the study region is dominated by loam, clay loam, silt loam, and sandy loam soils, according to an analysis of the texture of the soil. Because these soil types have adequate drainage and water-holding capacity, they are typically thought to be suitable for cotton cultivation. While the Barkhan district is generally appropriate for growing cotton, around 49% of northeast Balochistan was found to be somewhat suitable, approximately 47% more suitable, and approximately 0.7% with high suitability, according to the study's findings. All things considered; the results of this research add to our understanding of why cotton farming is appropriate in Balochistan's northeast. Policymakers, researchers, and farmers can utilize the findings to inform their decisions about land management and cotton output.

REFERENCES

Admasu, S., Desta, H., Yeshitela, K., & Argaw, M. (2022). Analysis of land suitability for apple-based agroforestry farming in Dire and Legedadi watersheds of Ethiopia: implication for ecosystem services. Heliyon, 8(11), e11217. Egypt. The Egyptian Journal of Remote Sensing and Space Science, 25(1), 301-311.

Ali, S., Mahmood, T., & Iqbal, J. (2015). Land suitability assessment for cotton using GIS in Punjab, Pakistan. Journal of Agricultural Sciences, 52(2), 139-148.

Amin, M. E., Mohamed, E. S., Belal, A. A., Jalhoum, M. E., Abdellatif, M. A., Nady, D., ... & Mahmoud, A. G. (2022). Developing spatial model to assess agro-ecological zones for sustainable agriculture development in MENA region: Case study Northern Western Coast,

Banuri, T. (1998) Pakistan: Environmental Impact of Cotton Production and Trade. Int. Institute of Sustainable Development, Canada

Booty, W. G., Lam, D. C. L., Wong, I. W. S., & Siconolfi, P. (2001). Design and implementation of an environmental decision support system. Environmental Modelling & Software, 16(5), 453-458.

Brite, E. B., & Marston, J. M. (2013). Environmental change, agricultural innovation, and the spread of cotton agriculture in the Old World. *Journal of Anthropological Archaeology*, *32*(1), 39–53. https://doi.org/10.1016/j.jaa.2012.08.003

Economic Survey of Pakistan (2017) Ministry of Food, Agriculture and Livestock, Economic Advisor Wing, Islamabad, Pakistan

Elsheikh, R. F. A., Shariff, A. R. B. M., Amiri, F., & Ahmad, N. B. (2013). Agriculture land suitability evaluator (ALSE): A decision and planning support tool for tropical and subtropical crops. Computers and Electronics in Agriculture, 93, 98-110.

Everest, T., Sungur, A., & Özcan, H. (2020). Determination of agricultural land suitability with a multiple-criteria decision-making method in Northwestern Turkey. International Journal of Environmental Science and Technology, 18(5), 1073–1088. https://doi.org/10.1007/s13762-020-02869-9

FAO (1976) A framework for land evaluation. Food and Agriculture Organization of the United Nations, Soils Bulletin No. 32. FAO, Rome

Gomez, C., White, J. C., & Wulder, M. A. (2016). Optical remotely sensed time series data for land cover classification: A review. ISPRS Journal of photogrammetry and Remote Sensing, 116, 55-72.

Gwathmey, C. O., Bange, M., & Brodrick, R. (2016). Cotton crop maturity: A compendium of measures and predictors. *Field Crops Research*, *191*, 41–53. https://doi.org/10.1016/j.fcr.2016.01.002

Ioelovich, M., & Leykin, A. (2008). Structural investigations of various cotton fibers and cotton celluloses. *Bioresources*, *3*(1), 170–177. https://doi.org/10.15376/biores.3.1.170-177

Kirkby, K.A., Lonergan, P.A., Smith, L.J., Scheikowski, L., Cooper, B.R. and Lehane, J. (2012) Innovative Disease Management

Mamatkulov, Z., Abdivaitov, K., Hennig, S., & Safarov, E. (2022). Land Suitability Assessment for Cotton Cultivation-A Case Study of Kumkurgan District, Uzbekistan. International Journal of Geoinformatics, 1(1). https://doi.org/10.52939/ijg.v18i1.2111

Mehmood, K., Ashraf, S., & Ashraf, I. (2021). Cotton production trends in Pakistan: An integrative review. Journal of Plant and Environment, 3(2). https://doi.org/10.33687/jpe.003.02.3747

Memarbashi, E., Azadi, H., Barati, A. H., Mohajeri, F., Van Passel, S., & Witlox, F. (2017). Land-Use suitability in Northeast Iran: Application of AHP-GIS Hybrid model. ISPRS International Journal of Geo-information, 6(12), 396. https://doi.org/10.3390/ijgi6120396

Moisa, M. B., Feyissa, M. E., Dejene, I. N., Tiye, F. S., Deribew, K. T., Roba, Z. R., ... & Gemeda, D. O. (2023). Evaluation of land suitability for Moringa Oleifera tree cultivation by using GIS and remote sensing: The case of Dhidhessa catchment, abay basin, Ethiopia. Oil Crop Science

Nyaradzo Marilyn Muzira, Terrence Darlington Mushore, Menas Wuta, Collin Mutasa, Emmanuel Mashonjowa, Land suitability analysis of Zimbabwe for the production of sorghum (Sorghum -bicolor) and maize (Zea mays) using a Remote Sensing and GIS based approach,Remote Sensing Applications: Society and Environment, Volume 23, 2021, 100553, ISSN 2352-9385, https://doi.org/10.1016/j.rsase.2021.100553. https://www.sciencedirect.com/science/article/pii/S2352938521000896.

Özkan, B., Dengiz, O., & Turan, İ. D. (2020). Site suitability analysis for potential agricultural land with spatial fuzzy multi-criteria decision analysis in regional scale under semi-arid terrestrial ecosystem. Scientific Reports, 10(1). https://doi.org/10.1038/s41598-020-79105-4

Patil, P. P., Khadse, R. R., & Kharche, V. K. (2017). Land suitability analysis for cotton cultivation in Maharashtra using GIS. International Journal of Advanced Research in Science and Engineering, 6(5), 121-130.

Perveen, S., Arsalan, M. H., Siddiqui, M. F., Khan, I. A., Anjum, S., & Abid, M. (2013). GIS-based multi-criteria model for cotton crop land suitability: a perspective from Sindh Province of Pakistan. FUUAST Journal of Biology, 3(1 june), 31-37.

Rasheed, H., & Naz, N. (2016). Modeling the Land Suitability using GIS and AHP for Cotton Cultivation in Punjab, Pakistan. Pakistan Journal of Scientific and Industrial Research. https://doi.org/10.52763/pjsir.phys.sci.59.2.2016.96.108

Shahzad, K., Mubeen, I., Zhang, M., Zhang, X., Wu, J., & Xing, C. (2022). Progress and perspective on cotton breeding in Pakistan. Journal of Cotton Research, 5(1). https://doi.org/10.1186/s42397-022-00137-4

Shan, W., Jiang, Y., Han, J., & Wang, K. (2016). Comprehensive cytological characterization of the Gossypium hirsutum genome based on the development of a set of chromosome cytological markers. *Crop Journal*, *4*(4), 256–265. https://doi.org/10.1016/j.cj.2016.04.001

Smith, W., Jones, R., & Williams, T. (2018). Evaluating land suitability for cotton cultivation in Texas using GIS and remote sensing. Agricultural Systems, 162, 21-32.

Widiatmaka, Ambarwulan, W., Santoso, P. J., Sabiham, S., Machfud, & Hikmat, M. (2016). Remote sensing and land suitability analysis to establish local specific inputs for paddy fields in Subang, West Java. Procedia Environmental Sciences, 33, 94–107. https://doi.org/10.1016/j.proenv.2016.03.061

Wright, S. (2020, September 7). Top Cotton Producing Countries In The World. WorldAtlas. https://www.worldatlas.com/articles/top-cotton-producing-countries-in-the-world.html

Wubalem, A. (2023). Modeling of land suitability for surface irrigation using analytical hierarchy process method in Belessa Districts, northwestern Ethiopia. *Heliyon*, *9*(3), e13937. https://doi.org/10.1016/j.heliyon.2023.e13937

Zolekar, R. B., & Bhagat, V. (2015). Multi-criteria land suitability analysis for agriculture in hilly zone: Remote sensing and GIS approach. Computers and Electronics in Agriculture, 118, 300–321. https://doi.org/10.1016/j.compag.2015.09.016.