The Use of Geospatial Techniques to Estimate Rice Production as a Measure for Waste Analysis: A Review

Lorie Cris S. Asube
College of Engineering and Geosciences, Caraga State University

Roland E. Otadoy
Department of Physics, University of San Carlos-Talamban Campus

https://doi.org/10.5109/7323407

出版情報：Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 10, pp.1184-1191, 2024-10-17. International Exchange and Innovation Conference on Engineering & Sciences
バージョン：

The Use of Geospatial Techniques to Estimate Rice Production as a Measure for Waste Analysis: A Review

Lorie Cris S. Asube[1,2,3], Roland E. Otadoy[4,5]
[1]College of Engineering and Geosciences, Caraga State University, Ampayon, Butuan City,
[2]Caraga Center for Geo-informatics, Caraga State University, Ampayon, Butuan City,
[3]School of Engineering, University of San Carlos, Talamban, Cebu City, Philippines,
[4]Department of Physics, University of San Carlos-Talamban Campus, Cebu City, Philippines,
[5]Center for Geoinformatics and Environmental Solutions, University of San Carlos-Talamban Campus, Cebu City, Philippines
corresponding author email: lsasube@carsu.edu.ph

Abstract: *Rice (Oryza Sativa L.) is an essential food for most of the world's population, and it plays a critical role in the global food system and contributes to food security. One outcome of food production in the rice industry is the creation of significant quantities of waste generated. Essential solid waste products from rice production are straw, husk, bran, and broken rice. These wastes by the rice industry present significant challenges regarding their volume, quality, and potential uses. Advancements in geospatial technology, such as utilizing Remote Sensing (RS) and Geographic Information Systems (GIS), present valuable and efficient solutions for estimating rice production. In this review article, several studies that use geospatial technologies to estimate rice production were reviewed. Then, by integrating geospatial data and models with rice production data, it is possible to gain insights into where and how waste is used at each stage of the rice production process.*

Keywords: Rice, Waste, Remote Sensing, Geographic Information Systems

1. INTRODUCTION

Rice (Oryza sativa L.) is a fundamental food element for global majority [1]. Remarkably, 90% of rice production occurs in Asian countries [2]. Rice is a crucial component of the global food supply chain, significantly supporting people's food stability, nourishment, and income generation. Precise and reliable estimates of rice cultivation areas and production are vital for expected population growth. Among the countries leading in rice production, China tops the list as the largest rice producer, generating 147.691 million tons between 2022 and 2023. India and Bangladesh follow, producing 125.039 million tons and 35.512 million tons annually, respectively. These nations are pivotal in satisfying the worldwide demand for rice, with China and India contributing over half of the global rice output [3]. Rice production worldwide is projected to hit 526.2 million tons on a milled basis from 2023 to 2024, marking a 0.4 percent increase from the production levels of 2022 to 2023. Moreover, rice trade on the international market is expected to reach 51.4 million tons in 2024 [4].

In 2023, the Caraga Region in the Philippines reported a rice production of 357,692.6 metric tons, up five percent from the 339,181.91 metric tons produced in 2022. There was a 1.9 percent increase in the rice-planted area, amounting to an expansion of 2,124 hectares in the region [5]. Monitoring rice yield and production is crucial for effective agricultural management [6]. It is vital in optimizing agricultural practices, guiding land use decisions, and quantifying rice waste. These efforts collectively contribute to enhancing food security and promoting sustainable development. Thus, it is essential to develop an effective method for accurately and timely estimating rice yield to manage agricultural production and secure food supply [7]. However, it is genuinely captivating that the most common methods for estimating rice cultivated areas depend on agricultural statistics gathered through field visits and farmer interviews [8]. Mapping out the extent of rice cultivation to estimate rice production involves conducting annual or seasonal sample surveys. These surveys create multiple sample clusters to assess cultivated land during the crop's growth. Field teams visit each cluster, documenting the areas, and then these figures are verified and processed by regional statistical personnel. While this approach is invaluable for tracking historical patterns in rice cultivation, it's notably labor-intensive, time-consuming, imprecise, expensive, inconsistent, and demands significant human resources [9]. Therefore, improvements in geospatial technologies provide promising methods for efficiently and promptly estimating rice yield on regional and national scales, such as RS and GIS [10]. These geospatial techniques are effective alternatives for mapping rice cultivation areas. [11],[12],[13],[14] and for predicting rice yield [1], [9], [11],[15],[16]. RS and GIS have become instrumental in this domain [18],[19]. This process involves the integration of RS and GIS data with crop models. These mathematical representations simulate crop growth and development, considering environmental variables like temperature, rainfall, and soil properties [19].

Moreover, utilizing RS and GIS to estimate crop yield and production offers significant benefits compared to conventional approaches. Remote sensing enables rapid data acquisition at a reduced cost and can cover vast areas, facilitating regional and national yield and production estimates. Geographic information systems enhance this with robust data integration and analysis capabilities, enabling the layering of diverse geospatial data to uncover patterns and relationships not easily noticeable through conventional means. Furthermore, crop models integrated with RS and GIS data can simulate crop growth under various environmental conditions, providing insights into potential yield and production outcomes under different scenarios. To forecast crop yields, this method combines RS and GIS data, including satellite imagery, meteorological information, and soil and land use maps [20]. The growth patterns of crops under different environmental conditions, like temperature fluctuations and rainfall variations, were simulated using crop models. It provides a detailed framework for predicting crop yields and production using these integrated datasets [17], [21].

Conversely, poor waste management could pose environmental and health risks to the public. While essential globally, the rice industry is also a significant waste source. As the world's second most cultivated crop, rice generates the most waste compared to other agricultural products [22]. Thus, this review aims to evaluate how geospatial techniques can be applied to estimate rice production, thereby providing a method for analyzing the associated waste. This review also seeks to explore the effectiveness of geospatial techniques and models, such as empirical, process-based, and semi-empirical, in accurately estimating rice production and to understand how the information can be leveraged to assess and manage the waste generated throughout the rice production process.

2. GEOSPATIAL APPROACHES IN AGRICULTURE

Agriculture is a cornerstone of economies, particularly in developing countries, where it is vital for economic stability and food security. Challenges facing the agricultural sector include shifting climate conditions, constraints on expanding farmland, and water shortages. These factors create a complex scenario for agriculture, necessitating innovative strategies and sustainable practices to ensure food security and the sector's resilience in the face of these constraints. The information emphasizes the significant need to monitor crop growth and health and implement timely intervention strategies. Recent developments in sensor technology, communication systems, and data analysis have improved sustainable agricultural practices, minimized resource consumption, and mitigated potential losses, thereby supporting higher and more sustainable yields essential for achieving global food security goals. Advanced technologies such as Geographic Information Systems (GIS), Global Navigation Satellite System (GNSS), Artificial Intelligence (AI), Remote Sensing (RS), Big Data Analytics (BDA), and Internet-of-Things (IoT) [23] have become essential for analyzing crops and soil, playing a significant role in global food stability [24]. Combined with other data sources, these technological tools deliver data-driven insights and information for precise, localized crop management, aiming to boost production levels [25]. Remote sensing and geographic information systems have greatly enhanced agricultural practices by improving yield estimation, soil mapping, crop checking, and precision agriculture. These technologies boost agricultural efficiency by streamlining labor-intensive tasks, addressing labor shortages, and creating new employment prospects [26]. Specifically, RS is instrumental in tracking crop development, spotting nutrient shortages, and pinpointing pest attacks. GIS is crucial in delineating soil properties, examining topographical data, and designing irrigation frameworks [27], [28].

3. APPLICATION OF GEOSPATIAL TECHNIQUES IN RICE PRODUCTION ESTIMATION

Estimating crop yield is a complex procedure that involves employing complicated models to forecast the yield of a specific crop throughout its growth cycle. These models are designed to integrate various vital factors that influence crop growth and yield. Its effectiveness can be significantly diminished when it encounters variations in soil conditions, stress factors, pressures, or management practices. These variations can lead to inaccuracies in predicting crop growth and yields. However, developments in using geospatial technologies such as Remote Sensing (RS) and Geographic Information Systems (GIS) have greatly enhanced the monitoring and estimation of crop growth and yields. These technological advancements have refined the processes and procedures involved in crop yield estimations, enabling more precise and reliable predictions [29], [30], [31]. These improvements underscore the evolving nature of agricultural monitoring and the potential for increased accuracy in forecasting yields, which is crucial for economic planning and food security strategies.

RS and GIS technologies generated maps and gathered geographic information data. Advanced high-resolution satellite imagery has enhanced the accuracy of predicting crop yields, distinguishing between crop types, estimating crop planting areas, and modeling crop growth [32], [33]. It has been a crucial method for assessing crop yield [34]. Traditional remote sensing research platforms for estimating crop yield are mainly divided into airborne remote sensing and ground remote sensing [1]. These types provide macroscopic monitoring and local observation, respectively [35]. However, there are various challenges associated with macroscopic monitoring. Several intrinsic and extrinsic factors influence the variability in crop yield. Spatial maps showing crop yields have been extensively used to understand the reasons behind yield variation across different areas [36].

Furthermore, remote sensing data can evaluate yield losses attributable to drought or flooding [37]. It's essential to use a range of vegetation indices since each provides unique wavelength bands related to specific crops and their stages of growth [38]. Due to the variability in environmental conditions, there are significant differences in annual rice crop yields. As a result, acquiring accurate and up-to-date crop yield data on national, international, and regional levels is increasingly vital for addressing global food security concerns [39]. Such data is crucial for efficient management of croplands, policy formulation, making informed decisions on imports and exports, setting insurance premiums, and planning for sustainable agricultural food production [40]. Several methods, such as remote sensing, empirical models, and crop simulation, have been utilized to predict crop yields across various scales [9]. RS has emerged as a highly effective tool for tracking the growth of crops, offering accurate and frequent updates that reflect the state of agriculture with precision [41]. Table 1 shows the different geospatial techniques in rice production estimation.

Table 1. Application of geospatial techniques in rice production estimation

Geospatial Techniques	Sensor Used	Data Analysis	Accuracy	Study Area	Reference
Remote Sensing	Sentinel-1 SAR	Regression analysis	RMSE = 0.8 tons/ha	Vietnam	[16]
Remote Sensing and GIS	Landsat 8 OLI	Linear regression analysis	RMSE = 0.016 ME = 0.8	India	[15]
Remote Sensing	UAV-borne hyperspectral remote sensing	Machine learning regression analysis	R^2 = 0.827 RMSE = 0.036,	China	[1]
Remote Sensing	Multi-temporal datasets, MODIS, MOSDAC (INDSAT 3D), SAR (Sentinel 1A)	Monteith (1977) approach to spectral yield modeling	RMSE = 0.15 tons/ha R^2 = 0.97	India	[42]
Remote Sensing	Sentinel 2	Crop simulation model	R^2 = 82%	India	[9]
Remote Sensing and GIS	MODIS	Statistical analysis	R^2 = 0538	Vietnam	[43]
Remote Sensing	Landsat Images	Linear regression analysis	R^2 = 0.7882.	Pakistan	[44]
Remote Sensing	X-band SAR	Regression analysis	R^2 = 0.80	Laos	[45]
Remote Sensing	ISRIC 2.0 Google Earth points-not sensor	Statistical analysis	R^2 = 0.81 RMSE = 238 Kg ha^{-1}	India	[46]
Remote Sensing	Sentinel-1A Synthetic Aperture Radar (SAR)	Analytical analysis	RMSE = 0.74 t ha^{-1} RE = 7.93%	China	[47]
Remote Sensing	Synthetic Aperture Radar (SAR)	Statistical analysis	<86-91% Yield Simulation	India	[12]
Remote Sensing	MODIS NDVI	Linear regression analysis	RMSE = 451.05 MAE = 425.35	Nepal	[8]
Remote Sensing	MODIS LAI	Gradient Boosted Regression (GBR)	R^2 = 220%	India	[48]
Remote Sensing	MODIS	NDVI regression analysis	R^2 = 0.6639	Indonesia	[49]
Remote Sensing	(UAV) based remote sensing	UAV image-based grain segmentation	R^2 = 0.98	Korea	[50]
Remote Sensing	Multispectral images by UAV	Regression analysis	R^2 = 0.292	China	[51]
Remote Sensing	Sentinel-1A C-Band SAR Data	Linear regression analysis	R^2 = 0.83 RMSE = 5.29	Philippines	[52]

4. RICE PRODUCTION TOWARDS RICE WASTE ANALYSIS

Rice is the world's second most extensively cultivated crop and the most prominent waste producer. As rice grows, a husk forms around the grains, serving as a protective coating, while bran is situated between the husk and the grain's endosperm [22]**.** About 1.35 tons of rice straw are produced in the field for every ton of harvested rice paddy. Moreover, per ton of paddy rice processed industrially produces 200 kg, 100 kg, and 140 kg of rice husk, bran, and broken rice, respectively [22]. Since the husk does not contain the nutritional value present in bran or broken rice, it has become a promising source of biomass for power generation [22]. The husk constitutes the most significant portion of waste from rice production, making up approximately 20% of the mass of paddy rice and straw [22]. The quantities of bran and broken rice produced can vary significantly and are primarily influenced by the efficiency of the processing techniques [53]. Based on an analysis of the rice processing steps, Fig. 1 was created to illustrate a comprehensive diagram detailing all the stages involved, including the inputs and outputs of each step. The diagram provides a detailed overview of the rice processing workflow, encompassing several critical stages such as harvesting, transportation, reception and pre-cleaning, drying, storage, shelling, milling/polishing, and selection and classification [22].

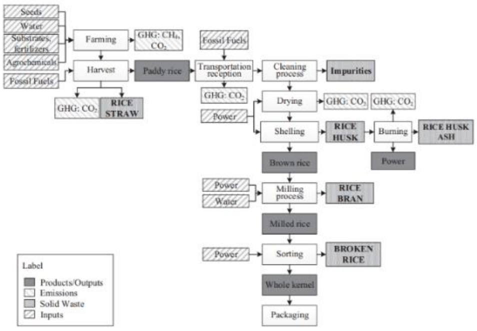

Fig. 1. Rice production workflow detailing inputs and outputs [22]

Fig. 2 shows the various stages and the leading products and wastes considering each proportion from rice production.

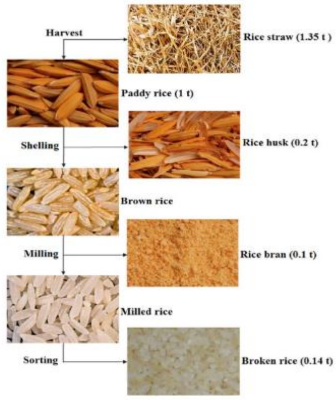

Fig. 2. Different products obtained in the conversion of paddy rice [22]

4.1 Rice Waste Generation and Its Optimal Utilization

The waste generated by the rice industry poses significant challenges regarding its volume, quality, and potential. Reusing and valorizing these wastes effectively involves identifying, assessing, measuring, and classifying residues. It is followed by their application in relevant industries through traditional or innovative new technologies. Despite challenges in finding economically and socially viable applications for agricultural waste, all components produced during the rice cultivation cycle can be utilized [54]. The diagram of the rice production process of the wastes produced at each stage is shown in Table 2.

Table 2. The byproducts produced during rice processing and their utilization.

Stages	Waste Generated	Utilization	Reference
Harvest	Straw	▪ Rice straw as a fuel source	[55]
		▪ It can be used for energy production, such as creating ethanol, biogas, and bio-oil.	[56]
		▪ Rice straw pellets that are used to produce industrial organic fertilizer.	[57] [54]
		▪ Utilizing rice straw in the manufacturing of pulp and paper.	
		▪ It will be utilized for mushroom production	
		▪ It will be used for feeding ruminants	[58]
Husking	Husk	▪ Polymeric composite resins and polymeric lumber from husk are sustainable alternatives to natural wood.	[59]
		▪ It is used as biomass for power generation.	[60]
Milling	Bran	▪ It holds potential as a functional food.	[61]
		▪ Extraction of proteins and starch, utilization in animal feed, extraction of oils, production of biodiesel, and use as an adsorbent.	[22]
Selection	Broken Rice	▪ Production of rice flour, starch extraction, functional foods, beer brewing, animal feed, ethanol production, and blending with whole rice.	[22]

4.1.1 Rice Straw

Rice straw fiber, often underutilized as an agricultural byproduct, shows promise for incorporation into polymer composites, which could help conserve wood and petroleum resources. Historically, burning rice straw in the fields has been a standard method for quick disposal, but this contributes to environmental pollution by releasing smoke and greenhouse gases into the atmosphere [54]. Rice straw is being utilized as a low-cost, natural option for animal feed due to the increasing demand for animal-sourced foods. As such, rice straw provides an affordable food source for livestock. In Vietnam, rice straw is the most abundant ruminant feed, especially during the dry season [62]. Amidst rising costs and constrained wood supplies, many developing countries have turned to non-wood-based pulps for paper production. In particular, India and China use non-wood plants such as wheat straw, cereal straw, and bagasse, which account for 70% of the raw materials in their pulp industries [57].

4.1.2 Rice Husk
The rice husk is the protective outer layer covering the rice grain [63]. Additionally, it acts as a protective shield, safeguarding against physical damage and assaults from pathogens, insects, and pests [64]. Also referred to as hull or chaff, rice husk is mainly utilized as an energy source in rice mills and poultry farming and for producing silica-rich cement. It is also used in smaller quantities as construction material and fertilizer. Despite these applications, most rice husks are either discarded in landfills or openly burned, significantly contributing to environmental pollution.

4.1.3 Rice Bran
Rice consists of bran and germ. Rice bran comprises approximately 80% carbohydrates, 2% proteins, 7-8% fatty acids, 7% dietary fiber, and trace minerals [65]. Despite its nutritional value, rice bran is unsuitable for human consumption mainly due to its tendency to become rancid, caused by the presence of lipases [65]. This waste is wholly used as cattle feed and as a raw material for oil extraction [66]. It is used mainly as animal feed due to its high nutritional content, particularly in fiber, which makes it a healthy option for pet diets.

4.1.4 Broken Rice
During processing, mechanical stresses cause some rice grains to break, resulting in a byproduct known as broken rice. This rice waste, called rice grits, consists of broken and defective grains. Broken rice offers various recycling opportunities, including the production of rice flour, use in animal feed, and as a component in beer production. Like whole grains, broken rice is rich in starch, making it a valuable energy source for human consumption. Recent studies have demonstrated that broken rice is a highly effective substrate for ethanol fermentation.

Moreover, it can be used as a vital raw material in producing lactic acid and other functional materials [22]. Broken rice and rice bran are well-suited for human consumption. Since broken rice maintains the same nutritional profile as whole rice, it can be applied in various high-value and quality applications, including protein or starch extraction [67].

5. CONCLUSIONS
Advancements in geospatial technology offer effective and cost-efficient solutions for accurately estimating rice yields on both regional and national levels. This review article shows that geospatial techniques like RS and GIS are effective alternatives for mapping rice cultivation areas and forecasting rice yields. Using geospatial techniques to estimate crop yields and production provides substantial advantages over traditional methods. RS allows for quick data collection at lower costs and can span extensive areas, supporting yield and production estimates on regional and national scales. GIS complements this by offering powerful data integration and analysis tools, which facilitate combining various geospatial data types to reveal patterns and relationships that are not apparent through traditional methods.

Moreover, integrating crop models with RS and GIS data enables crop growth simulation across different environmental conditions, offering valuable forecasts of potential yields and production scenarios. As the world's second most widely grown crop, rice produces more waste than any other agricultural commodity. The processing of rice encompasses multiple stages: harvest, husking, milling, selection, and finally, sorting and grading, with straw, husk, bran, and broken rice as the leading rice waste. The rice industry's waste presents considerable challenges regarding its volume, quality, and potential uses. This review article aims to assess how geospatial technologies can estimate rice production and provide a framework for analyzing the resultant waste.

6. ACKNOWLEDGMENT

This research is an integral component of a dissertation funded by the Philippine Government's Department of Science and Technology (DOST) through the Engineering Research and Development for Technology (ERDT) Scholarship program of the University of San Carlos, Cebu City, Philippines.

7. REFERENCES
[1] Y. Shen, Z. Yan, Y. Yang, W. Tang, J. Sun, and Y. Zhang, “Application of UAV-Borne Visible-Infared Pushbroom Imaging Hyperspectral for Rice Yield Estimation Using Feature Selection Regression Methods,” *Sustainability*, vol. 16, no. 2, p. 632, Jan. 2024, doi: 10.3390/su16020632.

[2] N.K. Fukagawa and L.H. Ziska, “Rice: importance for global nutrition,” vol. 65, 2019.

[3] USDA, “USDA, Foreign Agricultural Service, Production, Supply and Distribution database.”

[4] UN FAO, “Food and Agriculture Organization of the United Nations.”

[5] DA-Caraga, “Department of Agriculture-Caraga Region.”

[6] S. Delerce *et al.*, “Assessing Weather-Yield Relationships in Rice at Local Scale Using Data Mining Approaches,” *PLOS ONE*, vol. 11, no. 8, p. e0161620, Aug. 2016, doi: 10.1371/journal.pone.0161620.

[7] B. Duan *et al.*, “Remote Estimation of Rice Yield with Unmanned Aerial Vehicle (UAV) Data and Spectral Mixture Analysis,” *Front. Plant Sci.*, vol. 10, p. 204, Feb. 2019, doi: 10.3389/fpls.2019.00204.

[8] M. D. Islam *et al.*, “Rapid Rice Yield Estimation Using Integrated Remote Sensing and Meteorological Data and Machine Learning,” *Remote Sens.*, vol. 15, no. 9, p. 2374, Apr. 2023, doi: 10.3390/rs15092374.

[9] R. Mandapati *et al.*, “Crop Yield Assessment Using Field-Based Data and Crop Models at the Village Level: A Case Study on a Homogeneous Rice Area in Telangana, India,” *AgriEngineering*, vol. 5, no. 4, pp. 1909–1924, Oct. 2023, doi: 10.3390/agriengineering5040117.

[10] D. M. G. Dela Torre, J. Gao, and C. Macinnis-Ng, “Remote sensing-based estimation of rice yields using various models: A critical review,” *Geo-Spat. Inf. Sci.*, vol. 24, no. 4, pp. 580–603, Oct. 2021, doi: 10.1080/10095020.2021.1936656.

[11] Md. M. Islam, S. Matsushita, R. Noguchi, and T. Ahamed, “Development of remote sensing-based yield prediction models at the maturity stage of boro rice using parametric and nonparametric approaches,” *Remote Sens. Appl. Soc. Environ.*, vol. 22, p. 100494, Apr. 2021, doi: 10.1016/j.rsase.2021.100494.

[12] S. Pazhanivelan, K. P. Ragunath, N. S. Sudarmanian, R. Kumaraperumal, T. Setiyono, and E. D. Quicho, “INTEGRATING TIME-SERIES SAR DATA AND ORYZA CROP GROWTH MODEL IN RICE AREA MAPPING AND YIELD ESTIMATION FOR CROP INSURANCES,” *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.*, vol. XLII-3/W6, pp. 239–243, Jul. 2019, doi: 10.5194/isprs-archives-XLII-3-W6-239-2019.

[13] M. Prabhakar *et al.*, “Mapping Leaf Area Index at Various Rice Growth Stages in Southern India Using Airborne Hyperspectral Remote Sensing,” Biology and Life Sciences, preprint, Dec. 2023. doi: 10.20944/preprints202312.2021.v1.

[14] A.-X. Zhu, F.-H. Zhao, H.-B. Pan, and J.-Z. Liu, “Mapping Rice Paddy Distribution Using Remote Sensing by Coupling Deep Learning with Phenological Characteristics,” *Remote Sens.*, vol. 13, no. 7, p. 1360, Apr. 2021, doi: 10.3390/rs13071360.

[15] G. Chandra Paul, S. Saha, and T. K. Hembram, “Application of phenology-based algorithm and linear regression model for estimating rice cultivated areas and yield using remote sensing data in Bansloi River Basin, Eastern India,” *Remote Sens. Appl. Soc. Environ.*, vol. 19, p. 100367, Aug. 2020, doi: 10.1016/j.rsase.2020.100367.

[16] H. P. Phung, L. D. Nguyen, N. V. Anh Vu, N. K. Thanh, and L. V. Trung, “Application of multi-temporal Sentinel-1 SAR data for yield estimation of rice crops in An Giang, Vietnam,” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 964, no. 1, p. 012007, Jan. 2022, doi: 10.1088/1755-1315/964/1/012007.

[17] C. B. Pande and K. N. Moharir, “Application of Hyperspectral Remote Sensing Role in Precision Farming and Sustainable Agriculture Under Climate Change: A Review,” in *Climate Change Impacts on Natural Resources, Ecosystems and Agricultural Systems*, C. B. Pande, K. N. Moharir, S. K. Singh, Q. B. Pham, and A. Elbeltagi, Eds., in Springer Climate. , Cham: Springer International Publishing, 2023, pp. 503–520. doi: 10.1007/978-3-031-19059-9_21.

[18] M. Yaswanth Bhanu Murthy, Sk. Enaul Haq, K. Anne, and M. Sunil Babu, “Integration of Artificial Intelligence and IoT on Agricultural Applications,” in *Intelligent Systems for Social Good*, S. Mukherjee, N. B. Muppalaneni, S. Bhattacharya, and A. K. Pradhan, Eds., in Advanced Technologies and Societal Change. , Singapore: Springer Nature Singapore, 2022, pp. 29–38. doi: 10.1007/978-981-19-0770-8_3.

[19] H. Cen and L. Wan, “Crop Yield Estimation and Prediction,” in *Encyclopedia of Smart Agriculture Technologies*, Q. Zhang, Ed., Cham: Springer International Publishing, 2023, pp. 1–13. doi: 10.1007/978-3-030-89123-7_48-1.

[20] Nitin Liladhar Rane, M. Giduturi, Saurabh P. Choudhary, and Chaitanya Baliram Pande, “Remote Sensing (RS) and Geographical Information System (GIS) as A Powerful Tool for Agriculture Applications: Efficiency and Capability in Agricultural Crop Management,” Apr. 2023, doi: 10.5281/ZENODO.7845187.

[21] L. Wang, G. Zhang, Z. Wang, J. Liu, J. Shang, and L. Liang, “Bibliometric Analysis of Remote Sensing Research Trend in Crop Growth Monitoring: A Case Study in China,” *Remote Sens.*, vol. 11, no. 7, p. 809, Apr. 2019, doi: 10.3390/rs11070809.

[22] C. A. Moraes *et al.*, “Review of the rice production cycle: By-products and the main applications focusing on rice husk combustion and ash recycling,” *Waste Manag. Res. J. Sustain. Circ. Econ.*, vol. 32, no. 11, pp. 1034–1048, Nov. 2014, doi: 10.1177/0734242X14557379.

[23] S. Mishal Zahra *et al.*, “Application of Geospatial Techniques in Agricultural Resource Management,” in *Irrigation - New Perspectives [Working Title]*, IntechOpen, 2023. doi: 10.5772/intechopen.112222.

[24] B. K. Shukla, N. Maurya, and M. Sharma, “Advancements in Sensor-Based Technologies for Precision Agriculture: An Exploration of Interoperability, Analytics and Deployment Strategies,” in *ECSA 2023*, MDPI, Nov. 2023, p. 22. doi: 10.3390/ecsa-10-16051.

[25] J. A. Delgado, N. M. Short, D. P. Roberts, and B. Vandenberg, “Big Data Analysis for Sustainable Agriculture on a Geospatial Cloud Framework,” *Front. Sustain. Food Syst.*, vol. 3, p. 54, Jul. 2019, doi: 10.3389/fsufs.2019.00054.

[26] Art M. Dalman, Rogelyn A. Aguhob, Ruby Joy N. Buniel, Neil Caesar M. Tado, May Rose B. Osoteo, and Cindy May C. Belivestre, “Assessment on the Level of Mechanization in the Rice Production and Post-Production Systems in Surigao Del Sur,” *Proc. Int. Exch. Innov. Conf. Eng. Sci. IEICES*, vol. 9, pp. 201–206, Oct. 2023, doi: 10.5109/7157972.

[27] S. F. Elbeih, “Evaluation of agricultural expansion areas in the Egyptian deserts: A review using remote sensing and GIS,” *Egypt. J. Remote Sens. Space Sci.*, vol. 24, no. 3, pp. 889–906, Dec. 2021, doi: 10.1016/j.ejrs.2021.10.004.

[28] R. Sharma, S. S. Kamble, and A. Gunasekaran, “Big GIS analytics framework for agriculture supply chains: A literature review identifying the current trends and future perspectives,” *Comput. Electron. Agric.*, vol. 155, pp. 103–120, Dec. 2018, doi: 10.1016/j.compag.2018.10.001.

[29] K. A. Al-Gaadi *et al.*, “Prediction of Potato Crop Yield Using Precision Agriculture Techniques,” *PLOS ONE*, vol. 11, no. 9, p. e0162219, Sep. 2016, doi: 10.1371/journal.pone.0162219.

[30] E. Houshyar, P. Smith, M. Mahmoodi-Eshkaftaki, and H. Azadi, “Sustainability of wheat production in Southwest Iran: A fuzzy-GIS based evaluation by ANFIS,” *Cogent Food Agric.*, vol. 3, no. 1, p. 1327682, Jan. 2017, doi: 10.1080/23311932.2017.1327682.

[31] M. L. Mann and J. M. Warner, “Ethiopian wheat yield and yield gap estimation: A spatially explicit small area integrated data approach,” *Field Crops Res.*, vol. 201, pp. 60–74, Feb. 2017, doi: 10.1016/j.fcr.2016.10.014.

[32] S. Mondal, C. Jeganathan, N. K. Sinha, H. Rajan, T. Roy, and P. Kumar, “Extracting seasonal cropping patterns using multi-temporal vegetation indices from IRS LISS-III data in Muzaffarpur District of Bihar, India,” *Egypt. J. Remote Sens. Space Sci.*, vol. 17, no. 2, pp. 123–134, Dec. 2014, doi: 10.1016/j.ejrs.2014.09.002.

[33] M. Singha, J. Dong, G. Zhang, and X. Xiao, “High resolution paddy rice maps in cloud-prone Bangladesh and Northeast India using Sentinel-1

data," *Sci. Data*, vol. 6, no. 1, p. 26, Apr. 2019, doi: 10.1038/s41597-019-0036-3.
[34] G. Yang *et al.*, "Unmanned Aerial Vehicle Remote Sensing for Field-Based Crop Phenotyping: Current Status and Perspectives," *Front. Plant Sci.*, vol. 8, p. 1111, Jun. 2017, doi: 10.3389/fpls.2017.01111.
[35] P. Mangalraj and B.-K. Cho, "Recent trends and advances in hyperspectral imaging techniques to estimate solar induced fluorescence for plant phenotyping," *Ecol. Indic.*, vol. 137, p. 108721, Apr. 2022, doi: 10.1016/j.ecolind.2022.108721.
[36] A. Hajjarpoor *et al.*, "Characterization of the main chickpea cropping systems in India using a yield gap analysis approach," *Field Crops Res.*, vol. 223, pp. 93–104, Jun. 2018, doi: 10.1016/j.fcr.2018.03.023.
[37] I. Amjad *et al.*, "EVALUATION OF THE TOLERANCE OF RICE (ORYZA SATIVA) FOR SUBMERGENCE AND DROUGHT USING VARIOUS YIELD RELATED STRESS INDICES," *Biol. Clin. Sci. Res. J.*, vol. 2022, no. 1, Sep. 2022, doi: 10.54112/bcsrj.v2022i1.106.
[38] S. Kokhan and A. Vostokov, "Using Vegetative Indices to Quantify Agricultural Crop Characteristics," *J. Ecol. Eng.*, vol. 21, no. 4, pp. 120–127, May 2020, doi: 10.12911/22998993/119808.
[39] Y. Zhao, A. B. Potgieter, M. Zhang, B. Wu, and G. L. Hammer, "Predicting Wheat Yield at the Field Scale by Combining High-Resolution Sentinel-2 Satellite Imagery and Crop Modelling," *Remote Sens.*, vol. 12, no. 6, p. 1024, Mar. 2020, doi: 10.3390/rs12061024.
[40] P. Shanmugapriya, S. Rathika, T. Ramesh, and P. Janaki, "Applications of Remote Sensing in Agriculture - A Review," *Int. J. Curr. Microbiol. Appl. Sci.*, vol. 8, no. 01, pp. 2270–2283, Jan. 2019, doi: 10.20546/ijcmas.2019.801.238.
[41] Maram Bhargav Reddy and Dumpapenchala Vijay Reddy, "Recent Applications of Remote sensing in Agriculture-A Review," Aug. 2023, doi: 10.5281/ZENODO.8216660.
[42] M. Dwivedi, S. Saxena, Neetu, and S. S. Ray, "ASSESSMENT OF RICE BIOMASS PRODUCTION AND YIELD USING SEMI-PHYSICAL APPROACH AND REMOTELY SENSED DATA," *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.*, vol. XLII-3/W6, pp. 217–222, Jul. 2019, doi: 10.5194/isprs-archives-XLII-3-W6-217-2019.
[43] M. Vo Quang and H. Tran Thi, "Delineation of Rice Yield and Production in Combination of Crop Model and Remote Sensing," *Emir. J. Food Agric.*, Nov. 2023, doi: 10.9755/ejfa.2023.3172.
[44] S. M. H. Raza *et al.*, "Estimation of Net Rice Production by Remote Sensing and Multi Source Datasets," *Sarhad J. Agric.*, vol. 35, no. 3, 2019, doi: 10.17582/journal.sja/2019/35.3.955.965.
[45] M. Maki, K. Sekiguchi, K. Homma, Y. Hirooka, and K. Oki, "Estimation of rice yield by SIMRIW-RS, a model that integrates remote sensing data into a crop growth model," *J. Agric. Meteorol.*, vol. 73, no. 1, pp. 2–8, 2017, doi: 10.2480/agrmet.D-14-00023.
[46] R. Mandapati, M. K. Gumma, D. R. Metuku, and S. Maitra, "Field-level rice yield estimations under different farm practices using the crop simulation model for better yield," *Plant Sci. Today*, Oct. 2023, doi: 10.14719/pst.2690.
[47] J. Wang *et al.*, "Field-Scale Rice Yield Estimation Using Sentinel-1A Synthetic Aperture Radar (SAR) Data in Coastal Saline Region of Jiangsu Province, China," *Remote Sens.*, vol. 11, no. 19, p. 2274, Sep. 2019, doi: 10.3390/rs11192274.
[48] P. Arumugam, A. Chemura, B. Schauberger, and C. Gornott, "Remote Sensing Based Yield Estimation of Rice (Oryza Sativa L.) Using Gradient Boosted Regression in India," *Remote Sens.*, vol. 13, no. 12, p. 2379, Jun. 2021, doi: 10.3390/rs13122379.
[49] D. Yanti, I. Safitri, R. Rusnam, and E. Stiyanto, "Rice Productivity Estimation Using Remote Sensing Method," *J. Tek. Pertan. Lampung J. Agric. Eng.*, vol. 11, no. 3, p. 451, Sep. 2022, doi: 10.23960/jtep-l.v11i3.451-465.
[50] M. N. Reza, I. S. Na, S. W. Baek, and K.-H. Lee, "Rice yield estimation based on K-means clustering with graph-cut segmentation using low-altitude UAV images," *Biosyst. Eng.*, vol. 177, pp. 109–121, Jan. 2019, doi: 10.1016/j.biosystemseng.2018.09.014.
[51] N. Yuan *et al.*, "UAV Remote Sensing Estimation of Rice Yield Based on Adaptive Spectral Endmembers and Bilinear Mixing Model," *Remote Sens.*, vol. 13, no. 11, p. 2190, Jun. 2021, doi: 10.3390/rs13112190.
[52] K. Bolanio, L. R. P. Cubio, and E. A. Osin, "Estimating rice crop yield based on the Sentinel-1A C-band SAR data: a focus in the rice granary capital of Agusan del Sur, Philippines," in *Eighth Geoinformation Science Symposium 2023: Geoinformation Science for Sustainable Planet*, C. M. Roelfsema, A. Besse Rimba, S. Arjasakusuma, and A. Blanco, Eds., Yogyakarta, Indonesia: SPIE, Jan. 2024, p. 44. doi: 10.1117/12.3009655.
[53] B. L. Tan and M. E. Norhaizan, "Production of Rice By-products," in *Rice By-products: Phytochemicals and Food Products Application*, Cham: Springer International Publishing, 2020, pp. 13–39. doi: 10.1007/978-3-030-46153-9_3.
[54] A. Dabees, M. Ramadan, and A. Lisec, "A Review of Rice Straw Utilization Opportunities as Low Cost Agriculture in Egypt," in *XVI. International Conference on Logistics in Agriculture 2022: Conference Proceedings*, University of Maribor Press, Nov. 2022, pp. 19–32. doi: 10.18690/um.fl.1.2022.2.
[55] G. Athira, A. Bahurudeen, and S. Appari, "Sustainable alternatives to carbon intensive paddy field burning in India: A framework for cleaner production in agriculture, energy, and construction industries," *J. Clean. Prod.*, vol. 236, p. 117598, Nov. 2019, doi: 10.1016/j.jclepro.2019.07.073.
[56] A. Alengebawy, Y. Ran, N. Ghimire, A. I. Osman, and P. Ai, "Rice straw for energy and value-added products in China: a review," *Environ. Chem. Lett.*, vol. 21, no. 5, pp. 2729–2760, Oct. 2023, doi: 10.1007/s10311-023-01612-3.
[57] G. Singh, M. K. Gupta, S. Chaurasiya, V. S. Sharma, and D. Y. Pimenov, "Rice straw burning: a review on its global prevalence and the sustainable alternatives for its effective mitigation," *Environ. Sci. Pollut. Res.*, vol. 28, no. 25, pp. 32125–32155, Jul. 2021, doi: 10.1007/s11356-021-14163-3.
[58] B. A. Goodman, "Utilization of waste straw and husks from rice production: A review," *J. Bioresour.*

Bioprod., vol. 5, no. 3, pp. 143–162, Aug. 2020, doi: 10.1016/j.jobab.2020.07.001.
[59] H. S. A. Abdelaal and D. Thilmany, "Grains Production Prospects and Long Run Food Security in Egypt," *Sustainability*, vol. 11, no. 16, p. 4457, Aug. 2019, doi: 10.3390/su11164457.
[60] G. Jyothsna, A. Bahurudeen, and P. K Sahu, "Sustainable utilisation of rice husk for cleaner energy: A circular economy between agricultural, energy and construction sectors," *Mater. Today Sustain.*, vol. 25, p. 100667, Mar. 2024, doi: 10.1016/j.mtsust.2024.100667.
[61] Y. Jiang *et al.*, "Acclimation of methane emissions from rice paddy fields to straw addition," *Sci. Adv.*, vol. 5, no. 1, p. eaau9038, Jan. 2019, doi: 10.1126/sciadv.aau9038.
[62] C. El-dewany, A. Zaghloul, and F. Awad, "Utilization of Rice Straw as a Low-Cost Natural By-Product in Agriculture," 2018.
[63] May Rose Boston-Osoteo, Aldwin Jason B. Pontillo, and Arnold G. Apdohan, "UTILIZATION AND EVALUATION OF RICE HUSK ASH AND COCONUT SHELL ASH AS PARTIAL CEMENT REPLACEMENT FOR CONCRETE HOLLOW BLOCKS PRODUCTION," *Proc. Int. Exch. Innov. Conf. Eng. Sci. IEICES*, vol. 8, pp. 360–365, Oct. 2022, doi: 10.5109/5909117.
[64] Y. Zou and T. Yang, "Rice Husk, Rice Husk Ash and Their Applications," in *Rice Bran and Rice Bran Oil*, Elsevier, 2019, pp. 207–246. doi: 10.1016/B978-0-12-812828-2.00009-3.
[65] K. Gul, B. Yousuf, A. K. Singh, P. Singh, and A. A. Wani, "Rice bran: Nutritional values and its emerging potential for development of functional food—A review," *Bioact. Carbohydr. Diet. Fibre*, vol. 6, no. 1, pp. 24–30, Jul. 2015, doi: 10.1016/j.bcdf.2015.06.002.
[66] A. Kumar *et al.*, "Economic and sustainable management of wastes from rice industry: combating the potential threats," *Environ. Sci. Pollut. Res.*, vol. 24, no. 34, pp. 26279–26296, Dec. 2017, doi: 10.1007/s11356-017-0293-7.
[67] C. A. Moraes *et al.*, "Review of the rice production cycle: By-products and the main applications focusing on rice husk combustion and ash recycling," *Waste Manag. Res. J. Sustain. Circ. Econ.*, vol. 32, no. 11, pp. 1034–1048, Nov. 2014, doi: 10.1177/0734242X14557379.