Nanees Abakar
Roosevelt High School
Des Moines, Iowa, USA
Bangladesh, Sustainable Agriculture

Agroecology: The Secret to a Sustainable Future

Abstract

Child malnutrition rates are high in Rohingya refugee camps. According to the United Nations' 2023 estimates, over 57,000 children under five in the camps suffer from acute malnutrition (United Nations, 2024). Population density influences issues such as malnutrition and scarcity; Bangladesh, for instance, is a densely populated country with around 171,186,372 people (The World Bank, 2022). The urban population is around 39.71%, and 60.29% resides in rural areas (Kameke, 2024). However, lower urbanization in Bangladesh means a significant portion of the population does not have access to quality employment or housing (United Nations, 2020). The average household size in rural areas is 4.3 people, and most dwelling units in rural Bangladesh are in poor condition and are built with temporary materials, such as bamboo and reed (Bangladesh Bureau of Statistics, 2023). In terms of land, 62.3% of land in Bangladesh is arable (The Global Economy, n.d.). Additionally, eight million hectares of land are being utilized (Macrotrends, n.d.). In comparison to the average farm size in the U.S., Bangladeshi farm sizes are on average 1,877 times smaller (Shahbandeh, 2024). Many rural residents in Bangladesh make their living from agriculture and are unable to make adequate incomes to survive (Land Links, n.d.). Farmers utilize traditional subsistence farming to produce products such as rice, fruits, fish, and dairy and produce food from the limited amount of land available to them (Hix, 2006; International Trade Administration, 2022). As a result, scarcity is a significant issue within Bangladesh. Due to its dense population and limited resources, Bangladesh is particularly at risk of climate change and famine. This research paper explores improving sustainability within Bangladesh through utilizing agroecology, organically focused agriculture, polyculture, backyard farms, community-supported agriculture, permaculture, and artificial intelligence (AI) in conjunction.

Background and Context

Daily consumption needs in Bangladesh are often unmet because nutritious foods are not easily accessible at local shops. Foods like meat, eggs, and fish account for less than 10 percent of a rural person's diet, and flash floods and droughts can lead to food shortages (Rahman & Ferdousee, 2023). The typical rural diet in Bangladesh is not well-balanced due to the methods of food preparation; rice and cereal are the main foods consumed in Bangladesh, and minerals and vitamins are lost while washing rice before cooking. Occasionally, vegetables, fish, meat, and dairy products are eaten when available. However, many citizens in Bangladesh are not receiving the necessary proteins and micronutrients to be fully healthy. Barriers such as high food prices and transportation are prompting people in Bangladesh to consume vegetables and fruits less (Bhattacharjee et al., 2007).

Moreover, a study on the impact of welfare on market participation, led by Mohammad Hoq (a scientific officer at Bangladesh's Agricultural Research Institute), found that most farmers living in remote areas face insufficient transportation and poor market infrastructure. As a result, market access for Bangladesh's citizens in rural areas becomes significantly difficult (Hoq et al., 2021). Additionally, a research study spearheaded by Hitomi Hinata, a University of Tokyo graduate and specialist in global health policy, discovered that over two-thirds of women from Bangladesh report experiencing at least one perceived barrier to accessing healthcare. However, women who were in the richest wealth percentile or who owned a mobile telephone had lower rates of experiencing barriers to healthcare (Hinata et al., 2024). Socioeconomic status heavily influences accessibility to resources; while people in rural areas

struggle with access to local markets and health care, low-income people within urban centers commonly experience unstable employment and inhabit unhygienic and cramped areas (Action on Poverty, n.d.).

Moreover, challenges to fully obtaining sustainability within Bangladesh's agriculture are a lack of arable land and low agricultural productivity. Bangladesh is susceptible to destructive weather events (Burlingame et al., 2019). When impoverished people are unable to buy new equipment, sustainable farming becomes unrealistic for poor farmers; rural farmers do not have a backup source of income, and they are often forced to migrate to urban areas or sell their livestock (Shinde & Modak, 2013). As a result, unstable weather increases poverty for those who rely on farming for their livelihood in Bangladesh.

Furthermore, rapid urbanization in Bangladesh is negatively impacting the ecological balance. Farmland is decreasing at a rate of almost 1% every year. It is estimated that if Bangladesh continues losing farmland, there will be no usable land left after 2050. With support from other nations, Bangladesh's government is following sustainable methods for its agriculture, and longevity in Bangladesh is steadily improving (The Borgen Project, 2018). A significant challenge for food and soil security is land degradation. Bangladesh's government has shown interest in reversing land degradation by 2030. However, research finds that only the soil carbon stock is improving in Bangladesh. The rates of soil erosion, deforestation, and landslides are continuing to increase. The soil health of Bangladesh is negatively impacted by weak soil governance (Khan & Shoumik, 2022). Unplanned urbanization and rapid industrialization have caused over 69,000 hectares of agricultural land to decline yearly. Surges of refugees, like the Rohingya, migrating to areas cause a significant amount of deforestation within Bangladesh. The Rohingya's exposure to environmental disasters has increased due to the scale of environmental destruction (Ahmed et al., 2021). The infrastructure and concentrated population both contribute to cities becoming vulnerable to climate change and other environmental stressors within urban areas. Thus, food sustainability in Bangladesh is also becoming vulnerable (Rezvi, 2018).

Moreover, Dravidians are one of the oldest ethnic communities in Bangladesh and are mainly represented by the Santals, the biggest ethnic minority in Bangladesh's northern area (Ahsan, 2019). Agriculture is the main source of income for the Santals; they mainly farm crops like rice, tobacco, mustard, leafy vegetables, and cotton, and their farming practices are centered around traditional methods, such as shifting cultivation. The Santals also engage in fishing to fulfill their diet and raise livestock (Carrin-Bouez, 1998). However, barriers like climate change and seasonal flooding are making it difficult for them to sustain their traditional farming practices (Ahsan, 2019). Due to a lack of sustainability, there is a lack of resources available to sustain Bangladesh's dense population. However, there is a way to reduce this problem.

Solution

Agroecology consists of organically focused agricultural practices, and it is the solution to improving sustainability within Bangladesh. Cuba is known for transforming its agriculture into a sustainable model through agroecology. When Cuba lost access to mechanized farming and fossil fuel-reliant systems, they utilized and replaced them with permaculture (the development of agricultural ecosystems intended to be sustainable and self-sufficient) systems (Oxford English Dictionary, 2023). In 1991, the Soviet Union collapsed and removed economic aid. In consequence, Cuba was drained of oil, staple foods, and industrial farming systems. Citizens in Cuba became severely malnourished due to an increased reliance on rural farms (Our Changing Climate, 2018). The first initiatives Cuba took in shifting their agriculture system were utilizing biofertilizers and biopesticides combined with crop rotation, agroforestry, and crop-livestock integration. Then, Cuba utilized community-supported agriculture led by the National Small Farmers' Association; this involved utilizing non-government organizations (NGOs), public policies, government, and research institutes (Agroecology Info Pool, n.d.).

Bangladesh's agricultural situation is like the special period in Cuba because a significant amount of Bangladesh's population heavily relies on small-scale farmers and is experiencing malnutrition. Current food markets are not enough to feed the growing and dense population of Bangladesh. Implementing a similar agriculture model to Cuba's may make it possible for food markets to work better when they are smaller and isolated. This solution involves four parts: organically focused agriculture and polyculture, community-supported agriculture, backyard farms, and technological implementation.

Organically Focused Agriculture and Polyculture

The framework for implementing agroecology within Bangladesh involves creating a development strategy for both farm and non-farm growth, rapid diversification in agriculture, and improving the policy framework (World Bank, 2016). More specifically, a policy framework that supports the transition to agroecology may look like the expansion of land tenure, the localization of the food systems, and a rise in domestic agricultural markets (Machado & Healy, 2024). Agroecology is sustainable because it integrates diverse crops and non-crop species and copies the diverse organisms living in nature (Orion, n.d.).

Polyculture, a part of agroecology, involves growing a diverse number of crops in the same area; this results in decreased plant susceptibility to pests and increased soil health. Other agroecological technologies involve crop rotation, intercropping, and crop-livestock integration (Woodland Trust, n.d.). To utilize regenerative farming practices, there must be a transition to cross-value collaboration and a prioritization of ecosystem services through policy and legislation. Currently, the most used pesticides in Bangladesh are chlorpyrifos and dimethoate (Khatun et al., 2023). These pesticides can contaminate soil, sediment, and water ecosystems (Dar et al., 2019). A transition to biofertilizers and biopesticides is low in cost and more sustainable. On a different note, agroforestry is integrating trees into agriculture systems. This implementation of agroecology can help sustain agriculture during Bangladesh's unpredictable weather. For instance, trees can absorb rainwater and reduce the impact of flooding and erosion because they slow down the flow of rainwater (U.S. Department of Agriculture, 2024).

Community-Supported Agriculture

When small market farms are given the space to thrive, they can sustain growing populations. For instance, Miguel Salcine is the founder of Viva el al Ahmar in Havana. His farm is 27 acres but produces food for 80,000 people. Currently, Havana produces 90% of its food from small market farms (Our Changing Climate, 2018). Inspired by Cuba, Bangladesh's government would be responsible for funding and integrating natural pesticides. Yet, there may be resistance from the government to fund support in agroecology. Nurul Mohaimin Milton, general secretary of Bangladesh Paribesh Sangbadik Samity, states there is a lack of protection laws for agricultural land, which warrants the destruction of arable land (The Borgen Project, 2018). However, it is in the government's best interest to work in conjunction with its citizens. Cuba was able to thrive because they were in a moment of crisis and the government strongly backed the small-scale organic revolution. Cuba's success in sustaining its population with small-scale farmers should serve as an inspiration for Bangladesh's government to invest in agroecology. Additionally, research institutes and NGOs can help lower the cost of funding.

A study conducted by Mahbubur Rahman, an associate professor at the International Standard University, and Shamshad Ferdousee, an assistant professor of sociology at the State University of Bangladesh, found that community-based agriculture improves the consumption and production of food. They suggest that the government of Bangladesh upgrades social protection programs through open market sales (Rahman & Ferdousee, 2023). They also recommend that the Bangladeshi government consider implementing and funding organizations like the National Association of Small Farmers, as they were able to successfully support the spread of agroecology in rural Cuba (Fernandez et al., 2018). Continued investment in

community-based agriculture is needed to increase business jobs in smaller cities and rural areas that remain isolated. This solution will build a strong relationship between the community, farmers, and food.

Moreover, agroecology will open many job opportunities. For many ethnic minorities in Bangladesh, like the Dravidian people and rural ethnic groups, there is a high reliance on community (International Republican Institute, 2020). Community-supported agriculture connects local community members with farmers by acquiring weekly shares of locally grown items given by the grower throughout a period (Utah State University, 2016). Shareholders receive an upfront payment for the entire season's expenses. This funding aids in reducing the unpredictability of farming and helps cover the startup and manufacturing costs of items. Farmers are aware of who will receive food deliveries and the number of shareholders. Through planned workshops and activities, shareholders assist with agricultural labor such as picking, pruning, planting, and crop management. Community-supported agriculture in Bangladesh would involve growers hired by customers to work for them during the growing season (Bruch & Ernst, 2010). Community-supported agriculture and providing education on permaculture will ease the cultural transition to agroecology among the ethnic minorities in Bangladesh. Agroecology will give these ethnic minority groups a voice in their agriculture, land, and farming.

Backyard farms

Backyard farms are gardens managed by a community. The benefits of a backyard farm include the ease of moving crops during the same season, inexpensive costs compared to industrial farming, small spaces, and fewer garden pests. Local farmers that participate in subscription community-supported agriculture will market to the public to attract investors; farmers would then manage supply dates, pricing, and produce options (Bruch & Ernst, 2010). The unpredictability of marketing to public interest and engagement, weather, maintaining high-quality food, high initial costs, and land insecurity are limitations of backyard farms (Bruch & Ernst, 2010). There may either be too much or too little of a specific food product (McLaughlin, 2009). However, after initial costs, these farms offer financial stability for Bangladeshi citizens in the long run; more investment in agroecology will influence technological advancement and further increase the longevity of crops during unpredictable weather. Cuba is not the only example that proves sustainable agriculture works; a study that the American Chemical Society conducted discovered that sustainable farming methods could improve harvests by up to 80 percent within four years (The Borgen Project, n.d.). There is a strong incentive for the implementation of agroecology. This implementation involves education and awareness on agroecology, such as workshops in rural areas and partnerships with NGOs and developed countries like Japan, which has a history of collaborating with Bangladesh (Embassy of Japan in Bangladesh, n.d.).

Technological Implementations

Systems that play a major role in sustaining an agroecology-based agricultural system are technologies like soil moisture sensors and AI. Soil moisture sensors estimate the amount of water in soil and can be used to reduce the impact of flooding and drought (University of Minnesota Extension, 2019). If soil moisture sensors are paired with predictive weather systems, farmers can modify strategies based on predicted weather patterns (Marsh, 2023). Basic soil motion sensors would be the most appropriate to use for rural farmers and would cost around $10 to $50 per unit (NiuBol, 2023). In a singular rural area, 100 basic sensors would cost around $1,000 to $5,000. The costs for training farmers and local technicians on soil moisture sensor usage and maintenance may range from $500 to $2,000 for a small project. Moreover, solar panels for powering sensors may cost an additional $50 to $200 per sensor, and communication infrastructure, like routers and mobile data systems, could cost $500 to $5,000 (Bedord, 2020; Morris, Favor, & Rodriguez, 2022). Software for data collection and analysis could range anywhere from $500 to over $5,000, depending on the features and scale. Lastly, annual maintenance costs could be 10-20% of the initial hardware costs (Bedord, 2020; Morris, Favor, & Rodriguez, 2022; Soil Scout, n.d.).

On a larger scale, AI can be used in combination with soil motion sensors, agroecology, and permaculture in urban areas. With technological advancements and investment in AI, the efficiency and sustainability of permaculture-focused agriculture systems can improve. AI usage in Bangladesh is already being implemented, and in early 2024, the United Nations Educational Scientific and Cultural Organization (UNESCO) collaborated with the ICT Ministry and Aspire to Innovate to conduct assessments of AI literacy in Bangladesh. This project will help support Bangladesh in creating ethical AI guidelines and frameworks. Moreover, AI must be used ethically and in alliance with permaculture systems because permaculture focuses on promoting biodiversity and reducing reliance on non-renewable resources. UNESCO made major progress in addressing the ethical implications of AI and has created its Recommendation on the Ethics of AI (UNESCO, 2024).

However, AI would be inappropriate to use in rural areas of Bangladesh that do not have consistent access to electricity. AI can also affect data privacy, especially in rural areas, because AI heavily relies on data collection. Yet, AI can be extremely useful in data analysis; it can analyze data from soil sensors to monitor soil health, moisture levels, pH, and nutrient content. This can help farmers make informed decisions on how to manage soil. As a result, healthy ecosystems without an over-reliance on synthetic fertilizers can be promoted (Green & Caballero, 2024; DripWorks, 2024).

AI can also create permaculture design tools that can guide farmers in creating sustainable layouts based on local conditions and personalize lessons for each farmer. This can make permaculture more accessible to beginners and provide tailored advice and tutorials on permaculture practices (Green & Caballero, 2024). Existing programs like FarmOS use AI to track crop rotations, soil health, and other permaculture logistics (FarmOS, n.d.). Moreover, drone technology, like AI-powered drones, can survey permaculture sites and provide maps and data on plant health, water distribution, and soil conditions (Oluwafemidiakhoa, 2024). Investment in AI tools like these can support Bangladesh's transition to agroecology. Like Cuba, Bangladesh's government would be responsible for funding motion sensors, soil moisture sensors, and AI implementations; collaboration with non-profits like AI for Good (a nonprofit that collaborates with policy groups, think tanks, and other non-profits to assist in developing AI policy frameworks for national and international usage) and the USAID (a government organization that helps train farmers and commercial producers to adopt techniques that improve agricultural productivity) can also cut costs (Candid, n.d.; USAID, n.d.). Soil moisture sensors and AI can optimize irrigation and water efficiency, save costs in the long run, improve crop yields, and manage the impact of floods and droughts on crops.

Implications For Bangladesh's Ethnic Minorities

There are about 27 official ethnic minority groups in Bangladesh, with a combined population of approximately two million people in total. Bangladesh's ethnic minorities have their own languages and agricultural practices that are separate from mainstream Bengali society (International Republican Institute, 2020). It is a possibility that minorities in Bangladesh may become vulnerable to exploitation in the early stages of agroecology implementation. The International Republican Institute, an American nonprofit organization funded by the United States federal government, spearheaded a focus group study of plainland ethnic groups in Bangladesh to understand the challenges of minority groups. In all focus group discussions, participants mentioned preserving their land as a significant problem due to passive courts, illegal encroachment on ethnic areas, language barriers, and officials accepting bribes (International Republican Institute, 2020). Government resources are insufficient in remote areas with predominantly ethnic minority populations. For instance, Bangladesh's government offers allowances for vulnerable groups. However, these allowances are typically inaccessible to minorities because of remote government offices and officials accepting bribes (International Republican Institute, 2020). Implementation of agroecology involves the government providing shareholders with an upfront payment

for the entire season's expenses. Likewise, there may be resistance to regulating the upfront payment farmers receive. There must be policy changes that provide stricter regulations against the exploitation of minority communities in conjunction with permaculture systems. This involves a strong rule of law. Programs like the NCSC International Strengthening Rule of Law Program can provide support to Bangladesh during the early transition to agroecology. This will look like close collaboration with Justice and Parliamentary Affairs, the Ministry of Law, and the Judicial Administration Training Institute to create technical training and assistance in preventing bribery and exploitation of ethnic minorities in Bangladesh (National Center for State Courts International Programs, n.d.). Citizens must be aware of laws relating to bribery and exploitation, and there must be accountability upheld (fines or prison time) when laws are broken, even for government.

Additionally, Tessarae Mercer, an intern at the University of Washington Botanical Garden, conducted a study exploring barriers in sustaining a permaculture garden (Mercer, n.d.). She argues that education is vital in sustaining a permaculture model because permaculture is relatively new; many farmers in rural areas have not been exposed to concepts like “organic farming” and “sustainable agriculture” (Mercer, n.d.). If individuals do not have a clear understanding of permaculture, there may be a cultural resistance in transitioning to agroecology. However, education can raise awareness of practices like permaculture, and AI systems like Knewton and DreamBox can be used to make individualized curriculums for local farmers; there must be easily accessible electricity for AI to be utilized as an educational tool for those living in rural areas in Bangladesh (Goteka, n.d.; Knewton Alta, n.d.).

Conclusion

A successful sustainable agriculture model must function within communities, focus on biologically intensive farming on small-acre farms (due to Bangladesh’s lack of arable land), and rely on a web of farmers rather than a few large-scale operations. Yet, the limitations of agroecology are high initial costs, educational barriers, and cultural adjustments. However, technological advancements like soil moisture sensors and AI can be used to prevent the loss of agriculture during natural disasters. When policy is employed and Bangladesh’s current agriculture models are redesigned to be efficient, the elements of agroecology are utilized. As a result of implementing the steps of organically focused agriculture, backyard farms, community-supported agriculture, polyculture, and technologies like soil moisture sensors and AI, Bangladesh will be able to produce sustainable agriculture.

References

Action on Poverty. (n.d.). *Bangladesh.* Action on Poverty. https://actiononpoverty.org/our-impact/where-we-work/bangladesh/#:~:text=While%20those%20in%20rural%20areas

Agroecology Info Pool. (n.d.). *Cuba's agroecological revolution.* Agroecology Info Pool. https://www.agroecology-pool.org/portfolio/cubas-agroecological-revolution/

Ahmed, S., Simmons, W. P., Chowdhury, R., & Huq, S. (2021). The sustainability–peace nexus in crisis contexts: How the Rohingya escaped the ethnic violence in Myanmar, but are trapped into environmental challenges in Bangladesh. *Sustainability Science*, *16*(4), 1201–1213. https://doi.org/10.1007/s11625-021-00955-6

Ahsan, N. (2019, October 03). A 200-year-old practice is helping Bangladshi farmers adapt to climate change. *World Bank Blogs*. https://blogs.worldbank.org/en/endpovertyinsouthasia/200-year-old-practice-helping-bangladeshi-farmers-adapt-climate-change

Bangladesh Bureau of Statistics. (2023). Household income and expenditure survey HIES 2022. *2-10.* https://bbs.portal.gov.bd/sites/default/files/files/bbs.portal.gov.bd/page/57def76a_aa3c_46e3_9f80_53732eb94a83/2023-04-13-09-35-ee41d2a35dcc47a94a595c88328458f4.pdf

Bedord, L. (2020, November 30). *Sensors helping farmer better understand crops.* Successful Farming. https://www.agriculture.com/technology/data/sensors-helping-farmers-better-understand-crops

Bhattacharjee, L., Saha, S.K., & Nandi, B.K. (2007). *Food-based nutrition strategies in Bangladesh*. Food and Agriculture Organization. https://www.fao.org/3/ag126e/AG126E05.htm#:~:text=Cereals%2C%20largely%20rice%2C%20are%20the

Burlingame, B., Vogliano, C., & Eme, P. E. (2019). Chapter five - leveraging agricultural biodiversity for sustainable diets, highlighting pacific small island developing states. *Advances in food security and sustainability*. 4, 133-173.https://www.sciencedirect.com/science/article/abs/pii/S2452263519300060

Candid. (n.d.). *AI for good foundation.* Candid. https://www.guidestar.org/profile/81-1631000

Carrin-Bouez, M. (1998). *Culture summary: Santal*. HRAF. https://ehrafworldcultures.yale.edu/cultures/aw42/documents/000

Dar, M. A., Kaushik, G., & Villarreal-Chiu, J. F. (2019). Pollution status and bioremediation of chlorpyrifos in environmental matrices by the application of bacterial communities: A review. *Journal of Environmental Management*, *239*, 124–136. https://doi.org/10.1016/j.jenvman.2019.03.048

DripWorks. (2024, January 11). The role of artificial intelligence (AI) in smart irrigation systems. *DripWorks.* **https://www.dripworks.com/blog/the-role-of-artificial-intelligence-ai-in-smart-irrigation-systems**

Embassy of Japan in Bangladesh. (n.d.). Japan Bangladesh relations https://www.bd.emb-japan.go.jp/en/bilateral/jbrelation.html

FarmOS. (n.d.) FarmOS. **https://farmos.org/**

Fernandez, M., Nelson, E., Locke, K. A., Figueroa, G., & Funes, F. (2018). Cuba's agrifood system in transition, an introduction to the Elementa Special Feature. *Elementa: Science of the Anthropocene* (2018) *6*:75. https://doi.org/10.1525/elementa.335

Goteka, P. (n.d.). *Using artificial intelligence in the digital classroom.* Mobile Guardian, https://www.mobileguardian.com/using-artificial-intelligence-in-the-digital-classroom/

Green, D., & Caballero, M. (2024). Agriculture: Harnessing AI for healthier soils. *Open Access Government*, *42*(1), 414–415. https://doi.org/10.56367/oag-042-025-edit

Hinata, H., Lwin, Eguchi K. S., Ghaznavi, C., Hashizume, M., & Nomura, S. (2024). Factors associated with barriers to healthcare access among ever-married women of reproductive age in Bangladesh: Analysis from the 2017–2018 Bangladesh demographic and health survey. *PLOS ONE*, *19*(1). https://doi.org/10.1371/journal.pone.0289324

Hix, H. (2006). *Bangladesh: A Country at Risk*. World Food Prize. https://www.worldfoodprize.org/documents/filelibrary/images/youth_programs/research_papers/2006_papers/UnionHS_7370BB9127588.pdf

Hoq, M. S., Uddin, Md. T., Raha, S. K., & Hossain, M. I. (2021). Welfare impact of market participation: The case of rice farmers from wetland ecosystem in Bangladesh. *Environmental Challenges*. *5*, 100292. https://doi.org/10.1016/j.envc.2021.100292

International Republican Institute. (2020). *The challenges facing ethnic groups in Bangladesh: Land, dignity and inclusion.* Internation Republican Institute. https://www.iri.org/wp-content/uploads/2022/01/bangladesh-plainland-1_2.pdf

International Trade Administration. (2022, July 20). *Bangladesh – country commercial guide*. International Trade Administration. https://www.trade.gov/country-commercial-guides/bangladesh-agriculture-sectors#:~:text=Most%20agricultural%20production%20in%20Bangladesh

Kameke, L. (2024, February 28). *Share of rural population in Bangladesh from 2013-2022*. Statista. https://www.statista.com/statistics/760934/bangladesh-share-of-rural-population/

Khan, Z., & Shoumik, B. A. (2022). Land degradation neutrality concerns in Bangladesh. *Soil Security*, *9*(100075). https://doi.org/10.1016/j.soisec.2022.100075

Khatun, P., Islam, A., Sachi, S., Islam, Md. Z., & Islam, P. (2023). Pesticides in vegetable production in Bangladesh: A systemic review of contamination levels and associated health risks in the last decade. *Toxicology Reports*, *11*, 199–211. https://doi.org/10.1016/j.toxrep.2023.09.003

Knewton Alta. (n.d.). *Knewton adaptative learning and how it's unique.* Knewton Alta. https://support.knewton.com/s/article/Knewton-Adaptive-Learning-and-How-it-s-Unique

Land Links. (n.d.). *Bangladesh*. Land Links. https://www.land-links.org/country-profile/bangladesh/#:~:text=With%20a%20population%20density%20the

Machado, M. R., & Healy, M. (2024). Landscape multifunctionality, agroecology, and smallholders: a socio-ecological case study of the Cuban agroecological transition. *Landscape Research*, *49*(5), 685–703. https://doi.org/10.1080/01426397.2024.2329602

Macrotrends. (n.d.). *Bangladesh arable land 1961-2024*. Macrotrends. https://www.macrotrends.net/global-metrics/countries/BGD/bangladesh/arable-land

Marsh, J. (2023, June 8). *Ag tech providing solutions to drought-impacted farms.* Global Ag Tech Initiative. https://www.globalagtechinitiative.com/in-field-technologies/irrigation/ag-tech-providing-solutions-to-drought-impacted-farms/

Mercer, T. (n.d.). Permaculture: Barriers preventing farmers from integrating sustainable techniques and solutions to help overcome them. *University of Washington Bontanic Gardens.* Retrieved September 1, 2024 from **https://botanicgardens.uw.edu/wp-content/uploads/sites/7/2021/11/Permaculture_Capstone.pdf**

McLaughlin, C. (2009, December 19). *The advantages of growing backyard produce*. Fine Gardening. https://www.finegardening.com/article/the-advantages-of-growing-backyard-produce

Morris, M., Favor, K., & Rodriguez, O. (2022). *Soil moisture monitoring: Low-cost tools and methods.* National Center for Appropriate Technology. https://attra.ncat.org/publication/soil-moisture-monitoring-low-cost-tools-and-methods/

National Center for State Courts International Programs. (n.d.). *Bangladesh: Strengthening Rule of Law Program*. National Center for State Courts International Programs. https://www.ncscinternational.org/where-ipd-works/asia/2018/bangladesh-strengthening-rule-of-law-program

NiuBol. (2023, November 3). *Soil moisture sensor price*. NiuBol. https://www.niubol.com/Product-knowledge/Soil-Moisture-Sensor-Price.html

Oluwafemidiakhoa. (2024, June 29). *Navigating the skies: How autonomous drones and AI are revolutionizing logistics, agriculture, and surveillance.* Medium. **https://medium.com/kinomoto-mag/navigating-the-skies-how-autonomous-drones-and-ai-are-revolutionizing-logistics-agriculture-and-ed9c9edce2e2**

Orion. (n.d.). *This Cuban Town Has A Sustainability Lesson to Share*. Orion. https://orionmagazine.org/article/cuba-la-picadora-agroecology-sustainability/#:~:text=Rather%20than%20the%20oceanic%20monocultures

Our Changing Climate. (2018, July 20). *How Cuban agriculture went from industrial to sustainable* [Video]. YouTube. https://youtu.be/TZ0tovrhf5Y?si=bQmQNHzmnRkIUqGo

Oxford English Dictionary. (2023). Permaculture. In *Oxford English Dictionary.* https://doi.org/10.1093/OED/1087899309.

Rahman, M., & Ferdousee, S. (2023). Food security among the people living in rural Bangladesh: Insights from the northern region of the country. *Circular Agricultural Systems*, *3*(1). https://doi.org/10.48130/CAS-2023-0010

Rezvi, M. R. (2018). The factors of declining agricultural growth in Bangladesh and its impact on food security. *South Asian Journal of Social Studies and Economics*, 1(4), 1–9. https://doi.org/10.9734/sajsse/2018/v1i425810

Shinde, S. S., & Modak, P. (2013). Vulnerability of Indian agriculture to climate change. *Climate Vulnerability, 2.*, 139-152. https://doi.org/10.1016/b978-0-12-384703-4.00227-6

Shahbandeh, M. (2024, March 14). *Number and size of farms in the U.S. from 2012 to 2023*. Statista. https://www.statista.com/statistics/207273/number-and-size-of-us-farms/

Soil Scout. (n.d.). How to use wireless soil moisture sensors in smart farming. *Soil Scout.* https://soilscout.com/blog/how-to-use-wireless-soil-moisture-sensors-in-smart-farming-three-step-process

The Borgen Project. (2018, January 12). The Growth of Sustainable Agriculture in Bangladesh. *The Borgen Project.* https://borgenproject.org/sustainable-agriculture-in-bangladesh/#:~:text=Agriculture%20in%20Bangladesh%20is%20under

The Borgen Project. (n.d.). Sustainable farming in developing countries. *The Borgen Project* ***https://borgenproject.org/sustainable-farming-in-developing-countries/***

The Global Economy. (n.d.). *Bangladesh: Arable land, percent of land area*. The Global Economy. https://www.theglobaleconomy.com/Bangladesh/arable_land_percent/#:~:text=Arable%20land%2C%20percent%20of%20total%20land%20area&text=For%20that%20indicator%2C%20we%20provide

The World Bank. (2022). *Population, total-Bangladesh, world*. World Bank Open Data. https://data.worldbank.org/indicator/SP.POP.TOTL?most_recent_year_desc=true&locations=BD-1W

UNESCO. (2024, July 15). *The readiness assessment methodology (RAM).* UNESCO. https://www.unesco.org/en/articles/advancing-ai-ethics-bangladesh

United Nations. (2020, February 21). *Urbanization: Expanding opportunities, but deeper divides*. United Nations. https://www.un.org/development/desa/en/news/social/urbanization-expanding-opportunities-but-deeper-divides.html#:~:text=When%20properly%20planned%20and%20managed

United Nations. (2024, January 17). *Malnutrition: Baby Nur's story.* United Nations. https://bangladesh.un.org/en/257951-malnutrition-baby-nur%E2%80%99s-story?afd_azwaf_tok=eyJhbGciOiJSUzI1NiJ9.eyJhdWQiOiJiYW5nbGFkZXNoLnVuLm9yZyIsImV4cCI6MTcyNTIxMjkyMywiaWF0IjoxNzI1MjEyNjIzLCJpc3MiOiJ0aWVyMS05ZGM3N2RjNDgtaGJjbXAiLCJzdWIiOiI3NS4xNjIuMTEwLjc1IiwiZGF0YSI6eyJ0eXBlIjoiaXNzdWVkIiwicmVmIjoiMjAyNDA5MDFUMTc0MzQzWi1yMTlkYzc3ZGM0OGhiY21wOXVjcWZnZXRjbjAwMDAwMDA3azAwMDAwMDAwMDl6MWIiLCJiIjoieUJHckU0ZjBRQVRCUGZWS0g2cWNNVERwRzdwZ3RNeFRpYzR3WjAxaVdsbyIsImgiOiJOdWVoeE0tZGVIdkFRUlEwQ0lrOEduZ1hrVTkzanYxZFhEa1d2RENGcUVFIn19.HgctYPPy469aORWLxEumanPsg0P0O1Edqrkb8s8ielH13O-DEUYbnJOZmpwan7ey91PZW8k-dYU9xdL1QfjgChVlvVGCcvHoDm3CHRoSoSK-k3p6c0M00gnrhPmvCxogXG-6JabarIaWa11T2A0rH92lFhyPyM6jP2lQ3XtGSolMjc9wDsbSFZqKI3e1kta57c40DnL-Ry1SkNKivlgRpT1F8tIdWjdT577DFtM5P65-pyaX9il2s8CDOrmSgerTvpAH5J4vA5wRMuSaG__w33LgGTmHbIt2Ew8hoFCq9k8b5w6TxN-qerjd7kKyELYrbA7X89huc9Hz9djxl05u7Q.WF3obl2IDtqgvMFRqVdYkD5s

University of Minnesota Extension. (2019). *Soil moisture sensors for irrigation scheduling.* University of Minnesota Extension. https://extension.umn.edu/irrigation/soil-moisture-sensors-irrigation-scheduling

USAID. (n.d.). *Agriculture and food security.* USAID. https://www.usaid.gov/bangladesh/agriculture-and-food-security

U.S. Department of Agriculture. (2024). *Agroforestry.* U.S. Department of Agriculture. https://www.usda.gov/topics/forestry/agroforestry

Utah State University. (2016). *Community supported agriculture: Definition, benefits, barriers, and resources for growers*. Utah State University. https://extension.usu.edu/smallfarms/research/community-supported-agriculture-definition-benefits-barriers-resources

Woodland Trust. (n.d.). *Can woods and trees reduce flooding?* Woodland Trust. https://www.woodlandtrust.org.uk/trees-woods-and-wildlife/british-trees/flooding/