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They're Watching Us from Space?!? Using MODIS and Landsat Data to Monitor Evapotranspiration in Philippine Irrigation Systems

123.3 kg: the mass of 1,230 apples, two cougars, and the amount of rice consumed by the average Filipino in a year. Rice is a key crop for the Filipino people; it's eaten at most meals, central to indigenous rituals, and an important habitat for local flora and fauna. It's also a backbone of the island nation's agricultural economy. Of the 5.4 million hectares of arable land in the Philippines, 4.4 million hectares are used for rice farming. These figures obscure a disturbing question: if rice is central to Filipino rice, why must the agriculture-heavy country rely on foreign rice imports and continue to struggle with food security?

The Philippines is a nation composed of several small islands in Southeast Asia. It has a total land area of 298,170 sq km, with an estimated 41% of the land being used for agricultural purposes. Newly elected Ferdinand "Bongbong" Romualdez Marcos Jr. serves as president of the republic. His election in May of 2022 emerged from a platform that was "inherit[ed]" from Rodrigo Duterte, previous president of the Philippines and father of Marcos's running mate, Sara Duterte (Manahan 2022). Duterte's presidency had focused on improving infrastructure, combating corruption, initiating a controversial, zero tolerance war on drugs (Central Intelligence Agency, 2022). As of January 2022, the country has an estimated population of 111 million, and a little under 5 people live in each household. Around half of the population inhabit rural areas, but some cities – like the capital city of Manila – are home to millions of people. Most people work in service-oriented jobs, but the agricultural sector makes up a quarter of employment (Central Intelligence Agency, 2022). Farming is especially important for the wellbeing of those living in rural regions, where many farmers live in rural neighborhoods, called *barangays*, with their kin. Although urbanization in the last few decades has led to migration to urban areas, like Metro Manila, the population in the countryside has continued to rise. Households have access to electricity and indoor plumbing, but travel between regions remains difficult (Dolan, 1993).

The climate of the Philippines is tropical, with seasons generally being divided into a wet season and a dry season. Because of its environment, the Philippines is ideal for growing plants like bananas, corn, coconut, sweet potatoes, and mangos – hence the large agricultural labor force. In addition to fish and other seafood, these foods are staples to the Philippine diet (Hernandez, 2022). However, the most important crop is rice. Rice is central to Filipino meals, desserts, and alcohols (*Ricepedia*, 2022), and the crop maintains a special role in several indigenous rituals and beliefs. In addition to its economic and cultural value, rice paddies are important for the nation's biodiversity. From wild wetland birds to commercially raised fish, many animals call rice paddies home (de Jong, 2014).

Philippine demand for rice has made farmers of utmost importance to the economy. However, Filipino farmers often struggle to make ends meet. On average, farmers in the Philippines make less than USD 7 each day (Philippines Statistics Authority, 2019). Harvest yields are unpredictable because of the nation's vulnerability to typhoons, earthquakes, and other natural disasters. Poor infrastructure, especially in irrigation, worsens the impact of these natural disasters. Negative repercussions from this poor infrastructure have been exacerbated by the COVID-19 pandemic, with transportation and maintenance being more difficult than ever before (Conde, 2020 and Morales and Dela Crus, 2020). Additionally, increased rice imports have lowered rice prices and made it more difficult for Filipino farmers to earn a living. Governmental plans to achieve food self-sufficiency seem to grow more and more out of reach.

Because of its importance, improving rice yields and the lives of farmers have been central to Philippine governmental policy. One key aspect of this process has been boosting the efficacy of irrigation systems. More than two thirds of all Philippine rice crops are watered by irrigation systems. Although some of these systems are privately operated (*Philkoei*, 2022), the National Irrigation Administration (NIA) plans and maintain most irrigation projects in the Philippines (Inocencio, 2016). Past projects have largely focused on Central Luzon, but attempts are being made to revitalize other regions like Bicol and Mindanao (Sander, 1981).

Recent attempts to improve irrigation infrastructure include the Duterte administration's Build! Build! Build! plan. The Build! Build! Build! plan put forth by the Duterte administration has focused on improving transportation and public works, but it does not emphasize the agricultural sector (Heydarian, 2018). Complications from the COVID-19 pandemic have reduced the emphasis on agriculture and have extended timelines for many projects. However, the government has budgeted 1 trillion pesos (2 billion USD) into the program for 2022, with aims to improve irrigation-related issues like flood control (National Expenditure Program, 2022). While campaigning, President Marcos further asserted that his administration would be "more aggressive when it comes to irrigation targets" and that irrigation "will be one of the pillars of [the] agricultural program." (Rosario 2021). In addition to serving as president, Marcos also acts as Secretary of Agriculture and hopes to absorb the National Irrigation Administration (NIA) into his realm of influence.

There are many factors that contribute to weaknesses in Filipino irrigation systems, and a systemic overhaul would be necessary to combat them all. Technical issues, like operation deficiencies leading to increased water loss or inefficiency in using new technologies, are one contributor. At the management level, water thievery and ineffective leadership also contribute to faulty management. Furthermore, issues with collecting service fees and the complex relationship between Irrigation Associations (IAs), the NIA, and local farmers have limited the efficiency of systems (Inocencio and Barker, 2018).

Despite the numerous issues, one important problem is the disparity between operation and theoretical water yield. This stems from a lack of accurate estimates for crop water requirement (CWR). According to a 2014 assessment of four Philippine irrigation systems, the actual area irrigated by the system was consistently less than the planned areas (David and Tabio, 2014). This disparity was seen in each system, and it arose from a failure to account for wet season flooded areas, newly urbanized regions, and competition between domestic and irrigation water. Irrigation water is limited, especially in regions that utilize gravity-based irrigation and during the dry season (*Philkoei*, 2022). Conserving water is important to lower water costs for farmers and ensure sustainable water usage. Because they are frequently flooded, rice paddies require large amounts of water. Waterlogged soil can lead to methane emissions, and excess fresh water can become polluted. By ensuring that all water is maximized, a more sustainable agriculture system can be achieved. There are many factors influencing water usage, such as drainage rates, phenological stages, and crop type. However, one of the best ways to estimate CWR is through measuring evapotranspiration.

Evapotranspiration is the combination of water lost through soil evaporation and transpiration from crops. It is one of the most important factors in determining CWR in non-ideal conditions. Past methods of estimating evapotranspiration, as recommended by the Food and Agriculture Organization, include experimental data from the pan evaporation method or theoretical estimates from the Blaney-Criddle method (Brouwer and Heibloem, 1986). These methods, however, have proven inaccurate in large IAs that cover different environments, areas where weather conditions deviate from proposed norms, and on small IAs that lack proper training and technology.

New technologies, like commercially available satellite data, have opened new doors to estimate CWR. Studies done in West Java, Indonesia (Hongo, 2015). and the Saharanpur district of India (Kumari and Patel, 2013) have been successful in using satellite data to continuously calculate the water needed for rice throughout its growth cycle. Applying this technology to the Philippines would yield highly accurate values of evapotranspiration and water usage. These values would allow farmers to ensure all areas are equally irrigated, monitor current water usage, and adjust flooding rates. Using satellite data would create an equitable and economic solution for farmers and national organization like the NIA to properly irrigate rice paddies and decide which service areas are in most need of reform.

Satellites launched by the Landsat program, which began in 1972, contain the Thermal Infrared Sensors that provide regular thermal images of the earth. Using a method pioneered by Dutch researched Wim Bastiaanssen, Landsat data can be combined with information from local weather stations to map evapotranspiration in a model called Surface Energy Balance Algorithm for Land (SEBAL). SEBAL was later modified by American researchers to create Mapping Evapotranspiration with Internalized Calibration (METRIC). Until recently, however, these models required massive amount of downloading and computer processing. The Earth Engine, release by Google in 2010, cut out the process of storing and downloading data. Past models of evaluation evapotranspiration were adapted to the technology, and Earth Engine Evapotranspiration Flux (EEFlux) was created (Hall, 2018). Although tested in the United States, the METRIC-EEFLux model has proven effective in Italy (Nisa et al., 2021) and Mexico (Reyes-Gonzalez, 2018).

In the Philippines, studies on the efficacy of Landsat 7 in the Philippines have shown that the data is accurate, although they predate the creation of EEFlux (Hareez et al., 2002). It likely that data would be better now, as current technology uses data from Landsat 8. Landsat 8, which was launched in 2013, provides narrower spectral bands and improved calibration. When used with Landsat 7, it can provide thermal images every 8 days. With the launch of Landsat 9 in the September 2021, the data from the satellites will only continue to improve (*Landsat Science*, 2022).

Another satellite program that has been utilized in agriculture is the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the Terra and Aqua satellites. Unlike Landsat, MODIS provides daily updates on land conditions ("MODIS," 2021). These images, though lower quality that those provided by Landsat, would offer IAs more opportunities to adjust their water output. In addition to mapping evapotranspiration, MODIS can also map vegetation. For large IAs, this would aid in corroborating land-based methods of assessing rice paddy area. Estimating these areas would help Filipino IAs continuously adjust for urbanization (Xiao et al., 2006).

By combining MODIS and Landsat data, IA managers could regularly monitor evapotranspiration rates. When these rates are applied with other easily measured variables, they can be used to estimate CWR using methods established by the FAO. Many of these methods are currently in use; however, their current evapotranspiration data relies on theoretical values (Inocencio and Barker, 2018). With daily figures from MODIS and more specific, weekly values from Landsat, CWR would be constantly updated and applied to rice paddy flooding plans.

Because MODIS and Landsat data can be downloaded and analyzed off-site through EEFlux, the technology would be available to small IAs and rural regions. Currently, these regions assessment paddies through manual labor or drones; a free, web-based system would allow assessment to be quicker and communal. This saves money for both the farmers and the NIA. Although readily available, issues could be encountered in training managers on how to properly interpret data. The National Aeronautics and Space Administration's (NASA) Applied Remote Sensing Training (ARSET) provides free, online resources that train administrators in interpreting and applying MODIS and Landsat data ("ARSET Water Resources Trainings," 2022). Around 70% of the Philippine's rural population has access to fixed broadband internet, a figure that has been growing as the nation urbanizes (Sy, 2022). Most government-owned irrigation systems are in regions with infrastructure to support internet, making online training a possibility for administrators. Furthermore, the development of a centralized Irrigation Management Transfer program as a part of the Participatory Irrigation Development Project – a joint venture between World Bank and the Philippines that concluded in 2019 – has established a groundwork for standard training of farmers and irrigation managers (World Bank, 2019).

Although the cost of adapting MODIS and Landsat data as a metric to evaluate water distribution has a lower comparative cost than, say, building a dam, it is not negligible – especially in a country with extreme competition for financial resources, such as the Philippines. However, renewed government interest in irrigation systems (demonstrated by President Marcos's commitment to "100% coverage of our irrigable areas" and urging by outgoing Agriculture Secretary William Dar) would facilitate government spending on the project (Mendoza 2022). Although President Marcos's current plans to improve agriculture focus on water impounding facilities, they are not mutually exclusive with adapting MODIS and Landsat data. Rather, the data could be used as a metric to evaluate the efficiency of the impounding facilities, incentivizing its funding on an executive level. Beyond economic concerns, worries related to the time it takes to switch over to using MODIS and Landsat data may be present. However, the lack of large initial fees and promise of direct economic benefits should assuage those fear.

The implications of switching to a satellite-based method would expand beyond evaluating evapotranspiration. For example, future methods to conserve water could be more accurately tested. NIA renovation projects could be objectively assessed by measuring irrigation uniformity, changes in crop coverage, and evapotranspiration levels. This would maximize money spent on infrastructure. Rice growth stages could also be monitored, allowing farmers to harvest at the ideal moment. Another important effect that increased satellite usage would have for irrigation systems is the ability to better deal with natural disasters. MODIS data has already been used in the Philippines to evaluate damage (Boschetti, Mirco, et al, 2015), but training more rural farmers and small IAs would allow its positive impact to spread to regions that are worst impacts by disasters.

As the Filipino population continues to grow, it is imperative that staple crops, like rice, are produced at pace. More sustainable water usage would be a step towards helping the Philippines become food self-sufficient. By switching to a system that uses satellite data to evaluate crop water requirement, Filipino irrigation systems can better utilize decreasing water resources. Through rapid, efficient training at rural and centralized levels, the Philippines's irrigation would be provided with a much-needed boost, setting the systems up for future success.

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