INITIATIVE ON Asian Mega-Deltas

Suitability mapping for maize in the Mekong Delta, Cambodia

Lorena S. Villano[1], Jeny V. Raviz[1], Jorrel Khalil Aunario[1], Jane Girly Balanza[2], Alice G. Laborte[1]

[1]International Rice Research Institute

[2]Alliance of Bioversity International and CIAT

December 2024

Each crop has specific requirements to grow optimally in a given environment. Biophysical parameters such as climate, land and terrain, as well as, management practices, infrastructure and technological interventions (e.g., irrigation) could affect the suitability and productivity of a crop.

Biophysical suitability maps are useful in identifying locations and growing seasons (i.e. planting months) where and when crops can be grown. In addition, recommendations on cropping systems diversification can also be identified from the suitability maps of the priority crops in the Delta.

Materials and method

Biophysical suitability indicator was assessed based on the crop's requirements with respect to the climate conditions and land and terrain characteristics in the delta. Figure 1 shows the framework of the method for the suitability mapping. Climate suitability was evaluated using the EcoCrop model (Hijmans et al., 2001; Ramirez-Villegas et al., 2013) which considers monthly temperature and rainfall during a crop growing season. For the land and terrain suitability, the Land Use Suitability Evaluation Tool (Yen et al., 2006) was used with inputs including terrain (i.e. slope, flooding duration) and physical and chemical soil properties. Both models calculate suitability scores based on the parameters and threshold values defined for each crop. An overall suitability was derived from the combined climate, and land and terrain suitability outputs using the exponential/geometric mean method:

$$\text{Overall suitability} = f(S_T, S_R, S_L)$$
$$= (S_T * S_R * S_L)^{1/n}$$

where: S_T is the temperature suitability

S_R is the rainfall/water suitability

S_L is the land and terrain suitability

n is the number of factor groups

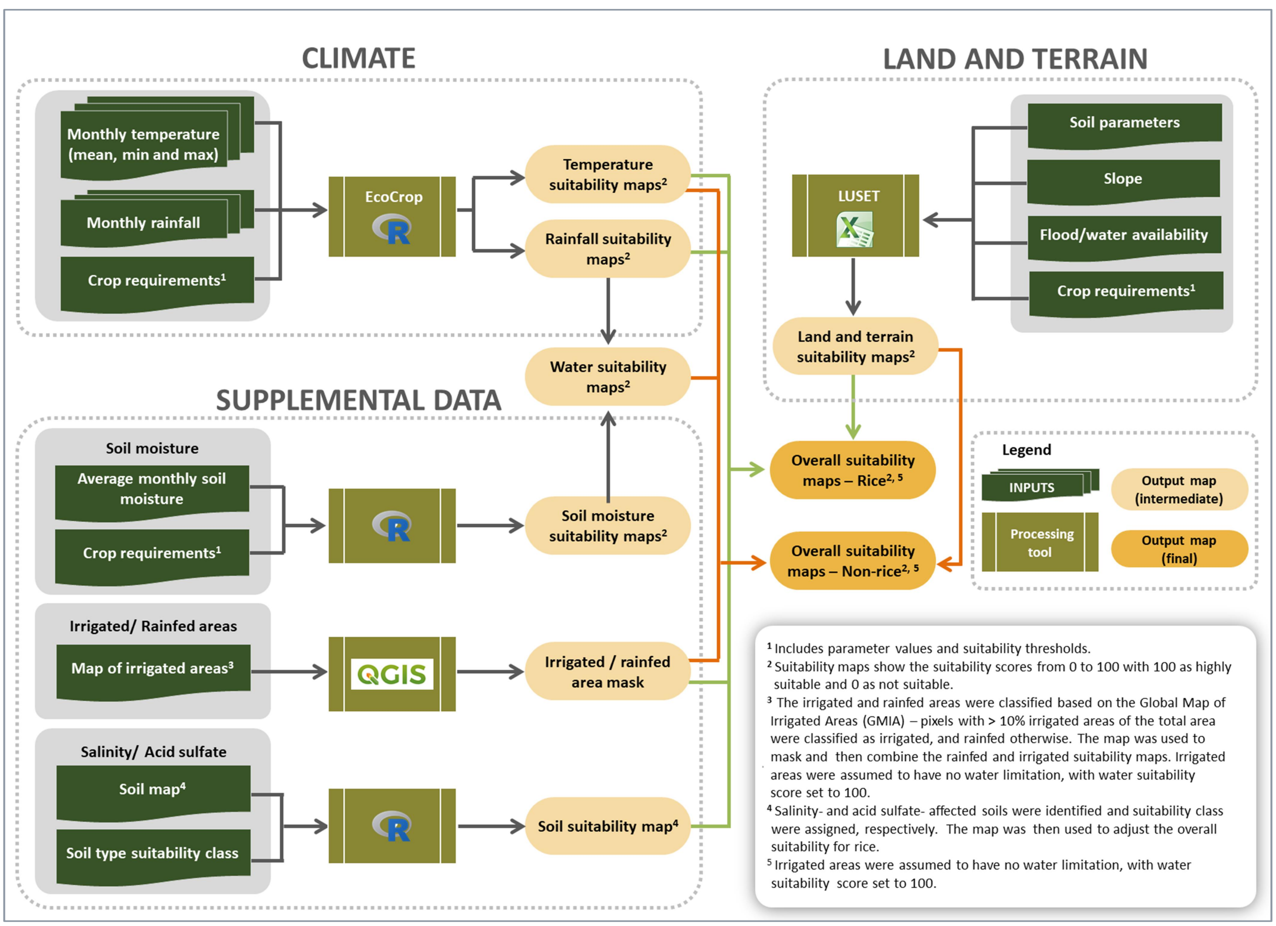
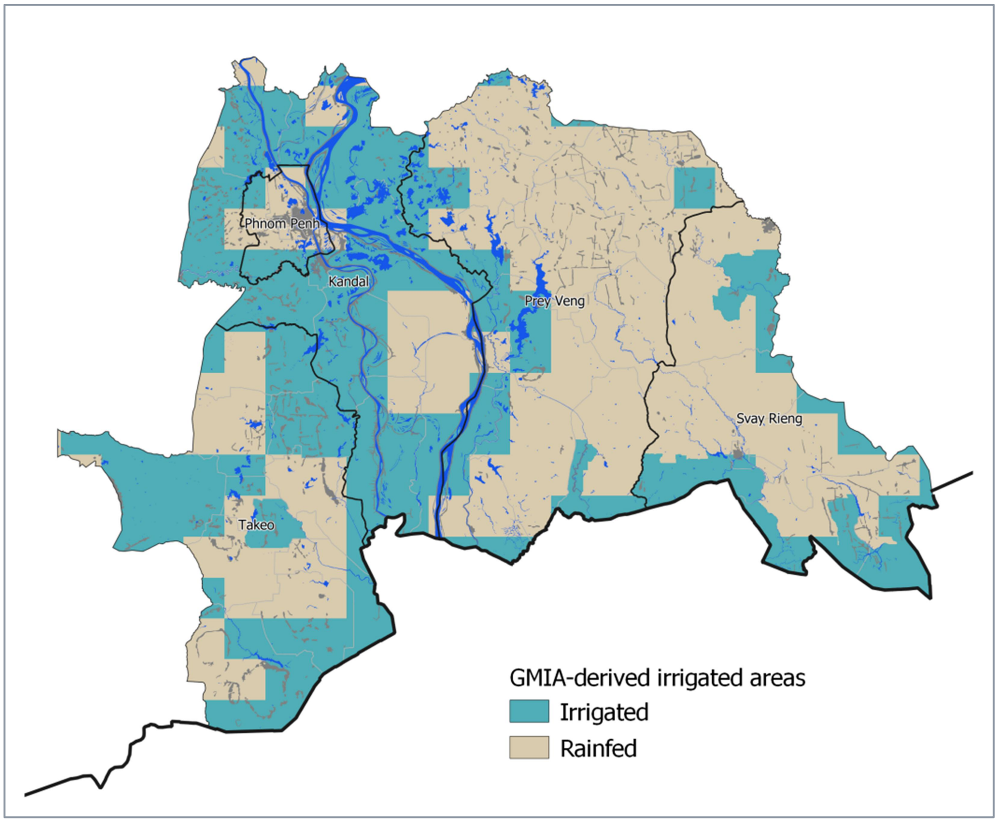


Figure 1. The methodological framework for crop suitability mapping.

Additional data on soil moisture, irrigation and saline and acid sulfate soils (where applicable) were also used to supplement and adjust the suitability scores. The irrigated and rainfed area map (Figure 2) was derived based on the Global Map of Irrigation Areas (GMIA V5.0; Siebert et al., 2013) wherein pixels which are > 10% irrigated were classified as irrigated, else rainfed. The map was shown to partners (agronomist/extension worker) from Provincial Department of Agriculture, Forestry and Fisheries (PDAFF) and updated based on their validation of the irrigated and rainfed areas in their respective provinces. Irrigated areas were assumed to have no water limitation, with water suitability score set to 100. The output is a map of overall suitability scores with values ranging from 0 to 100 with 0 as not suitable and 100 as highly suitable. Each map represents potential start of planting and the geographic distribution of suitability.

Tables 1 to 3 show the list of parameters and threshold values for the calculation of biophysical suitability for the maize crop.



Data Source: Global Map of Irrigation Areas (GMIA V5.0; Siebert et al., 2013).

Figure 2. Irrigated and rainfed areas in the Mekong Delta, Cambodia.

Table 1. Climate parameters and thresholds used for mapping the suitability of maize.

Climate parameters	Threshold values
Temperature	
Tkmp: absolute temperature that will kill the plant (°C)	0.8
Tmin: minimum average temperature at which the plant will grow (°C)	14
Topmin: minimum average temperature at which the plant will grow optimally (°C)	18
Topmax: maximum average temperature at which the plant will grow optimally (°C)	32
Tmax: maximum average temperature at which the plant will cease to grow (°C)	40
Rainfall	
Rmin: minimum rainfall (mm) during the growing season	300
Ropmin: optimal minimum rainfall (mm) during the growing season	500
Ropmax: optimal maximum rainfall (mm) during the growing season	1200
Rmax: maximum rainfall (mm) during the growing season	1800
Length of growing season:	
Gmin: Minimum length of the growing season (days)	120
Gmax: Maximum length of the growing season (days)	120

Basic data source: Adapted from LUSET (Sys et al., 1993).

Table 2. Soil moisture parameters and thresholds used for mapping the suitability of non-rice crops.

Soil moisture parameters[1]	Threshold values[2]
SMmin: minimum average soil moisture at which the plant will grow (volume %)	13
SMopmin: minimum average soil moisture at which the plant will grow optimally (volume %)	21
SMopmax: maximum average soil moisture at which the plant will grow optimally (volume %)	45
SMmax: maximum average soil moisture at which the plant will cease to grow (volume %)	53

[1] *The monthly average root-zone soil moisture (0 to 100 cm vertical average) from 2015 to 2022 was derived from the SMAP Level-4 (L4) soil moisture product (Reichle et al., 2022).*

[2] *Threshold values were based on expert's consultation and recommendation, Dr. Manoranjan Mondal of IRRI Bangladesh.*

Table 3: Terrain and soil parameters and suitability thresholds for maize as input to LUSET.

Land & terrain parameters	Threshold values						Weight	Description
	S3	S2	S1	S1	S2	S3		
Terrain								
Flood	2.5	2	1				1	Flooding (1 -no flood; 2 -short duration; 3 -long duration flood; 4 -very long duration / severe flood)
Drainage	4	3	2				2	Drainage (1 – good; 2 – moderate; 3 – imperfect; 4 – poor)
SlopeD	5	4	2				2	Slope (6 classes: 1 – 0 to 3 degrees; 2 – 3 to 8; 3 – 8 to 15; 4 – 15 to 20; 5 – 20 to 25; 6 – >25 degrees)
Soil characteristics								
CFragm	55	35	15				3	Coarse fragment (Vol. %)
SoilDpt	20	50	75				3	Soil depth (cm)
CaCO3	35	25	15				3	CaCO3 (%)
Gyps	20	10	4				3	Gypsum (%)
CECc	16	16	16				3	Apparent CEC Clay (cmol (+)/kg clay)
BS	20	35	50				2	Base Saturation (%)
SumBCs	2	3.5	5				3	Sum of basic cations (cmol (+)/kg soil)
pHH2O	5.2	5.5	5.8	7.8	8.2	8.5	2	pH H2O
ECedS	8	6	4				3	ECe (dS/m)
ESP	25	20	15				3	ESP (%)
OC	0.7	0.8	1.2				3	Organic carbon (%)
SoilTe	2	3	4	9	10		3	12 classes of soil texture (Soil Taxonomy)

Source: Sys et al., 1993

Notes:

1. *Suitability classes: S1 - highly suitable; S2 - moderately suitable; S3 - marginally suitable. Values which are greater than the upper threshold or less than the lower threshold are classified as not suitable.*
2. *Weight: Denotes the factor importance with 1 as very important and 3 as less important.*

The flooding duration data was generated from a map based on the multi-temporal MODIS 250m terra and aqua products. A Normalized Difference Flood Index (NDFI) was computed using the red (MODIS band 1) and the shortwave infrared (MODIS band 7) reflectance with the following formula:

$$NDFI = (red - SWIR) / (red + SWIR)$$

A pixel is classified as flooded/water based on the NDFI threshold value of > 0.08, and non-flooded/ -water, otherwise. Flooding duration was then estimated by identifying at least three (3) consecutive acquisitions with NDFI values > 0.08 within a temporal series. Three (3) consecutive acquisitions represent a 16-day period or interval. For annual crops, a 4-month flooding duration map was produced for each potential start of planting month, covering the four consecutive months starting from the planting month (i.e., Jan to Apr, Feb to May, …, Dec to Mar). For perennial crops, a flood duration map was derived based on the maximum period of flooding among all the flooding duration identified for every pixel within a year. These flood duration maps were derived for each year from 2003 to 2022, and the average was then calculated to generate the final flood duration maps. The map was then classified based on the criteria in Table 4.

Table 4. Criteria for flood classification based on duration.

Flood classes code and description	Flood duration in no. of consecutive acquisitions	Flood duration estimated in days
1 -no flood	< 4	< 32
2 -short duration	>=4 AND < 8	>=32 AND < 64
3 -long duration flood	>= 8 AND < 16	>= 64 AND < 128
4 -very long duration (severe) flooding	>=16 AND <=23	>=128 AND <=184
NA -permanent water	>23	>184

Very long duration flooding (4) represents flood duration of 4 to 6 months which is not permanent water but could be too long for most crops' suitability/survival. Longer than 6 months, the pixel was classified into permanent water (NA).

Results

The maps in Figure 3 show the monthly suitability for maize in the Mekong Delta in Cambodia. Maize is moderately to highly suitable in the majority of the provinces during both the dry and wet season months of December to April and May to October, respectively. While starting the month of June until October, flooded areas in the provinces of Takeo, Kandal and Prey Veng (dark orange areas in the maps) become not suitable for maize. Tables 5 and 6 show the estimated potential agricultural areas per province that are moderately to highly suitable for maize. Despite the unsuitable flooded areas in some months, maize can still be planted during the early wet season, making it suitable for almost the entire agricultural area in the region for both wet and dry season cropping. Validation of the suitability maps by local stakeholders and experts are needed to further improve the method and the results.

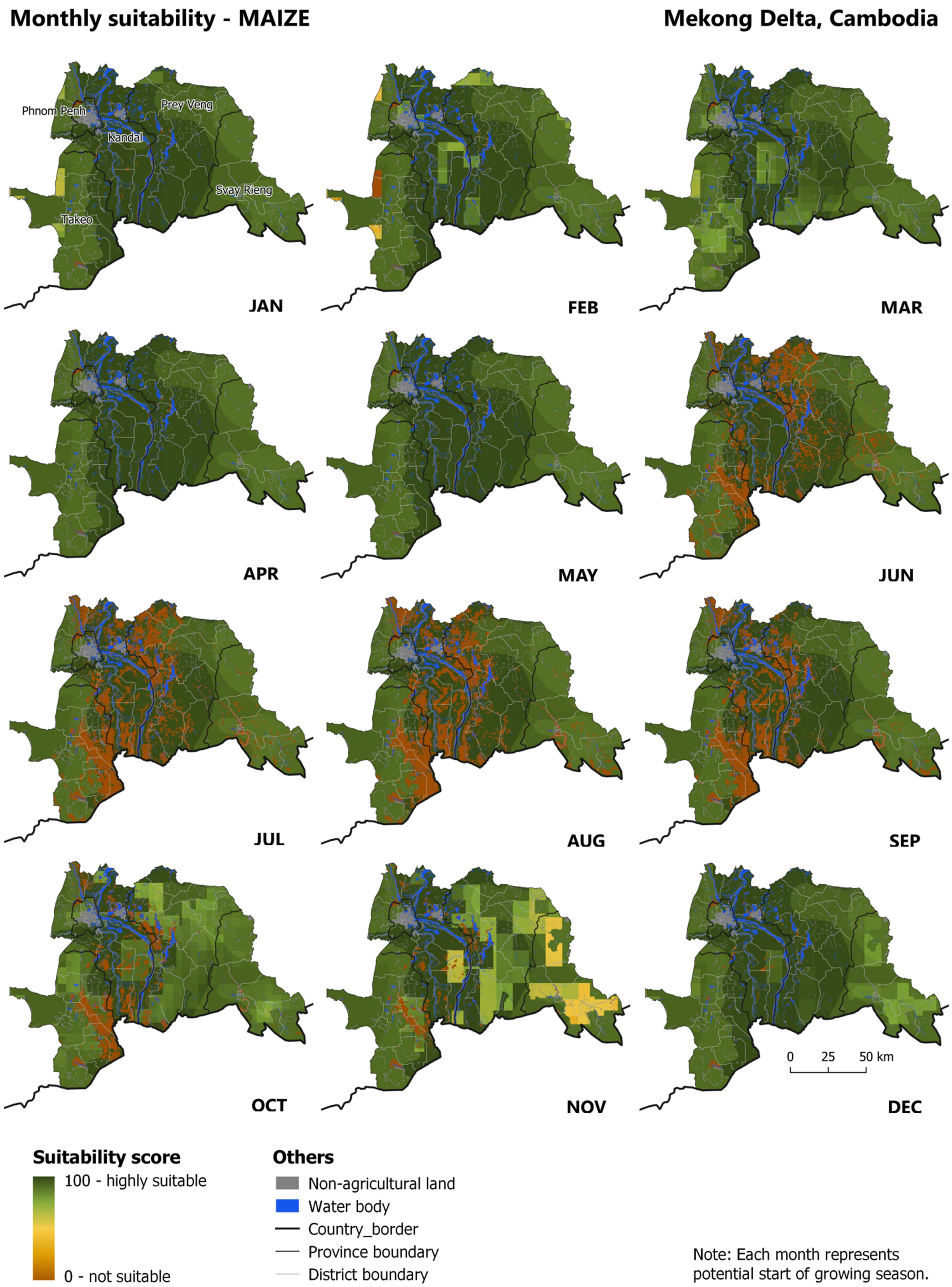


Figure 3. Monthly suitability for maize in the Mekong Delta, Cambodia.

Table 5. Agricultural area suitable for maize (wet season)[1].

Province	Total area (ha) [2]	Highly suitable[3]		Moderately suitable[4]	
		Area (ha)	% from total area	Area (ha)	% from total area
Kandal	287,851	280,723	97.5	12	0.00
Prey Veng	423,373	421,325	99.5	185	0.04
Svay Rieng	260,103	259,457	99.8	-	-
Takeo	311,616	310,395	99.6	225	0.07
Total	**1,282,944**	**1,271,900**	**99.1**	**423**	**0.03**

[1]Maize planted from April to October.

[2]Estimated based on the land use map of Cambodia, 2016 (GDA, MAFF). It includes the following land use classes which could potentially be used / suitable for agricultural crops: rice field; receding rice fields and floating rice fields; field crops; grassland; flooded grassland; swidden agriculture; shrubland; flooded shrub; barren land; and marsh or swamp.

[3]Derived based on the number of pixels with maximum suitability scores of >=85 across the monthly suitability maps that are classified as agricultural land area.

[4]Derived based on the number of pixels with maximum suitability scores of >=60 and <85 across the monthly suitability maps that are classified as agricultural land area.

Table 6. Agricultural area suitable for maize (dry season)[1].

Province	Total area (ha) [2]	Highly suitable[3]		Moderately suitable[4]	
		Area (ha)	% from total area	Area (ha)	% from total area
Kandal	287,851	280,680	97.5	386	0.13
Prey Veng	423,373	421,792	99.6	16	0.00
Svay Rieng	260,103	259,676	99.8	12	0.00
Takeo	311,616	310,424	99.6	218	0.07
Total	**1,282,944**	**1,272,572**	**99.2**	**632**	**0.05**

[1]Maize planted from November to March.

[2]Estimated based on the land use map of Cambodia, 2016 (GDA, MAFF). It includes the following land use classes which could potentially be used / suitable for agricultural crops: rice field; receding rice fields and floating rice fields; field crops; grassland; flooded grassland; swidden agriculture; shrubland; flooded shrub; barren land; and marsh or swamp.

[3]Derived based on the number of pixels with maximum suitability scores of >=85 across the monthly suitability maps that are classified as agricultural land area.

[4]Derived based on the number of pixels with maximum suitability scores of >=60 and <85 across the monthly suitability maps that are classified as agricultural land area.

Data sources

Data	Description	Data type/ Resolution	Source
Climate			
Monthly temperature (mean, minimum, and maximum)	Daily temperature data were used to derive the average monthly temperature from 1993 to 2022.	Raster 0.1°	AgERA5 (Boogaard et al., 2020)
Monthly rainfall	Daily rainfall data were used to derive the average monthly rainfall from 1993 to 2022.	Raster 0.05°	Climate Hazards Group InfraRed Precipitation with Stations (CHIRPS; Funk et al., 2014) https://www.chc.ucsb.edu/data/chirps
Crop requirement parameters for climate suitability	The list of climate parameters and threshold values for every crop are available at the FAO EcoCrop website. Threshold values for selected crops were updated accordingly based on consultation with experts.	CSV file	FAO-EcoCrop database (FAO, 2000) https://gaez.fao.org/pages/ecocrop
Land and terrain			
Soil map	Global spatial layer representing the soil mapping units to which the soil parameters can be linked.	Raster ~1 km	Harmonized World Soil Database version 2 (HWSD v2) https://gaez.fao.org/pages/hwsd; https://www.fao.org/documents/card/en/c/cc3823en
Soil parameters[1]	Selected soil data consolidated from the global dataset of HWSD v2. For this purpose, only the dominant soil within every soil mapping unit was considered. Additionally, the average values of the parameters from the 0 to 20 and 20 to 40 soil depth were used for annual crops.		FAO & IIASA. 2023. Harmonized World Soil Database Version 2.0. Rome and Laxenburg. https://doi.org/10.4060/cc3823en
Digital Elevation Model (DEM)	DEM maps are used to derive slope parameters (in degrees and in percentage).	Raster 90 meters	CGIAR-CSI Shuttle Radar Topographic Mission (SRTM; Jarvis et al., 2008) http://srtm.csi.cgiar.org
Flood duration	Flood duration maps (1 – no flood (<1 month); 2 – short duration flood (1 to 2 months); 3 – long duration flood (2 -4 months) Based on the Normalized Difference Flood Index (NDFI) derived from the 16-day composite MODIS 250m terra and aqua products (from 2003 to 2022).	Raster ~250 meters	Flood mapping methodology developed by IRRI (unpublished)
Crop requirement parameters for soil and terrain suitability	This dataset of suitability threshold is readily available and incorporated in the LUSET application.	Excel spreadsheets	LUSET (Sys et al., 1993)

Supplemental data			
Soil moisture	Average monthly root-zone soil moisture from 2015 to 2022 (0 to 100 cm vertical average)	Raster ~11km	SMAP Level-4 (L4) Soil moisture product (Reichle et al., 2022) https://nsidc.org/data/spl4smau/versions/7,
Irrigated area map	Used to identify areas equipped with irrigation - used to classify irrigated and rainfed areas; updated based on consultation with extension/agronomy staff from Provincial Department of Agriculture, Forestry and Fisheries (PDAFF), Cambodia	Raster ~10km	Global Map of Irrigation Areas V5.0 (GMIA) (Siebert, et al., 2013) https://www.fao.org/aquastat/en/geospatial-information/global-maps-irrigated-areas/latest-version/
Land use map of Cambodia (2016)	Map from which the agricultural lands were identified.	Vector (polygon shapefile)	General Directorate of Agriculture (GDA), MAFF, Cambodia
Mega-delta spatial extent and administrative boundary maps	Maps of the mega-delta provinces. These are used to cut/crop the global raster layers based on the area of interest (e.g.: mega-delta spatial extent and boundary.	Vector (polygon shapefile)	Deltas at Risk https://www.globaldeltarisk.net/data.html GADM https://gadm.org/

Acknowledgement

We would like to extend our sincere gratitude to Rica Joy Flor and Akhara Ouk for their valuable support and contributions.

References

Boogaard, H., Schubert, J., De Wit, A., Lazebnik, J., Hutjes, R., Van der Grijn, G. (2020). Agrometeorological indicators from 1979 to present derived from reanalysis. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). https://doi.org/10.24381/cds.6c68c9bb

FAO (2000). The Ecocrop Database. Rome, Italy.

FAO & IIASA. (2023). Harmonized World Soil Database Version 2.0. Rome and Laxenburg. https://doi.org/10.4060/cc3823en

Funk, C. C., Peterson, P. J., Landsfeld, M. F., Pedreros, D. H., Verdin, J. P., Rowland, J. D., & Verdin, A. P. (2014). A quasi-global precipitation time series for drought monitoring. US Geological Survey data series, 832(4), 1-12. https://dx.doi.org/10.3133/ds832

Hijmans, R. J., Guarino, L., Cruz, M., & Rojas, E. (2001). Computer tools for spatial analysis of plant genetic resources data: 1. DIVA-GIS. Plant genetic resources newsletter, 15-19.

Jarvis, A., Reuter, H.I., Nelson, A., Guevara, E. (2008). Hole-filled SRTM for the globe Version 4 Available from the CGIAR-CSI SRTM 90m Database. Retrieved from http://srtm.csi.cgiar.org

Ramirez-Villegas, J., Jarvis, A., & Läderach, P. (2013). Empirical approaches for assessing impacts of climate change on agriculture: The EcoCrop model and a case study with grain sorghum. Agricultural and Forest Meteorology, 170, 67-78. https://doi.org/10.1016/j.agrformet.2011.09.005

Reichle, R.H., G. De Lannoy, R.D. Koster, W.T. Crow, J.S. Kimball, Q. Liu, and M. Bechtold. (2022). SMAP L4 Global 3-hourly 9 km EASE-Grid Surface and Root Zone Soil Moisture Analysis Update, Version 7. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/LWJ6TF5SZRG3. Accessed July 24, 2023.

Siebert, S., Henrich, V., Frenken, K. & Burke, J. (2013). Update of the digital global map of irrigation areas to version 5. Rheinische Friedrich-Wilhelms-Universität, Bonn, Germany and FAO, Rome, Italy.

Sys, Ir. C., E. Van Ranst, J. Debaveye and F. Beernaert. (1993). Land Evaluation Part III -Crop requirement. Belgium General Administration for Development Cooperation. Agricultural Publications No. 7.

Yen, B. T., Pheng, K. S., & Hoanh, C. T. (2006). LUSET: Land Use Suitability Evaluation Tool User’s Guide. International Rice Research Institute.

Lorena S. Villano, l.villano@irri.org

Jeny V. Raviz, j.raviz@irri.org

Jorrel Khalil Aunario, j.aunario@irri.org

Jane Girly Balanza, j.balanza@cgiari.org

Alice G. Laborte, a.g.laborte@irri.org

CGIAR is a global research partnership for a food-secure future. CGIAR science is dedicated to transforming food, land, and water systems in a climate crisis. Its research is carried out by 13 CGIAR Centers/Alliances in close collaboration with hundreds of partners, including national and regional research institutes, civil society organizations, academia, development organizations and the private sector. www.cgiar.org

We would like to thank all funders who support this research through their contributions to the CGIAR Trust Fund: www.cgiar.org/funders.

To learn more about this Initiative, please visit this webpage.

To learn more about this and other Initiatives in the CGIAR Research Portfolio, please visit www.cgiar.org/cgiar-portfolio

INITIATIVE ON

Asian Mega-Deltas