Final Report

on

Examining the Ecological Dynamics of Reforestation at Landscape Level for Strengthening Resilience

Acknowledgements

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Abbreviations and Acronyms

BFD	Bangladesh Forest Department
BHWDB	Bangladesh Haor and Wetland Development Board
BUTM	Bangladesh Universal Transverse Mercator
BWDB	Bangladesh Water Development Board
CALIP	Climate Adaptation and Livelihood Protection
CCA	Canonical Correspondence Analysis
CEGIS	Center for Environmental and Geographic Information Services
DBH	Diameter and Breast Height
DPSIR	Driver-Pressure-State-Impact-Response
ES	Ecosystem Service
FAO	Food and Agriculture Organization
FGD	Focus Group Discussion
GDP	Gross Domestic Production
GHGs	Greenhouse Gases
GIS	Geographic Information Services
GoB	Government of Bangladesh
GPS	Global Positioning System
Ha	Hector
HILIP	Haor Infrastructure and Livelihood Improvement Project
IFAD	International Fund for Agricultural Development
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
KII	Key Informant Interview
LCCS	Land Cover Classification System
LGED	Local Government Engineering Department
LS	Low Suitable
LULC	Land Use / Land Cover
MAT	Maximum Attainable Yield
MS	Moderate Suitable
NS	Not Suitable
PMU	Project Management Unit
RAWES	Rapid Assessment of Wetland Ecosystem Services
RS	Remote Sensing
SAC	Species accumulation curves
S	Suitable
SO	Seed Orchard
SPA	Seed Production Areas
ToR	Terms of Reference
VS	Very Suitable

Executive Summary

There is a growing interest to understand and establishing forest nurseries in swamp ecosystem areas of Bangladesh. Socio-economic contributions of swamp tree nurseries, which are vital economic activities in rural areas of the *Haor* ecosystem are not adequately studied and well documented. Therefore, this study aims to evaluate the socio-economic as well as the ecological contribution of swamp small-scale tree nurseries. Both qualitative and quantitative data were from primary and secondary sources using nursery owner's surveys, key informant interviews and focused group discussions. Qualitative data were analyzed descriptively, while financial analysis was conducted for quantitative data. Ecological data and information were analyzed qualitatively. The result revealed that swamp nurseries were established both by government and non-government organizations. There were some private efforts also in establishing swamp nurseries. On average, 2200±1600 seedlings were produced per month per nursery in the 19 observed nurseries. Swamp nursery producer generates an annual net profit of 310,029 TK. Small-scale swamp nurseries owners were getting benefits in multiple forms such as subsistence, house construction, savings purposes, and most importantly, expanding their own business. However, the ecological aspect of seedling production was not satisfactory because of a lack of skilled labor supply, lack of access to high-quality germplasm, lack of technical skills, lack of nursery facilities, frequent flood and insect attacks, lack of training programs and most importantly organizational support was not up to the mark. In the observed nurseries, only two dominant swamp tree species Hijol (*Barringtonia acutangular*) and Koroch (*Pongamia pinnata*) seedlings were found. In most cases, those seedlings were morphologically not healthy and root structures were deformed which was identified as a major problem of reforestation program failure in *Haor* areas. Therefore, to make the reforestation program successful and create a livelihood for the rural poor in *haor* areas, there is an urgent need to develop quality seedlings-based swamp nurseries which is only possible through proper nursery management techniques. Therefore, actions such as ensuring the source of quality germplasm and proper training and support for seed germination, potting media, bagging and potting technique, seedling maintenance activities are recommended to engage new entrepreneurs (swamp nursery owners) together with financial support from the government and non-government agencies are some of the actions to be taken to strengthen the sector's development.

The swamp forests ecosystem in Bangladesh that once used to be common in *Haor* areas has become very rare due to overexploitation. The natural regeneration of this forest type is hardly visible in the wetland. As a result, swamp vegetation is now at the edge of extinction from the *Haor* region of Bangladesh. The reduction of swamp vegetation has altered local hydrological dynamics such as increased flash floods and wave action causing crop and infrastructure damages. In addition, excessive unscientific exploitation of swamp forests disturbed the ecological functions and gradually diminishes the food and shelter of fish species creating a significant decrease in fish production over the few decades and also threatening wildlife habitats tremendously.

To reverse such a trend, there is an urgent need to start a reforestation program. However, the silvics of individual species and dynamics of swamp forest stands are only marginally understood. The purpose of this study was to find detailed information on swamp vegetation water tolerance (i.e. flood duration and inundation tolerance mechanisms) range. Another objective was to identify a suitable habitat range for species that are dominant in the reforestation program in *Haor* areas. It was found that water stagnancy duration varies from 1-14 weeks and water depth ranges from 1-6ft for most of the swamp plants. Among these swamp trees, high water-tolerant species can tolerate waterlogging conditions for an average of 13 weeks, followed by medium tolerant species for seven weeks and low tolerant species for two weeks only. In the case of the water tolerance capacity of these species, the high water-tolerant group can tolerate an average of 4ft water followed by medium and low tolerant groups at the water height of 2.5ft and 1ft respectively. Hijol (*Barringtonia acutangula*), Koroch (*Pongamia pinnata*), Pitali (*Trewia nudiflora*) and Borun (*Crataeva magna*) were the dominant species used for exiting small scale reforestation programs.

For future large-scale plantations, the machine learning model shows that more than 50% of the Haor area is suitable for plantations. The model also indicates that these major swamp trees are sensitive to increasing temperature. The information generated through this study can be of enormous significance for the planners and managers to aid in developing plantation planning and the design of habitat restoration and enhancement efforts.

Tropical forests significantly contribute to global climate change mitigation through carbon sequestration which is also true in Bangladesh. However, the contribution of freshwater swamp forests is largely unquantified and neglected. To explore the carbon stock potentials of swamp trees, this study provides a detailed investigation of the carbon stock potential of planted swamp vegetation located in north-eastern Bangladesh. A total of 82 10x10m sample plots were established across swamp plantation Sites where trees with ≥5cm diameters at breast height (DBH) were considered. The present study found that Koroch (*Trewia nudiflora*) was the dominant species, followed by Hijol (*B. acutangula*) and Pitali (*T. nudiflora*) planted in the plantation programs. The total estimated carbon stock in swamp trees was 131.90 t/ha, where above-ground carbon was 151.68 t/ha and below-ground, carbon was 19.78 t/ha. Among five or six commonly used swamp tree species, only Koroch (*Trewia nudiflora*) has a high carbon storage capacity (128.04 t/ha) followed by Hijol (8 t/ha) and Borun (7t/ha). The remaining species' carbon stock was extremely low, which ranges from 0.31-8 t/ha. Vegetation density was extremely poor in most of the study sites which has a significant effect on the carbon capture capacity of swamp vegetation. Conserving and restoring the existing and degraded swamp forests will help to increase the carbon budget of the region.

Swamp vegetation is an important nature-based solution against erosion and wave force reduction. When flood moves through swamp vegetation, tree roots and trunks obstruct water flow and increase soil surface roughness. Increasing vegetation densities in degraded freshwater swamp ecosystems will increase more barriers and roughness against severe floods. However, the effectiveness of swamp vegetation in wave force reduction depends on root and trunk diameter, root height from existing ground level, ground coverage of root system, vegetation density, the diameter of the trunk, and water level. Unfortunately, Site and species-specific information on these aspects is missing. Considering this fact, the present study aims to estimate selected swamp vegetation roughness coefficients to highlight their ability to reduce flood force/velocity. The results showed that Hijol, Koroch, Pitali, Borun are the dominant species in freshwater swamp forests. Manning's number calculation further indicates that there are no significant differences in resistance against water flow among Hijol (*B. acutangula*), Koroch (*P. pinnata*), and Pitali (*T. nudiflora*) regardless of vegetation density and water depth. In addition to that, Vetiver Grass (*V. nemoralis*) shows high resistance against water flow compared to other species observed in this study. This study suggests that the combination of Vetiver Grass with Hijol (*B. acutangula*), Koroch (*P. pinnata*), Pitali, or Borun will significantly reduce severe flow velocity. However, to make these preliminary findings more acceptable, it is recommended to run a hydrodynamic model.

Swamp forest ecosystems provide numerous ecosystem services for human wellbeing. This unique ecosystem is declining rapidly. To reverse these trends, restoration activities such as reforestation is often practiced. Therefore, restoration managers and decision-makers need to know the progress or outcome of the restoration initiative, such as reforestation in the swamp ecosystem. In this study, capacities to provide ecosystem services by different reforested Sites were considered as restoration success. Among many ecosystem service (ES) assessment techniques, only a few of them are rapid and applicable for restoration managers where resources are a constraint. Here, RAMSAR's rapid ES assessment technique was applied to assess the restoration outcomes in the freshwater swamp forest ecosystem of Bangladesh. This assessment technique found that most of the reforested Sites show good restoration outcomes except a few sites in terms of ecosystem services. Therefore, swamp forest restoration managers can take necessary steps to improve restoration outcomes from the remaining Sites.

Ecological restoration is widely practiced as a means of rehabilitating ecosystems and habitats that have been degraded. Concepts and attributes from the resilience literature can help improve restoration and monitoring efforts under changing environmental conditions. However, after an extensive literature review and local people's opinion, resilience attributes of freshwater swamp forests were identified. The study found that seed dispersal potential, species water tolerance (water depth and duration tolerance), plant functional traits (bole/trunk and root structure), habitat connectivity, and hydrologic connectivity are the major resilience attribute of the freshwater swamp forest ecosystem. The study proposed that the integration of resilience attributes identified in the study in the reforestation program will increase good restoration outcomes.

1. Introduction

1.1 Background

Bangladesh is situated in the largest deltaic floodplain in the world is one of the most vulnerable countries due to global climate change (Sohel et al., 2015a). According to the Ramsar Convention's definition, more than two-thirds of the landmass of Bangladesh can be classified as an aquatic ecosystem (FAO, 1988). These consist of a wide variety of water bodies, including lakes, oxbow lakes, rivers, flood plains, coastal wetlands, paddy fields, and ponds (Craig et al., 2004). Among different types of wetland, *Haor* ecosystem is the most diverse. In Bangladesh, *Haors* are found mainly in the north-eastern region that covers the upper Meghna river basin area (Approximately 8600 km^2) (BWDB, 2019). *Haor* ecosystems form a unique mosaic of habitats with an extremely rich diversity of flora and fauna. They support the livelihood of many people through fishing, support agriculture, and provide materials for thatching and fuel for domestic use (Sohel et al., 2015a; Rana et al., 2009). This initiative of large-scale reforestation activity will create new small-scale forestry businesses through nursery establishment. In addition, nursery businesses and plantation establishments in *Haor* areas will provide diversified ecosystem services. Considering these positive aspects, the present study will explore the economic and ecological significance of nursery establishment in *Haor* areas.

The *Haor* once was with plenty of wildlife and aquatic resources and covered with swamp forest, which in the recent time has become a fast-degraded landscape facing increased pressure and threats (Ahmed et al., 2008; BHWDB, 2012). The forest resources (swamp and reed land plants) in the *haor* area have no proper conservation and management technique, for which those are declining gradually. Such rapid degradation of the forested wetland ecology is causing devastating consequences such as severe flash floods on the community people living in, around, and downstream of the *haor* who for generations were dependent for their livelihoods upon vital functions, services, and benefits provided by this wetland. An early flash flood caused by intense rainfall in the hilly area of India causes severe damage to paddy fields just before harvesting during the pre-monsoon season (i.e., April to mid-May) (BWDB, 2019). During monsoon, *Haors* receive surface runoff water from rivers and canals that cause severe wave action. Due to high wave action, erosion of *Haor* settlement areas became a common phenomenon in *Haor* areas (BHWDB, 2012). Forest degradation in upstream areas as well as in *Haor* areas is further accelerating the intensity of early flash floods. To overcome this situation, *haor* reforestation can be a great tool. Integrating the knowledge of *Haor* vegetation dynamics into the reforestation program can enhance haor resilience in terms of ecosystem services. In addition, large reforestation activity will create new small-scale forestry businesses through nursery establishment. This nursery business and plantation establishment in *Haor* areas will provide diversified ecosystem services. Therefore, regional planners need to know the minimum proportion of plantation cover that is required in reducing flood flow in these forested wetlands to improve *haor* wetland resilience and ecosystem function. However, to date, there has been little research on this issue, particularly in *Haor* Areas of Bangladesh.

With the target of improving the livelihood and ecosystem function of the *haor* area; recently a project has been initiated titled '*Haor* Infrastructure and Livelihood Improvement Project (HILIP)' by the Ministry of Local Government, Rural Development, and Cooperatives, Bangladesh funded by the IFAD. LGED is implementing HILIP in 28 Upazila under five *haor*-based districts namely Brahmanbaria, Habiganj, Kishoregonj, Netrokona, and Sunamganj. The Climate Adaptation and Livelihood Protection (CALIP) is a supplementary project of HILIP. Through this project, LGED aims to develop *haor* infrastructure without harming the *haor* ecosystem. Therefore, the *haor* area requires a holistic eco-friendly plan for any development actions to keep a harmonious relationship between humans and nature that is essential for the sustainability of these *haor* wetlands. Keeping this in mind, LGED launched a research project that aims to understand the dynamics of the *haor* ecosystem for a successful reforestation program which in turn will improve the livelihood of the *Haor* people.

1.2 Study Objectives

The study aims to assess and evaluate the resilience of reforestation and a wider variety of land use within the *haor* area.

1.3 Scope of Work

The scope of work is composed with following tasks as per ToR:

Task l	Reconnaissance base line survey of reforestation at landscape level;
Task ll	Assess the economic and ecological significant of Swamp tree nursery establishment & plantation (Hijol, Koroch, Vetiver, Murta, Medicinal plants) in *Haor* areas;
Task lll	Assess the best land utilization practices by crop diversification & cropping pattern in *Haor* landscape level and homestead areas;
Task lV	Examine what contributes to resilience: how forest ecosystems function in *Haor* areas;
Task V	Identify land use pattern changes of the *Haor* areas over the period and projection of expected land use change;
Task Vl	To quantify the impacts of tree planting and management on flood flows to help guide planting the right tree in the right place to reduce downstream flood risk;
Task Vll	To find potential project areas at landscape level where afforestation/ reforestation can be strengthening climate resilience;
Task Vlll	Assess and evaluate forest resilience in the context of sustainable forestry, ecosystem service provision as well as recreation, sequestration, biodiversity, soil stability, GHG balance, and climate change mitigation in wider mosaic of land use;
Task lX	Explore appropriate indicators of resilience, their use in detecting ecosystem instability;
Task X	Provide tools to assess and improve resilience across the range of functions of forests in relation to climate change and policy and operational decisions in *Haor* region;
Task Xl	Explore how resilience may be enhanced in *Haor* areas; and conduct Qualitative & quantitate analysis of ecological dynamics of reforestation;
Task Xll	Workshop with key staff from HILIP/CALIP to present & discuss the findings and to share the findings with different stakeholders;
Task Xlll	Publish the research finding taking consent of Project Director, HILIP, PMU.

1.4 Study Area

LGED is implementing HILIP in 28 Upazila under five *haor*-based districts namely Brahmanbaria, Habiganj, Kishoregonj, Netrokona, and Sunamganj. A stratified sampling approach will be followed in selecting suitable Sites from five districts for the study. It is important to note that *Haor* of the North East region of Bangladesh can be divided into three categories (Figure 1.1, 1.2, and 1.3) depending on the geographical location and flooding characteristics of the area:

1. Foothill and near hill *haor*.
2. Floodplain area *haor*.
3. Deeply flooded *haor*.

The *haors* along the border areas of Sunamganj, Sylhet and all *haors* of Habiganj, and Maulvibazar districts are situated near hills or at foothills. Most of the *haor* areas of Sylhet, Netrokona and Brahmanbaria are within the floodplains. All the *haors* of Kishoreganj, and most of the *haors* of Sunamganj districts are deeply flooded. Out of the seven *haor* districts, Sunamganj may be termed as the mother of the *haor* region.

From seven *haor* districts, five (05) *Haor* districts will be selected based on floodplain characteristics (Table 1.1). In the case of Deep flooded *Haor*, *Haors* will be selected from Sunamganj and Kishoreganj; In the case of floodplain type *haor*, only Netrokona district will be considered. Lastly, one Hoar will be selected from Habiganj District. During *Haor* selection, forested *haor* will be given priority based on preliminary literature and Google earth image analysis.

Table 1.1: Selection of Haor Districts based on Haor Characteristics

District	Haor type	Study Site for this project
Sunamganj, Kishoreganj	Deep flooded *Haor*	Sunamganj and Kishoreganj
Sylhet, Netrokona, Brahmanbaria	Floodplain *Haor*	Netrokona and Brahmanbaria
Maulvibazar and Habiganj	Foothill *Haor*	Habiganj

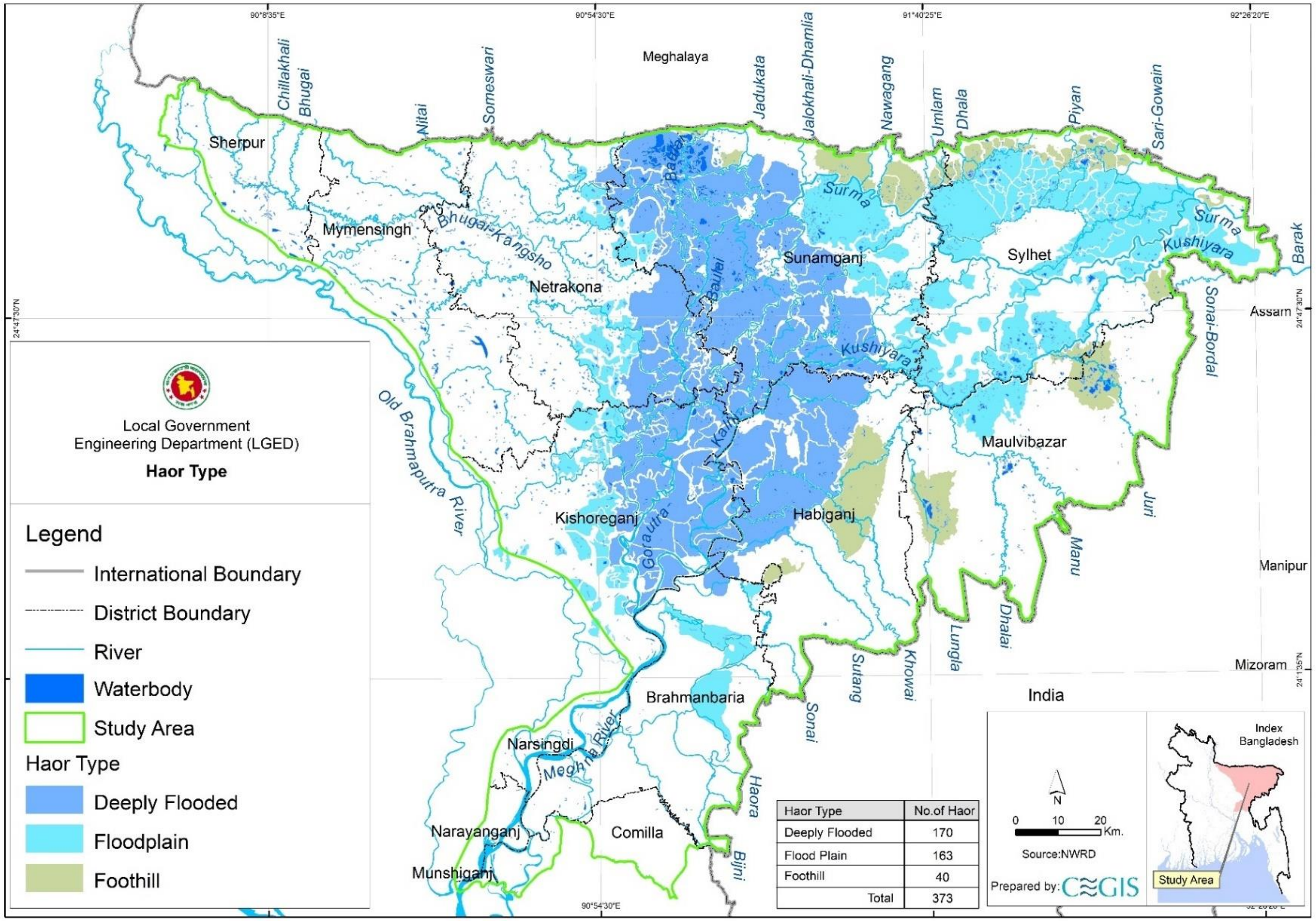


Figure 1.1: Map of *Haor* Types as per Inundation Depth

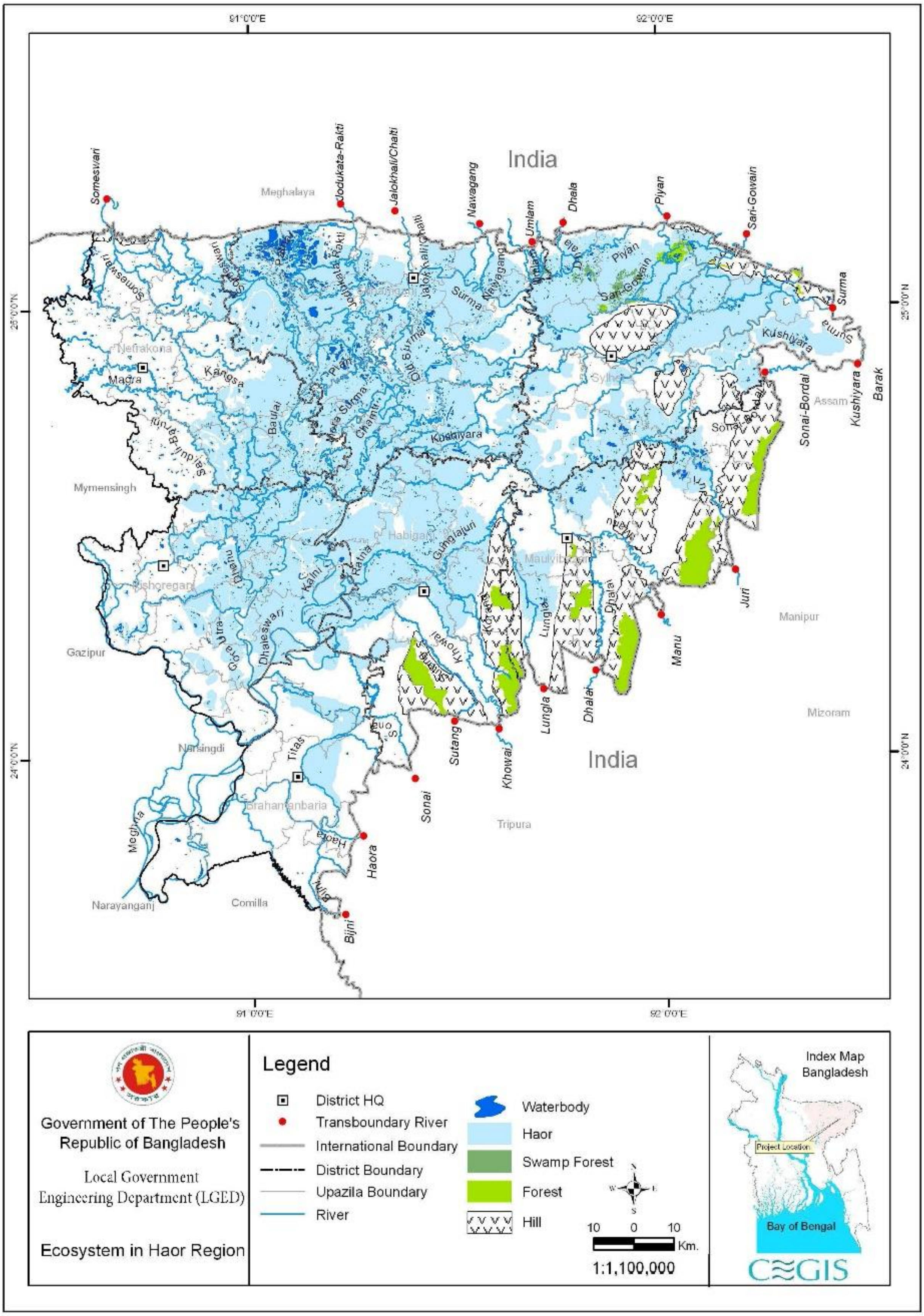
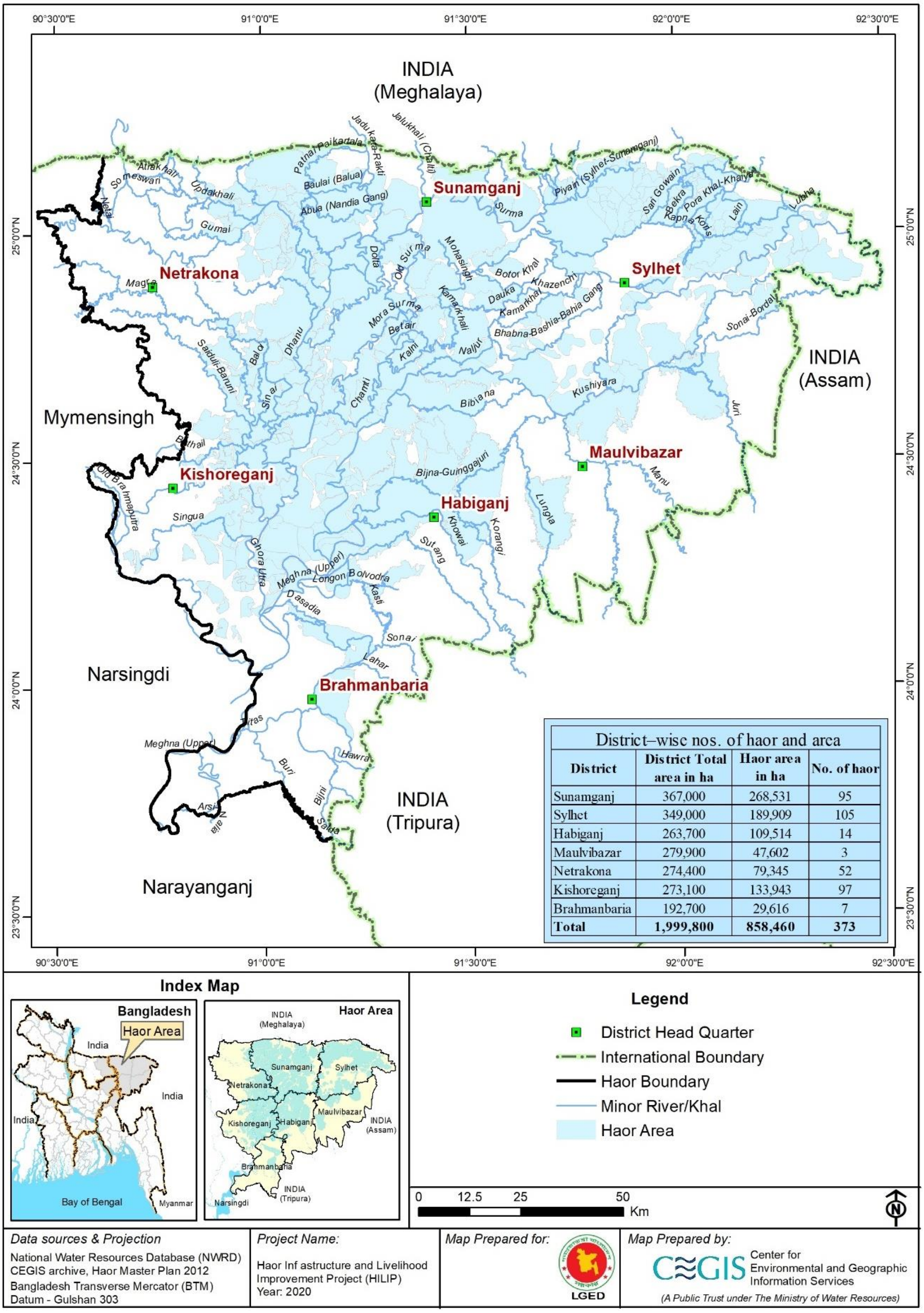


Figure 1.2: Map of *Haor* Area with Forests and Waterbodies



District–wise nos. of haor and area

District	District Total area in ha	Haor area in ha	No. of haor
Sunamganj	367,000	268,531	95
Sylhet	349,000	189,909	105
Habiganj	263,700	109,514	14
Maulvibazar	279,900	47,602	3
Netrakona	274,400	79,345	52
Kishoreganj	273,100	133,943	97
Brahmanbaria	192,700	29,616	7
Total	**1,999,800**	**858,460**	**373**

Figure 1.3: Distribution of *Haor* Areas in Five Districts

1.5 Limitation of the Study

The main limitation of this study is to complete all the tasks within the stipulated seven-month time. In addition to this, publishing the research findings in the journal/research Site is a time constraint issue as the publication of research is dependent on the research reviewers and the research Site authority. Last but not least, the prevailing COVID-19 pandemic may delay the field activities and subsequently report submission.

2. Methodology

2.1 Conceptual Framework of the Study

The dynamics of the water cycle in a basin/catchment depend on climate, geomorphology, vegetation cover, and freshwater ecosystems typology. In contrast, modifications of the hydrological cycle and degradation of aquatic habitats depend on the harmonization of population density, agriculture, infrastructure development, and hydro-technical infrastructure with the ecosystem potential (Zalewski, 2010 and 2015). *Haor* ecosystem of Bangladesh is also largely influenced by hydrology, land use, and climate. People who live there, more or less, are dependent on *Haor* resources such as fish and vegetation for their livelihoods (Choudhury and Faisal, 2005). As the *haor* floods annually, settlements are clustered along its slightly raised fringes. The *haor* once was with plenty of wildlife and aquatic resources and covered with swamp forest, which in the recent time has become a fast-degraded landscape facing increased pressure and threats from flash floods, wave action-oriented erosion, swamp vegetation loss. To reduce such stresses from *Haor* ecosystem, reforestation can be a great tool that can regulate wave action and protect from soil erosion, thereby will improve ecological resilience (Figure 2.1). In addition, the large-scale plantation will create employment opportunities through nursery establishment which in turn will increase livelihood resilience in the face of climate change. Hence, this whole study will focus on three major components such as hydrology, biota, and the physical environment of *Haor* to reduce the stresses of the *Haor* ecosystem (Figure 2.1).

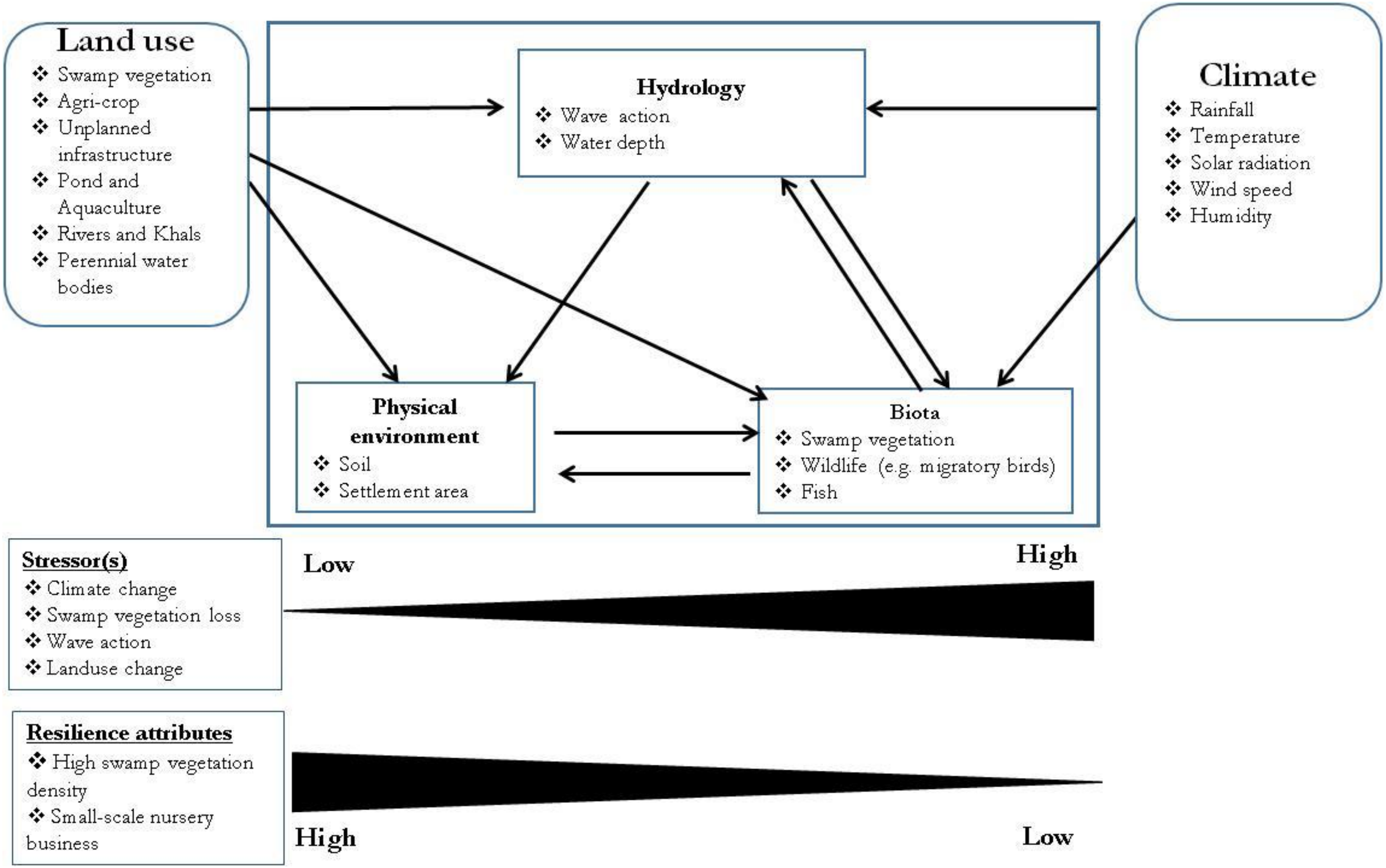


Figure 2.1: Conceptual Diagram Showing the Key Characteristics of *Haor* Ecosystem Properties such as Hydrology, Physical Environment and Biota), Key Stressors and the Relationships with Resilience Attribute

2.2 Detailed Methodology

The study includes a total of 13 tasks as per ToR (Terms of Reference). Tasks wise study methods are explained in the following sections:

2.2.1 Baseline Survey of Reforestation at Landscape Level

The baseline situation of the study was conducted through primary and secondary data and information. The overall procedure is given below:

***Secondary Data Analysis*:** The location and area of reforested land-related data and information were received from LGED. In addition to this, other documents such as *Haor* Master Plan, reports from IUCN, etc. was reviewed for ensuring the location and area of swamp forest and such reforested patches.

***Satellite Image Analysis*:** The High-Resolution satellite images from Google Earth platform were used to identify the existing forest patches which was also combined with information provided by LGED. For identifying the prospective lands, settlement boundaries, roads alignments, edges of perennial water bodies were initially selected using Google earth images and field observation.

Detail Field Survey: After preparing preliminary information about the reforestation Sites, the field team was moved to the respective areas for primary data collection. Field data and information were collected through different techniques including:

- Physical observation of floral composition of *Haor* areas that includes reforested land. 82 plot sizes of 10mx10m were established in 28 reforested Sites to collect trunk diameter (m), root height from existing ground level (m), root diameter (m), ground coverage of root system in the area (mxm), no. of roots, no. of trees in the area/plot, water depth (m), DBH of the tree, the height of a tree, distance between trees and species information.
- Twenty-one (21) Focus Group Discussions (FGD) were conducted to know ecosystem service status and resilience situation's after reforestation programs.
- A total of 19 nurseries were interviewed for detecting the ecological and economic significance of swamp nurseries
- A total of 24 FGD were conducted to know about suitable cropping patterns at the homestead level.
- For this whole study LGED, forest department, fisheries department, and Department of agriculture extension officers were interviewed together with local people.

A brief summary of task specific method is given in Table 2.8.

2.2.2 Assessment of Ecological and Economic Significance of Swamp Tree Nursery Establishment

Task-II is to explore the ecological and economic significance of nursery seedling production for reforestation. To accomplish this objective, the following methods were applied.

Site selection

There are seven districts in *haor* areas of Bangladesh. Among them, five *Haor*-based districts namely Brahmanbaria, Habiganj, Kishoregonj, Netrokona, and Sunamganj, were selected purposively based on previous and ongoing reforestation programs and swamp nursery availability.

Table 2.1: Nursery Locations and Details of Major Swamp Species Considered

Site ID	Nursery locations	Major Seedlings	Type of Nursery
1	Bishwamvarpur Sadar (25.100685, 91.300821)	Kadam (*Athocephalus chinensis*), Amloki (*Phyllanthus emblica*), Pitraj (*Aphanamixis polystacy*), Kathbadam (*Termenalis catappa),* Hijol (*Barringtonia acutangula*), Jam (*Syzygium cumini*), Koroch (*Pongamia pinnata*), Arjun (*Terminalia arjuna*)	Government land
2	South Sunamgonj (24.939697, 91.408004)	Kadam (*Athocephalus chinensis*), Neem (*Azadirachta indica*), Jam (*Syzygium cumini*), Arjun (*Terminalia arjuna*), Raintree (*Samanea saman*), Sil koroi (*Albizia procera*), Chickrasi (*Chukrasia tabularis*)	Government land
3	Forest Department (25.058690, 91.389302)	-	Government land
4	Dirai Upazilla (24.793735, 91.352966)	Sil koroi (*Albizia procera*), Kala koroi (*Albizia procera*), Rain tree (*Samanea saman*)	Government land
5	kalinagar, Dirai (24.814105, 91.306239)	Hijol (*Barringtonia acutangula*), Koroch *(Pongamia pinnata)*	Own
6.	Sunamganj Sadar (25.069173, 91.402045	Hijol (*Barringtonia acutangula*), Koroch *(Pongamia pinnata)*, Rain tree (*Samanea saman*)	Own
7.	Sunamganj Sadar (25.071256, 91.402261)	Jarul (*Lagerstroemia speciosa*), Jam (*Syzygium cumini*), Hijol (*Barringtonia acutangula*), Koroch *(Pongamia pinnata)*, Rain tree (*Samanea saman*)	Own
8.	Jamalgoanj (25.000104, 91.234118)	-	Government land
9.	Khaiyasar, B.Baria. (23.982125,91.106314)	Rain tree (*Samanea saman*)	Rented
10.	Farid plant nursery, Habiganj (24.342124,91.430085)	Rain tree (*Samanea saman*), Jam (*Syzygium cumini*)	Own
11.	Itna, Kishorganj (24.527054, 91.101771)	Arjun (*Terminalia arjuna*), Jarul (*Lagerstroemia speciosa*), Chickrasi	Government land
12.	Mithamoin Upazilla, kishoreganj (24.415605, 91.054218)	Borun, Jarul (*Lagerstroemia speciosa*), Jam (*Syzygium cumini*), Hijol (*Barringtonia acutangula*), Koroch *(Pongamia pinnata)*	Government Land
13.	Poshchimvadei, Habiganj Sadar (24.344539,91.427620)	Kadam (*Athocephalus chinensis*), Jam (*Syzygium cumini*), Arjun (*Terminalia arjuna*), Rain tree (*Samanea saman*), Eucalyptas (*Eucalyptus camaldulensis*)	Lease
14.	Wild nature conservation division nursery, Habiganj (24.342497,91.429661)	-	Government Land
15.	Near Bishwaroad, B. Baria (24.048074,91.115501)	Kadam (*Athocephalus chinensis*), Jam (*Syzygium cumini*), Arjun (*Terminalia arjuna*), Rain tree (*Samanea saman*)	Rented
16.	Medda, B.Baria (23.986895,91.108729)	Kadam (*Athocephalus chinensis*), Jam (*Syzygium cumini*)	Lease
17.	South Medda, FD Nursery, B.Baria (23.987187,91.110029)	Jarul (*Lagerstroemia speciosa*), Jam (*Syzygium cumini*), Hijol (*Barringtonia acutangula*), Arjun (*Terminalia arjuna*)	Government Land
18.	Sorail Sadar, FD Nursery, B.Baria (24.072671,91.109875)	Jarul (*Lagerstroemia speciosa*), Jam (*Syzygium cumini*), Akashmoni (*Acacia auriculiformis*)	Government land
19.	Puniout Bypass, B.Baria (23.961348,91.100961)	Rain tree (*Samanea saman*), Jam (*Syzygium cumini*)	Lease

Selection of respondents

Survey respondents included small-scale swamp forest nursery owners. Three types of nurseries owners, such as private, government, and non-government nursery officials were considered as a survey respondent. Information about the presence of nursery operators in the study area was gathered from key informants, including personnel from the forest department, LGED, and residents.

Data and information gatherings

The socio-economic characteristics of nursery owners such as family size, educational level, occupation, income source, length of the nursery business, and ownership of nursery land-related information were collected. To evaluate the profitability of nursery establishment, financial analysis such as annual fixed cost (e.g., lease land, rented land, buildings, vehicles, machinery) and annual variable cost (e.g., labor cost, cow-dung, fertilizer, insecticides, irrigation, soil, pot, polybag, seed purchase, seedling purchase) related data and information were collected. In addition to that average seedling production cost, average seedling sale value, and the number of seedlings sold per annum related information were also collected to get a clear picture of nursey business profitability.

To know the ecological significance of nursery seedling stock production and their influence on reforestation success, various information such as the source of germplasm, seedling morphological condition (root and stem structure), nursery facilities (e.g., vegetative propagation facilities, germination shed, potting shed, transplanted shed, hardening bed, seed treatment were collected.

Respondents were interviewed using a semi-structured questionnaire. In addition to that, focus group discussions were conducted in all 19 nurseries. Each nursery interview session lasts for three to four hours. Issues discussed included opportunities and constraints of the operation of the swamp nurseries, species availability, and selection process, sources of germplasm, assistance are given by supporting agencies, and possible alternative measures to improve the overall swamp forest nursery in *haor* areas of Bangladesh.

2.2.3 Assessment of Best Land Use Practices by Crop Diversification Pattern in Haor Homestead Areas

Crop choice and cropping pattern for any specific area mainly depend on three factors. They are- edaphic suitability, climatic suitability, and economic suitability. Suitability assessments for a crop of the area were done first. But for this study economic study was not taken into account. The agro-edaphic and agro-climatic suitability of all crops were evaluated. Then combined suitability of each crop was calculated.

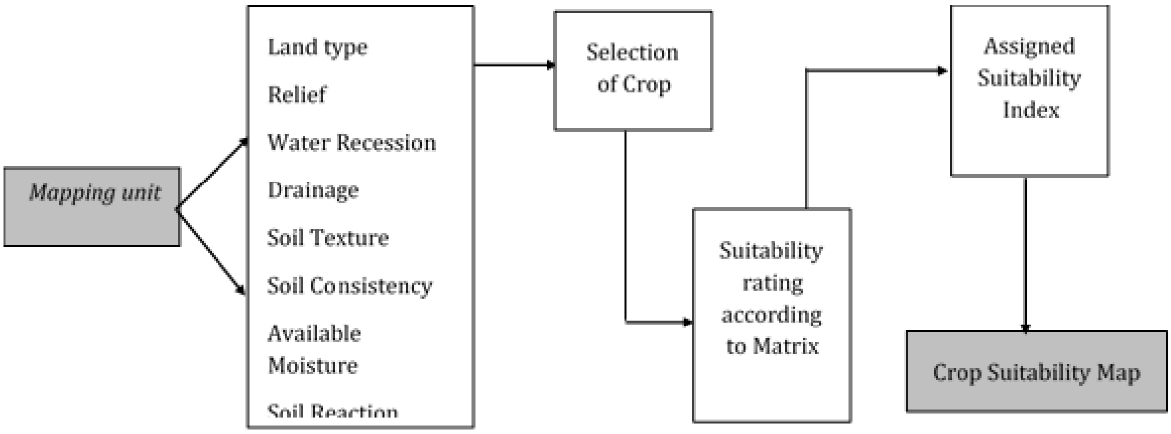
The suitability of crops depends on the different physical and chemical properties of land and soil. The crop suitability of the soils is done by considering the information contained in the Upazila Nirdeshikas. It describes the crop suitability under irrigated and non-irrigated conditions taking care of nine major soil and landform characteristics. The major properties which have been considered for suitability rating are Land type, Relief, Water Recession, Drainage, Soil texture, Soil consistency, Available moisture-holding capacity, Soil reaction, and soil salinity. These parameters are classified according to the different levels of intensity.

The suitability parameters are designed in such a way that they can be chosen depending on the selection criteria from the listed soil and land parameters. If the parameters in the suitability table are updated with the Check Box option, then only those parameters are available to enter the crop suitability component in the suitability-rating matrix. The suitability rating of the crop is classified as Suitable, Moderately Suitable, and Not Suitable for different crops. The matrix in the Upazila Nirdeshika is used to assign the suitability rating for a particular crop. The cross-marks in each row indicate the suitability rating for that particular crop. To analyse the suitability rating of a crop, the mapping unit-based soil and land properties are extracted and compared with the matrix to designate the corresponding rating. The map unit-based parameters, which have been investigated, are shown in the table.

Table 2.2: Crop Suitability Parameters

Land & Soil Parameters	Properties	Land & Soil Parameters	Properties
Land type	Highland	Soil Texture (top soil)	Sand
	Medium Highland 1		Sandy Loam
	Medium Highland 2		Loam
	Medium Lowland		Clayey Loam
	Lowland		Clay
	Very Lowland	Soil Consistency (top soil)	Loose
Relief	Plain		Friable
	Undulating		Hard
	Sloppy	Available Moisture Holding Capacity (top soil)	Low
Water Recession	Extremely Early		Medium
	Very Early		High
	Early		Very High
	Normal	Soil Reaction (topsoil)	Extremely Acidic
	Late		Strongly Acidic
	Very Late		Moderately Acidic
Drainage	Excessively Drained		Neutral
	Well Drained		Moderately Alkaline
	Moderately Well Drained		Strongly Alkaline
	Imperfectly Drained		Extremely Alkaline
	Poorly Drained	Salinity (topsoil)	Non-Saline
	Very Poorly Drained		Very Slightly Saline
Suitability rating Suitable Moderately Suitable Not Suitable			Slightly Saline
			Moderately Saline
			Strongly Saline
			Extremely Saline

The analysis of crop suitability is based on the soil group information of a mapping unit. A mapping unit may be composed of different soil groups and their suitability may vary according to soil and land properties. Hence a map unit is said to be suitable if all the above nine parameters tally as suitable. If any property tally with the moderately or not suitable rating, the whole unit is reassigned as moderately suitable or not suitable. So, within a map unit, the percentage of area with the suitability rating is calculated and the suitability index is assigned. The suitability index is defined according to the percentage of area covered within the soil unit. So, a soil unit could be indexed as Dominantly Suitable as well as Mainly or Some suitable for a particular crop. There could be seventeen possible suitability indexes according to the index parameter combinations. The procedure for analysing crop suitability is shown in the flow diagram. Besides this, homestead level suitable crop was assessed by doing KII with relevant experts and FGD with the local community.



Source: CEGIS

Figure 2.2: Flow Diagram of Crop Suitability Mapping

2.2.4 Assessment of Resilience Indicators that Contributes to Swamp Forest Ecosystem Functions

The objective of this Task IV is to identify the resilience attributes that facilitate *Haor* ecosystem function.

Identification of Resilience Attribute

An intensive systematic literature review was conducted to identify the most important resilience attribute. Resilience attributes can be categorized into physical attributes and biological attributes. Life history (species type, successional status, seed dispersal ability, reproductive strategy, Biological adaptation to disturbance) of available species were investigated through scientific literature.

People's perception towards swamp forest resilience indicators

In total, 21 FGDs were conducted in *Haor* areas to know the resilience indicator that contributes to swamp forest functions.

2.2.5 Assessment of Land Use Pattern Changes and Projection

Assessment and monitoring of land cover dynamics are essential for the sustainable management of natural resources, environmental protection, biodiversity conservation, and development of sustainable livelihoods, particularly for a populated country like Bangladesh where the land cover/uses are subjected to continuous changes. The main objectives of this component are preparing land cover maps for 2000, 2010, and 2019 and change analysis. The historical land cover maps were prepared using images and available ground-based reference information. The cloud-free multi-spectral images were preferred for land cover mapping. The land cover classes in the *haor* area were selected following the Bangladesh Land Representation System. The Bangladesh Land Representation System was developed in 2015 for the Bangladesh using Land Cover Classification System (LCCS) adopted by the FAO. This approach has the advantage of facilitating the integration of time series land cover data consistently. The images were projected into the Transverse Mercator Projection system which is locally known as Bangladesh Universal Transverse Mercator (BUTM).

The historical land cover information table were generated for 2010 and 2019. The iCLUE model was used to project the different land use scenarios.

2.2.6 Tree Planting Impact Quantification and Management of Wave Action

The overall objective of this task is to investigate the potential of reforestation in reducing wave action in *Haor* Areas of Bangladesh. The influence of vegetation on water movement resistance in the floodplain is dependent on the density and height of plants, waterlogging tolerance period, wave height, and force. Hence, to estimate the effect of tree plantation on wave action "manning roughness coefficient (n)" was used (Walczak et al., 2015). Depth of the submergence of the vegetation, diameter of the plants, and average spacing of plants were collected from the field for this purpose.

Selection of swamp vegetation for plantation design to reduce wave action

A total of 82 plots were established in 28 plantation Sites, each of which was 10×10m. From each Site, three plots were established based on plantation availability. The number of individuals of each species was counted. Individual tree DBH ≥5cm was considered. All trees within 10m×10m plot size were enumerated. To get information about species dominance, a rank abundance curve was used. The rank abundance curve shows that Koroch was the dominant species among all the plots, followed by Hijol, Pitali, and Borun. Therefore, these four dominant species together with Vetiver grass were used to investigate the capacity of these species in reducing wave action and extreme runoff.

Data collection for Manning's roughness coefficients estimation

Tree species-related data and information such as root height from existing ground level (m), root diameter, ground coverage of root system in the area (mXm), tree density in the area, the diameter of the trunk, and water level were collected from 82 vegetation plots from five districts (Sunamganj, Netrokona, Habiganj, Kishoreganj, and Brahmanbaria). Higher tree density was observed for Koroch followed by Hijol. The following table presents the available dominant tree information of *Haor* districts (Table 2.3).

Table 2.3: Collection of Dominant Swamp Tree Information

Tree Information	Hijol (*B. acutangula*)	Koroch (*P. pinnata*)	Borun (*C. magna*)	Pitali (*T. nudiflora*)
Root system				
Root Height from existing ground level (m)	0.4m [range:0.2 -0.4m from ground level]	0.4m [range:0.1 -0.7m from ground level]	0.39m [range:0.01 -0.4m from ground level]	0.39m [range:0.2 -0.65m from ground level]
Water Depth (m)	2.25m [range: 1-3.5m]	2.5m [range: 0.5-4m]	2.75m [range: 1-3m]	2.75m [range: 1-3.5m]
Root diameter	0.18m [mean value]	0.23m [mean value]	0.12 m [mean value]	0.28m [mean value]
Ground coverage of root system in area (mxm)	4 m^2 [mean value]	3 m^2 [mean value]	5m^2 [mean value]	1 m^2 [mean value]
No. of Roots	6 [mean value]	8 [mean value]	3 [mean value]	6 [mean value]
Trunk system				
Water Depth	2.25m [range: 1-3.5m]	2.5m [range: 0.5-4m]	2.75m [range: 1-3.5m]	2.75m [range: 1-3.5m]
Number trees in the Area*	76 tree/ha	585 tree/ha	38 tree/ha	52 tree/ha
Horizontal area of the plantation	8200 sq. meter	8200 sq. meter	8200 sq. meter	8200 sq. meter
Diameter of the Trunk	0.50 m [mean value]	0.49 m [mean value]	0.68m [mean value]	0.59m [mean value]

*N.B. *In 28 Sites, 82 plots were established. Each plot 10x10m*

The available existing tree creates resistance to the high-water flow and monsoon wind-generated waves. The water flow through the existing tree species is obstructed by roots/trunks systems, which create resistance. The equivalent of Manning's number can represent this resistance. To calculate the equivalent Manning number of the existing tree species, both the trunks and the roots system of dominant tree species have been measured in the *haor* districts. The calculations of equivalent Manning's numbers for the existing tree species considering root in the first step and trunk in the second step are given below.

Step 1

Bed shear stress (τ) is generally related to depth averaged flow velocity (V) on the basis of a friction factor (f/2) is shown in Equation 1.

$$\frac{\tau}{\rho} = \frac{f}{2}.V^2 \text{ .... Equation 1}$$

where, ρ is the water density.

The friction factor is related to the Nikuradses roughness height (κ_N) and Reynold's umber (Re) by the Colebrook & White formula in Equation 2.

$$\sqrt{\frac{f}{2}} = 6.4 - 2.45 \ln\left(\frac{k_N}{h} + \frac{4.7}{\text{Re}\sqrt{f}}\right) \text{ ....Equation 2}$$

where, h is the water depth.

This is the most precise way of including the friction factor, but it can only be solved by iteration. In practical cases, a Manning number determines the friction factor in the Equation 3.

$$\frac{f}{2} = \frac{g}{M^2 h^{1/3}} \text{ ....Equation 3}$$

Combining the equations assuming a rough boundary layer we get in the Equation 4.

$$M = \sqrt{\frac{g}{h^{1/3}}}\left(6.4 - 2.45 \ln\left(\frac{k_N}{h}\right)\right) \text{ ....Equation 4}$$

The roots of the existing hoar trees can typically have a length scale of 0.20m. Remembering how Nikuradses roughness height is defined, it has been assumed that a root height of 0.20m corresponds to a Nikuradses roughness height of (4 times 0.205m) 0.8m. We have collected the following specific information (Table 2.4) from the selected Site locations.

Step 2

The trunks also create resistance to the flow. The resistances induced by the trunks need to be incorporated in the bed resistance in the Equation 5.

$$A\tau_M = A\tau + nF \text{ ....Equation 5}$$

where, 'A' is horizontal area of the existing tree coverage, 'n' is number of trees in the area and 'F' the force from the trunk on the water body as can be calculated by the Equation 6.

$$F = c\frac{1}{2}\rho(Dh)V^2 \text{ ....Equation 6}$$

Where c is a constant and D the diameter of the trunk of the existing tree species. Combining the equations leads to the Equation 7.

$$M_M = \left(\frac{1}{M^2} + \frac{n}{A}.D.c.\frac{h^{4/3}}{2g} \right)^{1/2}$$ ....Equation 7

The Manning roughness is calculated by combining the Nikuradses roughness height (K_N) and water depth.

$$M = \sqrt{\frac{g}{h^{1/3}}} \left(6.4 - 2.45 \ln\left(\frac{k_N}{h} \right) \right)$$ ....Equation 8

Equivalent Manning's number for existing swamp tree root system

The tree contains variable roots and the trunk creates resistance to the flow. The flow of water through the tree afforestation forest is obstructed by the matrix of roots/trunks, which creates bed resistance. This bed resistance can be represented by an equivalent Manning number. For calculation of the equivalent Manning number of different tree species, both the trunks and the roots of different trees Hijol (*Barringtonia acutangula*), Koroch (*Pongamia pinnata*), Borun (*Crataeva magna) and* Pitali *(Trewia nudiflora)* species have been considered. Manning roughness is calculated both for the root system and trunk system. Root and Trunk systems of selected tree species are presented in Table 2.4.

Table 2.4: Roots and Trunk System for the Selected Tree Species

SL No.	Scientific Name	Local name	Trunk Dia (m)	Root Dia (m)	Root height from existing ground level (m)	Nikuradses roughness height (4 times of root height)
1	*Barringtonia acutangula*	Hijol	0.5	0.18	0.4	1.6
2	*Pongamia pinnata*	Koroch	0.49	0.23	0.4	1.6
3	*Crataeva magna*	Borun	0.68	0.12	0.39	1.56
4	*Trewia nudiflora*	Pitali	0.59	0.28	0.39	1.56

2.2.7 Finding of Potential Areas for Afforestation/Reforestation Program

Swamp vegetation water depth and duration of tolerance and their habitat

Swamp vegetation survival during plantations depends on the species' water tolerance limit that including water depth and duration. Water tolerance of plant species varies from species to species. Some species can tolerate extreme waterlogging conditions, while some cannot survive extreme waterlogging conditions. Literature review, vegetation survey, and consultation with local people were conducted in 28 locations of five *haor* districts, to know plant species availability and their waterlogging characteristics. Based on water depth and duration, swamp vegetation was grouped into 'high', 'moderate', and 'low' water-tolerant species. Species water-tolerant grouping was done using Hierarchical clustering methods. Cluster analysis is a method of classification aimed at grouping objects (in this case, "species") based on the similarity of their attributes (in this case, "water depth" and "water duration"). Euclidean distance was chosen as the criterion for cluster combination. The procedure produces a tree-like diagram (a dendrogram) that illustrates the relationships between all the samples based on a defined measure of similarity. This dendrogram shows the level where clusters were joined together and the species within each cluster.

Swamp vegetation dominance in existing reforestation programs

A total of 82 plots were established in 28 plantation Sites, each of which was 10×10m. From each Site, three plots were established based on plantation availability. Individual tree DBH ≥5cm was considered. All trees within 10m×10m plot size were enumerated. Both DBH and height were measured. Diversity analysis was calculated using the species richness, Shannon diversity (H′), and Simpson diversity (D′) indices. All the calculations were done using the R package. Species accumulation curves (SAC) were used to estimate the number of vegetation species in the plots. Species accumulation curves show the species richness for combinations of Sites.

Dominant swamp vegetation habitat range modelling for future reintroduction

Species occurrence data and spatial rarefying

Swamp species occurrence data were collected from a vegetation plot survey conducted in 82 plots was established in 28 plantation Sites of *Haor* districts. The present study used a total of 119 occurrence records of dominant species such as Kadam (*Athocephalus chinensis*), Hijol (*Barringtonia acutangula*), Borun (*Crataeva magna*), Jarul (*Lagerstroemia speciosa*), Koroch (*Pongamia pinnata*), Jam (*Syzygium cumini*), Pitali (*Trewia nudiflora*) respectively from extensive field survey. All the species naturally grow in the north-eastern region of Bangladesh. It is important to note that Maxent requires input occurrence data to be spatially independent to perform well. Spatially auto correlated occurrence points introduce biases into the model, which is often ignored by the researchers (Veloz, 2009; Hijimans et al., 2012; Boria et al., 2014). To overcome such issues, the number of spatially independent localities was spatially rarefied using SDM toolbox 2.030 in ArcGIS 10.3 by eliminating all but one-point present within a single grid cell to avoid double counting of presence points. This has reduced our sampled species occurrence points. After spatial ratifying, there were 52 occurrence spatially independent points and only four species have the required number of points for habitat suitability models (Table 2.5).

Table 2.5: Species Occurrence Data from Existing Reforestation Programs in Haor Areas

Species	Initial points	Rarified points	Considered for model
Kadam (*Athocephalus chinensis*)	4	4	No*
Hijol (*Barringtonia acutangula*)	20	11	Yes
Borun (*Crataeva magna*)	12	6	Yes
Jarul (*Lagerstroemia speciosa*)	2	2	No*
Koroch (*Pongamia pinnata*)	63	18	Yes
Jam (*Syzygium cumini*)	2	2	No*
Pitali (*Trewia nudiflora*)	16	9	Yes
Grand Total	**119**	**52**	**-**

**N.B. at least five occurrence points is required by Maxent for suitability modeling*

Climate Variables

We primarily selected 19 bioclimatic variables obtained from the WorldClim database (ver. 1.4, Hijmans et al., 2005). All variables were measured at the 1 km resolution and processed using SDMtoolbox v2.4 (http://www.sdmtoolbox.org/) and ArcGIS10.3 interface, having the same cell size, extent, and projection systems (WGS84 Longitude-Latitude projection). Interpreting SDM Results are difficult when predictor variables are highly correlated (Kivinen et al., 2008); so, only less correlated variables (Pearson correlation coefficient $r < 0.80$) were used in the MaxEnt model (Elith et al., 2010). This was done using SDMtoolbx v2.4. Finally, eight (08) climate variables i.e., isothermally (BIO3), temperature annual range

(BIO7), mean temperature of the wettest quarter (BIO8), annual precipitation (BIO12), precipitation of driest month (BIO14) and precipitation seasonality (BIO15) were considered that influence the distribution of species (Table 2.6).

Table 2.6: Climate Variables Used in the Study

Code	Climatic variables	Unit
BIO 1	Annual mean temperature	ºC
BIO 2	Mean diurnal range (mean of monthly max. and min. temp.)	ºC
BIO 3	**Isothermality ((Bio2/Bio7) × 100)**	**-**
BIO 4	**Temperature seasonality (standard deviation × 100)**	**C of V**
BIO 5	Maximum temperature of warmest month	ºC
BIO 6	Minimum temperature of coldest month	ºC
BIO 7	**Temperature annual range (Bio5–Bio6)**	**ºC**
BIO 8	**Mean temperature of wettest quarter**	**ºC**
BIO 9	Mean temperature of driest quarter	ºC
BIO 10	Mean temperature of warmest quarter	ºC
BIO 11	**Mean temperature of coldest quarter**	**ºC**
BIO 12	**Annual precipitation**	**mm**
BIO 13	Precipitation of wettest period	mm
BIO 14	**Precipitation of driest period**	**mm**
BIO 15	**Precipitation seasonality (CV)**	**C of V**
BIO 16	Precipitation of wettest quarter	mm
BIO 17	Precipitation of driest quarter	mm
BIO 18	Precipitation of warmest quarter	mm
BIO 19	Precipitation of coldest quarter	mm

N.B. Variable with bold were used for final model run. The other variables removed because of high colinearity

Spatial Modeling

We used the Maximum entropy algorithm (MaxEnt version 3.3.3 k) for species distribution modeling in our study (Phillips et al., 2006; Phillips and Dudík, 2008). MaxEnt is a machine learning program that derives the probability of presence on a pixel-by-pixel basis and performs well compared with other species distribution models since it requires presence-only data (Phillips et al., 2004 and 2006). It is widely used for species distribution modeling, as it is effective even with small sample sizes (Elith et al., 2011). In ecological niche/ habitat suitability modeling, sampling bias is a common problem. To counter the sampling bias of occurrences, a background selection process was implemented by using SDMtoolbox, a python-based plugin for ArcGIS. The average of 15 replicates for each model was taken as the final predictions.

Model evaluation and interpretation

The receiver operating characteristic curve (ROC) was used to evaluate the model performance. A greater area under the curve (AUC) value (0 ~ 1) indicates a better predictive performance. The Jackknife test was adopted to assess the importance of each variable in the modeling. MaxEnt generates an estimate of habitat suitability for the species that varies from 0 (lowest suitability) to 1 (highest suitability).

2.2.8 Assess and Evaluate Forest Resilience in the Context Ecosystem Services Provision such as Sequestration, Biodiversity, GHG Balance, and Climate Change Mitigation in Wider Mosaic of Land Use

The overall objective of this task is to assess and evaluate *Haor* forest resilience in terms of ecosystem service provision such as recreation, biodiversity, soil stability, GHG balance, and climate change mitigation through carbon sequestration.

Vegetation survey

A total of 82 (10×10m) plots were established in 28 Sites of the plantation areas. From each Site, three plots were established based on plantation availability. Individual tree DBH ≥5cm was considered. All trees within 10m×10m plot size were enumerated. Both DBH and height were measured.

Biomass estimation in trees

Total biomasses of trees were estimated after adding above and below-ground biomass. As the study was conducted in newly planted swamp areas, it was impossible to cut all the trees and brought them to the laboratory to estimate biomass. After reviewing models developed by several authors from across the world (FAO, 1997; Brown et al., 1989), the model of Brown et al., (1989) was found most suitable to estimate the above-ground biomass of the area. This method was reported suitable for estimating above-ground biomass by several other authors (Alamgir and Al-Amin, 2008; Steffan-Dwenter et al., 2007; Alves et al., 1997 Schroeder et al., 1997), particularly in tropical forests. Below ground biomass was calculated considering 15% of above-ground biomass (Mac-Dicken, 1997). The model for above ground biomass estimation is as follows;

$$Y = \text{exp.}^{\{-2.4090+0.9522\ \ln(D^2HS)\}}$$

Where, Y = above-ground biomass in Kg; H = Height of the trees in meter; D = Diameter at breast height (1.3m) in cm; S = Wood density in units of g/cm^3.

Estimation of organic carbon in trees

After calculating biomass following the above-described method, carbon content was calculated based on the assumption that carbon content is 50 percent of the woody biomass (Brown, 1997). The carbon stock of each tree was calculated as 50 % of its biomass (Brown and Lugo, 1982; Dixon et al., 1994).

Soil sampling for soil nutrient analysis

Soil samples were collected from only one depth ranging from 0–30 cm. From each plot, three soil samples were collected to make a composite sample. Soil samples were collected in polythene bags using a soil core. Soil samples were sent to Bangladesh Soil Research Development Institute, Sylhet for organic carbon, nitrogen (N), phosphorous (P), potassium (K) analysis. Soil nutrient data were used to investigate the influence of soil nutrients on swamp tree species composition.

Diversity analysis and soil parameter influence on species diversity

Diversity analysis was calculated using the species richness, Shannon diversity (H′), and Simpson diversity (D′) indices. All the calculations were done using the R package. Species accumulation curves (SAC; or species-richness curves, collector's curves, species effort curves) were used to estimate the number of vegetation species in the plots Species accumulation curves show the species richness for combinations of Sites. Canonical Correspondence Analysis (CCA) was used to analyse the relationship between the distribution of plants and environmental variables. CCA is a direct gradient analysis technique that relates community variation (composition and abundance) to environmental variation, enabling the significant relationship between environmental variables and community distribution to be determined. CCA assumes that meaningful environmental variables have been identified and measured.

2.2.9 Identification of Appropriate Indicators of Haor Ecosystem Resilience

This task overlaps with Task IV (Scope of Study). Therefore, this task was assessed simultaneously with the evaluation of task IV.

2.2.10 Tools to Assess and Improve Resilience Across the Range of Functions of Forests in Relation to Climate Change and Policy and Operational Decisions in Haor Region

RAWES rapid assessment of ecosystem service

To assess wetland ecosystem services, a modified methodology developed by The Ramsar convention was adopted (RRC-EA, 2020). This method can provide a qualitative or relative assessment of the range of ecosystem services provided by a wetland (McInnes and Everard, 2017). A list of ecosystem services (ES) (Table 2) provided by Millennium Ecosystem Assessment (2005) was grouped into four categories namely provisioning, regulating, cultural, and supporting services. The provided ES list was modified based on local swamp forest ecosystem conditions. Supporting ES are the services that are necessary for the production of other remaining ES, where provisioning ES are the products (e.g. biomass, timber, wildlife, fodder) obtained from a particular ecosystem, regulation ES are the services derived from a particular LULC (e.g. erosion control, flood protection, climate regulation), and cultural ES is the non-material services (e.g. recreation and aesthetic value) obtained from a LULC (MEA, 2005). To assess ES of 28 reforested Sites of swamp areas, virtual training was provided to the field team on the concepts of wetland ES before going to the field. The field team has interviewed various stakeholders such as officials of Government and non-government organizations, residents near the plantation area. Altogether 29 KII and 21 FGD were conducted to know ES situations after reforestation programs. A modified version of the RAMSAR relative scoring scale was applied. The scale ranging from 0 to 5, where 0=no relevant capacity; 1=low relevant capacity; 2=relevant capacity; 3=medium relevant capacity; 4=high relevant capacity and 5=very high relevant capacity.

Data analysis

Simple counting of the score given for each ecosystem service was done. Hierarchical cluster analysis using Euclidean distance and ward linkage function was used to present common groupings of ecosystem services provided by certain swamp-reforested Sites.

Table 2.7: Swamp Forest Ecosystem Services Component Considered for ES Assessment and Examples of the Questions

Sl. No.	Ecosystem Services	Example	Questions
Provisioning services	Food	Fish, fodder, edible plants for human	▪ Does fish production increases after reforestation? ▪ Do people use reforested swamp vegetation as fodder and food?
	Timber	Timber for house construction	Do people used reforested swamp trees for house construction?
	Fuelwood	Fuelwood	Do people use reforested swamp trees parts as fuelwood?
	Medicinal uses	Plants used as traditional medicines	Are there any medicinal uses of the reforested plants?
Regulating services	Local climate regulation	Reducing air temperature through shade	Do the reforested swamp plantations provide shade and reduce temperature?
	Flood regulation	Reduction of flood flows	Do the reforested swamp plantations reduce intense flood water flow?
	Protection from wave	Reduction of wave force	Do the reforested swamp plantations reduce intense wave force?

Sl. No.	Ecosystem Services	Example	Questions
	Soil erosion control	High vegetation density can increase soil binding capacity	Does the swamp vegetation provide protection from soil erosion?
Cultural services	Recreation and tourism	Provide recreation such as fishing, swimming, or as a tourism spot	Is the reforested swamp plantations area used for recreational purposes?
	Aesthetic value	The area is used as a subject for commercial development	Do the reforested swamp plantations create desirability for house or any other commercial development adjacent to it?

Sources: Adapted and modified from McInnes and Everard 2017

2.2.11 Conduction of Qualitative and Quantitative Analysis of Ecological Dynamics of Reforestation

Based on Task-I to Task-X a comprehensive management plan was developed to increase swamp forest resilience in *Haor* areas of Bangladesh.

2.2.12 Workshop with Key Staff from HILIP/CALIP to Present & Discuss the Findings and to Share the Findings with Different Stakeholders

After finalizing the given scope of work, a daylong workshop was organized with all the stakeholders including key staff from HILIP/CALIP to present & discuss the findings.

2.2.13 Publication

With the consent of the project director of HILIP at least one article will be prepared and submitted to a Scopus index journal. Please note that publishing an article in a reputed journal takes at least six months to one year as the article will face a rigorous peer-review process. Preparation and submission of an article will be done after the completion of the study.

Table 2.8: Task-wise Brief Description of Methods

Task ID	Task Details	Methods
Task l	Reconnaissance baseline survey of reforestation at landscape level.	Details are given below from Task II to Task Xlll.
Task ll	Assess the economic and ecological significance of Swamp tree nursery establishment & plantation (Hijol, Koroch, Vetiver, Murta, Medicinal plants) in Haor areas.	19 nurseys were visited, semi-structured questionnaire, FGD, KII, seedling morphological condition observation and measurement.
Task lll	Assess the best land utilization practices by crop diversification & cropping pattern in *Haor* landscape level and homestead areas.	24 FGDs at homestead level, landscape level crop suitability modelling was performed considering soil parameters such as Soil Texture, Available Moisture Holding Capacity, Soil pH and soil salinity.
Task lV	Examine what contributes to resilience: how forest ecosystems function in *Haor* areas.	21 FGDs and review of scientific literature.
Task V	Identify land use pattern changes of the *Haor* areas over the period and projection of expected land use change.	Satellite images from 2000, 2010 and 2019. iCLUE model was used for the land use projection.
Task Vl	To quantify the impacts of tree planting and management on flood flows to help guide planting the right tree in the right place to reduce downstream flood risk.	82 vegetation plots were established in 28 plantation Sites, each of which was 10×10m to calculate manning roughness coefficient (n) which is an indicator of vegetation resistance capacity against water flow/wave action.

Task ID	Task Details	Methods
Task Vll	To find potential project areas at landscape level where afforestation/ reforestation can be strengthening climate resilience.	Eighty-two vegetation plots were established in 28 plantation Sites, each of which was 10×10m to know dominant species used in previous plantation projects. Swamp vegetation water depth and duration tolerance and their preferred habitat information were gathered from previously published reports, and validation was done through 28 FGDs. After that habitat suitability model was performed to know site suitability of the dominant swamp tree species.
Task Vlll	Assess and evaluate forest resilience in the context of sustainable forestry, ecosystem service provision as well as recreation, sequestration, biodiversity, soil stability, GHG balance, and climate change mitigation in wider mosaic of land use.	82 vegetation plots were established in 28 plantation Sites, each of which was 10×10m to measure carbon stock and species diversity. 82 soil samples were collected to know soil nutrient status and their effect on swamp vegetation.
Task Xl	Explore how resilience may be enhanced in *Haor* areas; and conduct Qualitative & quantitate analysis of ecological dynamics of reforestation.	
Task lX	Explore appropriate indicators of resilience, their use in detecting ecosystem instability.	This task overlaps with Task IV.
Task X	Provide tools to assess and improve resilience across the range of functions of forests in relation to climate change and policy and operational decisions in *Haor* region.	A Method called Rapid Assessment of Wetland Ecosystem services (RAWES) developed by Ramsar convention was applied to asses' ecosystem service resilience. Altogether 21 FGDs were conducted to gather information on ecosystem service resilience;
Task Xll	Workshop with key staff from HILIP/CALIP to present & discuss the findings and to share the findings with different stakeholders.	Inception and Progress Workshops were conducted by CEGIS. Workshop on the Draft Final Report will be conducted by CEGIS as per the schedule set by the HILIP, LGED.
Task Xlll	Publish the research finding taking consent of Project Director, HILIP, PMU.	This will be done prior to the acceptance of the final study report.

3. Baseline Status of *Haor* Reforestation

3.1 Preferred Species in Nurseries of *Haor* Area

The majority of the nursery considers both swamp and non-swamp tree species such as Koroch (*Pongamia pinnata*), Hijol (*Barringtonia acutangular*), Kadam (*Athocephalus chinensis*), Jaam (*Syzygium cumini*), Jarul (*Lagerstroemia speciosa*), Neem (*Azadirachta indica*), Arjun (*Terminalia arjuna*), Raintree (*Samanea saman*), Sil koroi (*Albizia procera*), Chickrasi (*Chickrassia tabularis*), Kala koroi (*Albizia lebbeck*), Amloki (*Phyllanthus emblica*), Rayna (*Aphanamixis polystacy*) and Kathbadam (*Termenalis catappa*). Unfortunately, number of swamp tree species is negligible and limited to only (*Pongamia pinnata*), Hijol (*Barringtonia acutangular*), Kadam (*Athocephalus chinensis*), Jam (*Syzygium cumini*), and Jarul (*Lagerstroemia speciosa*) and many of them were not native to that *haor* ecosystem. Selection of species in swamp nurseries depends on various factors such as availability of germplasm, the demand for planting stock, timber quality and fast growth, identified by supporting agency, suitability to the planting site, wave protection, to attract fish, to attract wildlife, fuelwood supply, use for boundary demarcation and medicinal purposes.

3.2 Species Composition and Forest Structure of Swamp Afforestation

The *beel* areas do not have large patches of the forest except a few scattered small patches of Hijal, Panibaj, Karoch, Borun, Kadom, Dumur (*Ficus hispida*), Jagmo dumur (*Ficus racemosa*), Khoi babla (*Pithecellobium dulce*), Rayna/pitraj (*Aphanamixis polystachya*), Pakur (*Ficus lacor*) and Kathh badam (*Terminalia catappa*). Perennial water bodies of *Haor* ecosystem also do not have large forest patches, however, have some submerged vegetation such as Ghechu, Shapla, Punchuli, Kanta shola (*Hydrilla verticillata*), Pata shaola (*Vallisneria spiralis*), Jhaji (*Ceratophyllum sp.*), Najas sp., etc. Plantations were mainly concentrated near the roadside and in Kandas. Major species found near road sides area Rendi koroi *(Samanea saman),* Chambal *(Albizia richardiana),* Shirish *(Albizia lebbeck),* Arjun *(Terminalia arjuna),* Neem *(Melia sempervirens),* Gamar *(Gmelina arborea),* Kadom, Bahera *(Terminalia bellirica),* etc. Hijal and Karoch are the two major species planted in *Kandas.*

Survey data from this study shows that Kadam (*Athocephalus chinensis*), Hijol (*Barringtonia acutangula*), Borun (*Crataeva magna*), Jarul (*Lagerstroemia speciosa*), Koroch (*Pongamia pinnata*), Jam (*Syzygium cumini*), Pitali (*Trewia nudiflora*) were the dominant species considered for plantation in *haor* areas. In the plantation areas, the tree density of Koroch (585.37/ha) was found highest followed by Hijol (75/ha), Pitali (52/ha), Borun (37/ha).

3.3 Morphological and Physical Traits of Swamp Vegetation Planted for Reforestation

Morphological and physical attributes of swamp trees such as root diameter, trunk diameter, tree height, tree diameter, root diameter, number of roots, ground coverage of roots, spacing, and water depth data were collected from sampled plots. Trunk diameter was highest (1.07m) for less dominant Shewra species followed by Borun (0.68m), Pitali (0.59m), Hijol (0.50m), and other species. Borun and Kadam trees' height was near 10m. Whereas Koroch, Pitali, and Shewra were on an average 6m in height. The average diameter of all the sampled species ranges from 0.15-to 0.23m. Ground coverage of root was highest for Borun followed by Koroch and Pitali. Root diameter was highest for Pitali followed by Korch and Hijol (Table 3.1).

Table 3.1: Morphological and Physical Traits of Swamp Vegetation Planted for Reforestation

Species	Trunk Diameter (m)	Distance between trees (m)	Tree Height (m)	Tree Diameter (m)	Root height from ground level (m)	Water depth (m)	Root Dia (m)	No. of Roots	Ground coverage of root system (mxm)
Borun	0.68 [0.28-1.18]	2.04 [0.5-3]	11.83 [5-20]	0.23 [0.13-0.37]	0.39 [0.31-0.49]	2.75 [0.5-3.5]	0.12	2.00	5 [0.8-20]
Hijol	0.50 [0.11-1.20]	2.74 [1-5]	6.32 [5-12]	0.25 [0.1-0.82]	0.4 [0.19-0.45]	2.25 [0.5-3.5]	0.18 [0.12-0.3]	5.33 [4-9]	4.00
Jam	0.49 [0.32-0.70]	2.30 [1.5-3]	8.43 [5-16]	0.18 [0.15-41]	0.7 [0.7-0.7]	1.75 [0.5-3.5]	0.15	NA	NA
Jarul	0.30[0.17-0.62]	2.00 [2-2]	8.25 [6-11]	0.17 [0.13-0.21]	0.00	1.15 [1-1.2]	NA	NA	NA
Kadam	0.60 [0.22-1.14]	2.35 [1.5-5]	10.08 [5.2-20.5]	0.22 [0.18-0.35]	0.00	2.03 [1-3.5]	NA	NA	NA
Koroch	0.49 [0.07-1.81]	2.05 [0.5-5]	6.69 [4.8-17]	0.31 [0.04-1.68]	0.4 [0.01-6]	2.5 [0.5-4]	0.23 [0.01-0.72]	8.42 [2-21]	3 [1-7]
Pitali	0.59 [0.26-1.12]	1.90 [1-3]	9.18 [5-15]	0.22 [0.09-0.86]	0.39 [0.21-0.65]	2.75 [1-3.5]	0.28 [0.1-0.6]	3.72 [1-7]	1.00
Shewra	1.06 [0.50-1.70]	3.53 [3-3.8]	6.36 [5.1-8]	0.25 [0.19-0.29]	0.00	3.5 [3.5-3.5]	NA	NA	NA
Koroi	0.20 [0.1-0.25]	2.25 [2-2]	9.30 [7-10]	0.15 [0.08-0.21]	0.00	1.3 [0.5-2.1]	NA	NA	NA

N.B. Values of morphological and physical attributes presented are mean values of each parameter. Values presented in parenthesis indicates minimum and high values of each parameter. 'NA' indicates no data available.

3.4 Soil Quality Status in Swamp Vegetation Plots

Eighty-two (82) Soil samples were collected from 82 plots of 28 sites to analyse Organic Carbon (OC), Nitrogen (N), Phosphorus (P), and Potassium (K). The average OC% in all plantations plots was 1.40% where the minimum and maximum OC% ranges from 0.12% to 4.75%. N% varies from 0.01% to 0.32% with an average of 0.12%. Average Phosphorus (P) and Potassium (K) concentration was 9.09mg/kg and 0.15mg/100g soil (Table 3.2).

Table 3.2: Soil Quality Status in Swamp Vegetation Plots

Site name	Site ID	Plot	OC%	N%	P (mg/kg)	K (mg /100 g soil)
Matain *haor*	Site1	p1	0.82	0.08	14.51	0.07
Matain *haor*	Site1	p2	1.98	0.17	5.37	0.13
Matain *haor*	Site1	p3	1.79	0.15	8.39	0.14
Matain *haor*	Site1	p4	1.59	0.14	5.1	0.1
Matain *haor*	Site1	p5	0.89	0.09	14.11	0.1
Matain *haor*	Site1	p6	2.3	0.19	5.2	0.11
Matain *haor*	Site1	p7	0.74	0.07	11.39	0.15
Jatichar *Beel*	Site2	p1	1.63	0.14	4.94	0.18
Bhati laoranjani	Site3	p1	0.55	0.05	8.19	0.07
Bhati laoranjani	Site3	p2	2.06	0.17	7.96	0.18
Bhati laoranjani	Site4	p3	2.03	0.17	8.1	0.13
Borokhal *Beel*	Site4	p1	0.78	0.08	6.15	0.08
Borokhal *Beel*	Site4	p2	0.23	0.02	5.38	0.05
Borokhal *Beel*	Site4	p3	0.31	0.03	5.21	0.05
Chatol *Beel*	Site5	p1	1.79	0.16	7.37	0.18
Chatol *Beel*	Site5	p2	0.74	0.07	7.23	0.08
Chatol *Beel*	Site5	p3	1.09	0.1	5.23	0.11
Huglia *Beel*	Site6	p1	1.87	0.17	3.14	0.13
Huglia *Beel*	Site6	p2	1.52	0.14	4.38	0.15
Huglia *Beel*	Site6	p3	1.01	0.1	3.06	0.24
Telka *Beel*	Site7	p1	1.21	0.12	8.85	0.15
Telka *Beel*	Site7	p2	2.11	0.18	6.9	0.15
Kasipur Liradigha *Beel*	Site8	p1	1.09	0.1	7.28	0.2
Kasipur Liradigha *Beel*	Site8	p2	1.32	0.12	5.45	0.09
Kasipur Liradigha *Beel*	Site8	p3	1.13	0.11	6.96	0.09
Ghotghotia *Nadi*	Site9	p1	2.34	0.19	14.99	0.26
Ghotghotia *Nadi*	Site9	p2	2.22	0.19	12.91	0.12
Ghotghotia *Nadi*	Site9	p3	1.87	0.16	26.23	0.17
Boromedi *Beel*	Site10	p1	1.13	0.11	2.41	0.14
Boromedi *Beel*	Site10	p2	1.52	0.13	4.58	0.21
Boromedi *Beel*	Site10	p3	0.97	0.1	2.66	0.19
Jogodoba *Beel*	Site11	p1	0.62	0.06	9.07	0.13
Jogodoba *Beel*	Site11	p2	0.94	0.09	12.57	0.14
Jogodoba *Beel*	Site11	p3	0.94	0.09	9.74	0.14

Site name	Site ID	Plot	OC%	N%	P (mg/kg)	K (mg /100 g soil)
Boiragimara	Site12	p1	1.13	0.11	2.41	0.14
Boiragimara	Site12	p2	1.52	0.13	4.58	0.21
Boiragimara	Site12	p3	0.97	0.1	2.66	0.19
Noinda *Beel*	Site13	p1	1.95	0.17	19.67	0.22
Noinda *Beel*	Site13	p2	1.21	0.11	17.88	0.19
Noinda *Beel*	Site13	p3	1.4	0.12	22.48	0.18
Khagail *Beel*	Site14	p1	0.89	0.09	2.96	0.12
Khagail *Beel*	Site14	p2	2.37	0.19	4.39	0.23
Khagail *Beel*	Site14	p3	1.59	0.14	3.45	0.13
Baskar *Beel*	Site15	p1	4.75	0.32	2.68	0.09
Baskar *Beel*	Site15	p2	2.73	0.24	5.39	0.1
Baskar *Beel*	Site15	p3	1.01	0.1	4.8	0.16
Chato udaytara *Beel*	Site16	p1	1.01	0.1	3.06	0.24
Chato udaytara *Beel*	Site16	p2	1.44	0.12	2.29	0.12
Chato udaytara *Beel*	Site16	p3	0.97	0.09	3	0.13
Dholapakhna Jamalganj	Site17	p1	1.52	0.13	5.17	0.18
Dholapakhna Jamalganj	Site17	p2	1.52	0.14	2.81	0.16
Dholapakhna Jamalganj	Site17	p3	1.4	0.12	3.05	0.16
Chatirchar	Site18	p1	1.52	0.13	19.58	0.17
Chatirchar	Site18	p2	1.21	0.11	21.08	0.24
Chatirchar	Site18	p3	1.24	0.11	23.73	0.18
khagrakhal	Site19	p1	1.85	0.15	11.94	0.13
khagrakhal	Site19	p2	1.21	0.11	18.56	0.12
khagrakhal	Site19	p3	1.47	0.13	21.59	0.11
Kuri *Beel*	Site20	p1	1.24	0.12	20.66	0.18
Kuri *Beel*	Site21	p2	1.05	0.09	18.23	0.17
Kuri *Beel*	Site20	p3	1.4	0.12	15.78	0.19
Bogadubu *Khal*	Site21	p1	1.36	0.12	15.66	0.19
Bogadubu *Khal*	Site21	p2	1.67	0.14	15.92	0.18
Bogadubu *Khal*	Site21	p3	1.59	0.14	17.04	0.22
Dalerkandi Road Site, Austagram	Site22	p1	1.52	0.13	5.87	0.2
Dalerkandi Road Site, Austagram	Site22	p2	1.4	0.12	7.01	0.27
Dalerkandi Road Site, Austagram	Site22	p3	1.32	0.12	4.6	0.24
Khadier Beel, Itna	Site23	p1	1.44	0.12	2.29	0.12
Khadier Beel, Itna	Site23	p2	0.97	0.09	3	0.13
Khadier Beel, Itna	Site23	p3	1.24	0.11	5.91	0.14
Nali *Beel*	Site24	p1	2.26	0.18	4.29	0.21
Nali *Beel*	Site24	p2	2.73	0.22	1.56	0.26
Barkapur, Kalmakanda	Site25	p1	1.17	0.11	6.37	0.12
Barkapur, Kalmakanda	Site25	p2	1.4	0.12	9.1	0.18
Barkapur, Kalmakanda	Site25	p3	1.52	0.13	15.32	0.16
Chandi titas khal, Brahmanbaria	Site26	p1	1.36	0.12	19.6	0.2

Site name	Site ID	Plot	OC%	N%	P (mg/kg)	K (mg /100 g soil)
Chandi titas khal, Brahmanbaria	Site26	p2	1.44	0.13	15.93	0.2
Chandi titas khal, Brahmanbaria	Site26	p3	1.83	0.15	17.18	0.61
Katiar khal, Habiganj	Site27	p1	0.12	0.01	8.14	0.06
Katiar khal, Habiganj	Site27	p2	0.55	0.06	5.06	0.09
Katiar khal, Habiganj	Site27	p3	0.7	0.06	5.1	0.12
Bhadikara, Habiganj	Site28	p1	0.93	0.09	6.07	0.09

4. Economic and Ecological Significance of Swamp Tree Nursery

4.1 Nursery Ownership

A total of nineteen (19) nurseries in five *Haor* districts were identified and interviewed (Chapter 2: Table 2.1). There were more government-operated nurseries compared with those managed private/ individually. Government nurseries were established by Bangladesh Forest Department (BFD) and LGED (Local Government Engineering Division, Bangladesh). For those who are operating nurseries individually, it was their primary occupation. Most of the nursery owners were involved with this business for the last 5-10 years.

4.2 Species Preference in Swamp Nurseries

The selection of species in swamp nurseries is initially based on the objectives of production. However, other factors influence nursery owners to grow specific seedlings. For example, availability of germplasm (52%), demand of planting stock (84%), timber quality and fast growth (79%), identified by supporting agency (52%), suitability to the planting Site (73%), wave protection (58%), to attract fish (31%), to attract wildlife (36%), fuelwood supply (90%), use for boundary demarcation (47%) and medicinal purposes (31%) (Figure 4.1).

The majority of the nursery considers both swamp and non-swamp tree species such as Koroch (*Pongamia pinnata*), Hijol (*Barringtonia acutangular*), Kadam (*Athocephalus chinensis*), Jaam (*Syzygium cumini*), Jarul (*Lagerstroemia speciosa*), Neem (*Azadirachta indica*), Arjun (*Terminalia arjuna*), Raintree (*Samanea saman*), Sil koroi (*Albizia procera*), Chickrasi (*Chickrassia tabularis*), Kala koroi (*Albizia lebbeck*), Amloki, Rayna (*Aphanamixis polystacy*) and Kathbadam (*Termenalis catappa*). Unfortunately, number of swamp tree species is negligible and limited to only (*Pongamia pinnata*), Hijol (*Barringtonia acutangular*), Kadam (*Athocephalus chinensis*), Jam (*Syzygium cumini*), and Jarul (*Lagerstroemia speciosa*) (Chapter 2: Table 2.1) and many of them were not native to that *haor* ecosystem.

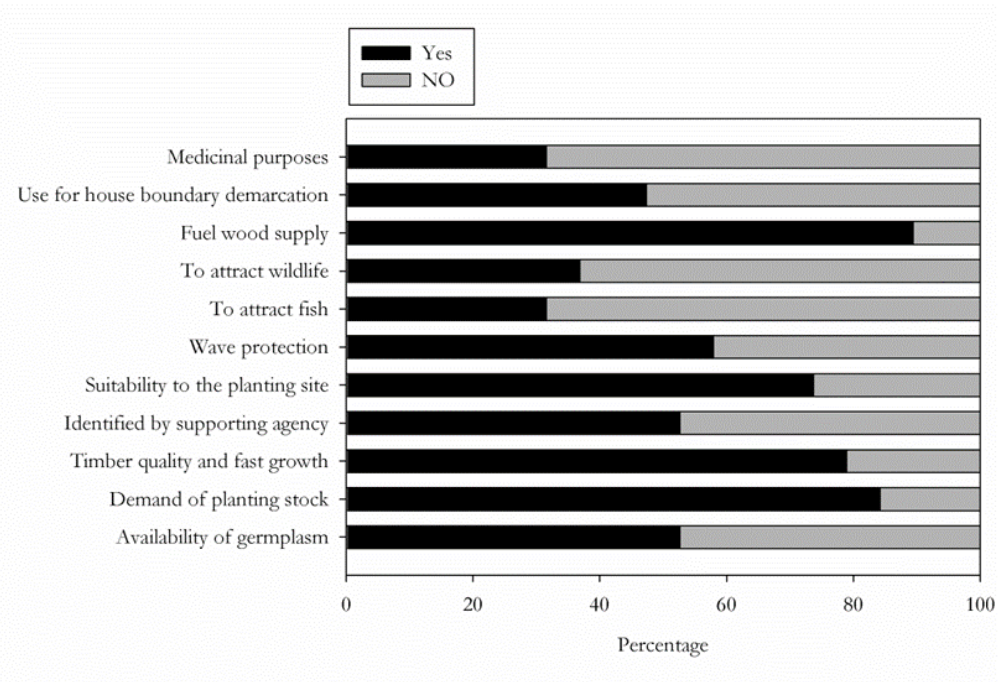


Figure 4.1: Basis on Deciding the Species to Rise

4.3 Profitability of Swamp Nursery Business

It was tough to get reliable information on production cost and selling price of seedlings because most operators/owners do not keep records of expenses incurred in nursery seedling production. However, from the FGDs and key informant interviews, it was found that commonly raised seedling production cost ranges from 15-20 TK only, and selling price ranges from (20-40 TK) only (Table 4.1). On average, 2200±1600 seedlings were sold per month per nurseries in the observed nurseries. Most nurseries have some annual variable cost for seed production such as labor cost, cow-dung, fertilizer, insecticides, irrigation, soil, pot, polybag, and Seed purchase of approximately 5,00,971 TK (Table 4.1). Nursery owners use their profit primarily to expand their nursery business and subsistence (Figure 4.2).

Table 4.1: Economic Profitability of Swamp Nursery Business

Species	Average production cost (TK) [range]	Average sale value (TK) [range]	No. of seedling sold per annum	No. of seedling sold cost per annum
Kadam (*Athocephalus chinensis*)	15-20 /-	30-40/-	2,000	100,000
Hijol (*Barringtonia acutangular*)	15-20 /-	20-40/-	1,500	105,000
Jam (*Syzygium cumini*)	15-20 /-	20-40/-	5,000	400,000
Koroch (*Pongamia pinnata*)	15-20 /-	20-40/-	1,500	90,000
Jarul (*Lagerstroemia speciosa*)	10-12 /-	20-22/-	1,000	80,000
Rain tree (*Samanea saman*)	5-10/-	30/-	1,200	36,000
			Total	**811,000**

Analysis of yearly cost associated with small-scale swamp nursery

Annual fixed cost (TK)		**Annual variable cost (TK)**		**Nursery benefit per annum**
Lease Land	200,000	Labor cost	200,000	8,11,000 -5,00,971 TK
Rented Land	240,000	Crowding	17,571	
Buildings	40,000	Fertilizer	22,285	
Vehicles	25,000	Insecticides	11,000	
Machineries	50,000	Irrigation	70,000	
		Soil	53,187	
		Pot	30,000	
		Polybag	46,428	
		Seed purchase	50,500	
Total Cost	**5,55,000 TK**		**5,00,971 TK**	**310,029 TK**

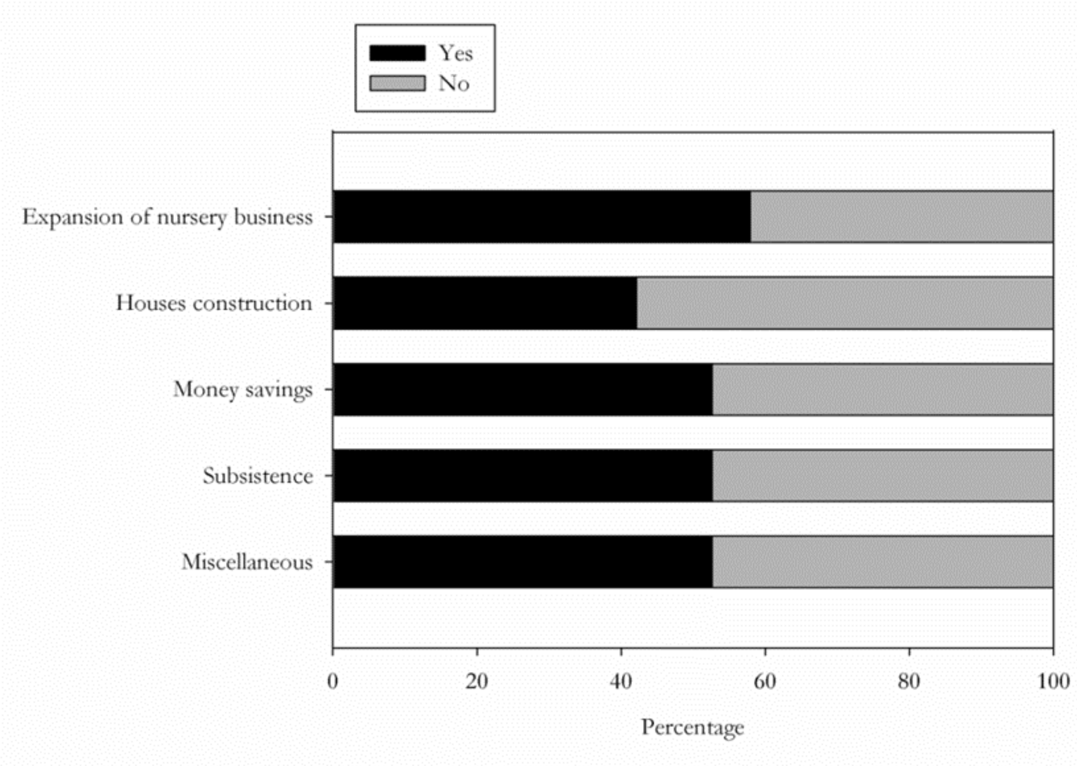


Figure 4.2: Socio-economic Benefits from Swamp Nurseries

4.4 Ecological Aspect of Swamp Nurseries

4.4.1 Source of Germplasm

The quality of plan tick stock (seedling) is primarily associated with the selection of germplasm sources. Seed Orchard (SO) and Seed Production Areas (SPA) offer the highest quality of germplasm as they maintain genetic quality through mother trees.

Unfortunately, the Swamp ecosystem is heavily degraded, and it is pretty challenging to establish SO and SPA in that area now. Therefore, a nursery owner doesn't have access to that germplasm. In most cases, germplasm is collected from unselected sources such as planted or naturally growing seed trees on the roadside or a bounded area and sometimes from the market (Figure 4.3). These trees were not established for seed production purposes and cannot be guaranteed to produce germplasm with high physical, physiological, and genetic quality.

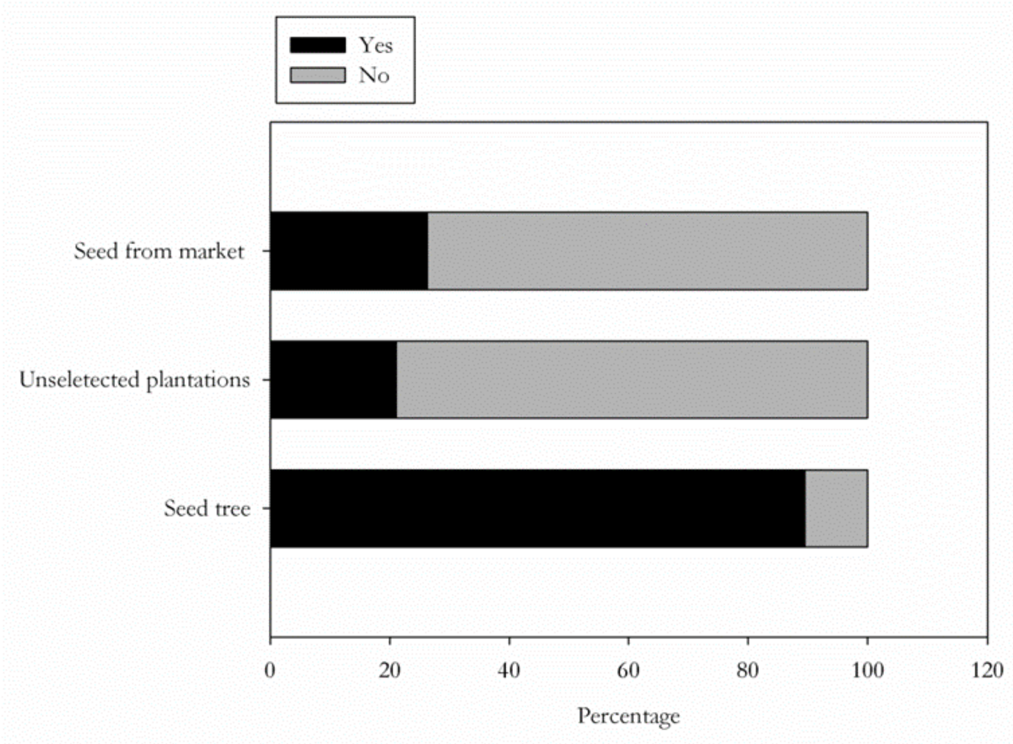


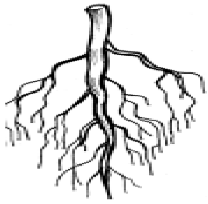
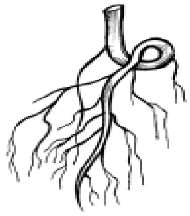
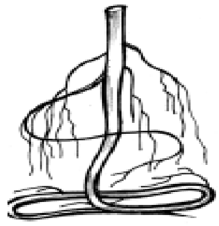
Figure 4.3: Sources of Planting Stock

4.4.2 Morphological Structure of the Seedlings

A high-quality planting stock must have a healthy root system with a straight taproot and many fibrous roots and be free from deformities. Fine root systems are important for the absorption of water and nutrients. In this study, three root structures the healthy root system, a deformed root system, and a spiral root system were investigated. It was observed that two main swamp species Hijol and Koroch don't have a healthy root structure. Only four nurseries Hijol and Koroch had healthy root systems (Table 4.2). It is generally recommended that if any seedlings are similar to the following illustrations of unhealthy root structure, we should discard them for plantation. From this study, it was observed many nurseries' seedlings have poor rooting structures (Table 4.2).

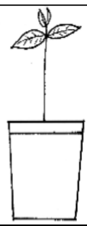
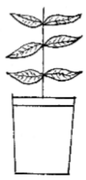
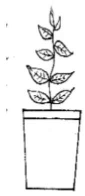
Seedling stem structure also has a significant effect on the quality of plan tick stock. In this study, we have tested the stem structures of different nursery seedlings. If any of the seedlings in the nursery are similar to the illustrations shown in Table 4.3, we need to discard them for further plantings. Unfortunately, most of the nursery seedlings have identical structures that are shown in the illustrations shown in Table 4.3, indicating low-quality planting stock.

Table 4.2: Root Structure Condition of Swamp Seedlings in the Nursery

Species	Root Structure*		
	**Healthy root system (no. of nurseries)	**Deformed root system (no. of nurseries)	**Spiral root system (no. of nurseries)
			
Hijol (4 nurseries)	2	2	-
Korach (5 nurseires)	2	1	2
Kadam (9 nurseries)	7	1	1
Jarul (4 nurseries)	3	1	-
Jam (8 nurseires)	4	2	2

**N.B. Total 19 nurseries were observed, **N.B. Portrait of root structure were obtained from Gregorio et al. (2020)*

Table 4.3: Morphological Condition (Stem Structure) of Swamp Seedlings in the Nursery

Species	**Bent stem**	**Too small**	**Few leaves**	**Two stem**	**Dead shot**	**Small leaves**	**Overgrown**
							
Hijol (n=11)	2	3	3	1	2	-	-
Korach (n=6)	2	1	-	1	1	-	-
Kadam (n=8)	1	4	2	1	-	-	-
Jarul (n=7)	-	2	1	2	1	-	-
Jam (n=3)	-	-	-	2	1	2	4

**N.B. Total 19 nurseries were observed*

***N.B. Portrait of root structure were obtained from Gregorio et al. (2020)*

Table 4.4: Seedlings Morphological Attributes when Sold for Plantation

Species	**Seedling height**	**Root collar diameter**	**Individual sturdiness quotient (SQ)**
Kadam (*Athocephalus chinensis*)	208cm	20mm	10.4
Hijol (*Barringtonia acutangular*)	6.4cm	11mm	0.58
Jam (*Syzygium cumini*)	8.5cm	21.5mm	0.4
Koroch (*Pongamia pinnata*)	130cm	13mm	10
Jarul (*Lagerstroemia speciosa*)	80cm	7.5mm	10.7

Kadam stem

Kadam root

Arjun stem

Arjun root

Hijol stem

Hijol root

Jam stem

Jam root

Raintree stem

Raintree root

Koroch stem

Koroch root

Figure 4.4: Morphological Structure of Major Swamp Species

4.5 Technical Skills in Planting Stock Production

In general, the planting stock growers need basic skills and an understanding of seedling quality assessment. Nevertheless, it is apparent from the morphological observation that seedling producers lack this skill. To test their knowledge, the Sturdiness quotient (SQ) (i.e., the ratio of the height of the seedling to the root collar diameter) was investigated to express the seedling's vigor and robustness. Three sample seedlings for each species available during the nursery visit were taken for destructive sampling to assess the seedling quality using these parameters. Among the five (05) commonly observed species taken for destructive sampling from all nurseries, only two had desirable sturdiness quotient values of less than six. This indicates that most of the seedlings raised were lanky, etiolated, or not robust. These findings indicate that the seedlings raised both in small-scale and government nurseries are of sub-optimal quality and unlikely to withstand the adverse ecological conditions in most planting Sites. Apart from this, it was found that nursery operators have some basic skills in vegetative propagation techniques such as cuttings and layering's to produce seedlings. However, this is not a common practice in the observed nurseries (Table 4.5). They also use seed treatment for seed germination (Table 4.6).

Table 4.5: Vegetative Propagation Techniques Applied in the Swamp Nurseries

Techniques	Yes	No	Species considered
Cuttings	21.05	78.94	Jam, Kadam, Rain tree
Layering's	10.52	89.47	Jam, Kadam, Rain tree
Tissue culture	0	100	NA

Table 4.6: Seed Treatment Applied in the Swamp Nurseries

Species	Pre-sowing treatment
Hijol	Cold Water treatment, Sun-dry
Kadam	Cold Water treatment, Sun-dry
Jam	24 hour soaking in water
Jarul	Cold water treatment

4.6 Nursery Operator's Opinion about Plant Mortality when Planted for Reforestation

Respondents were interviewed to explore the reason behind plant mortality in reforestation programs. The majority have opined that mortality is the main reason behind it followed by inappropriate planting and uprooting of trees (Figure 4.5). Low-quality seedlings might be the reason for plant mortality when planted for reforestation.

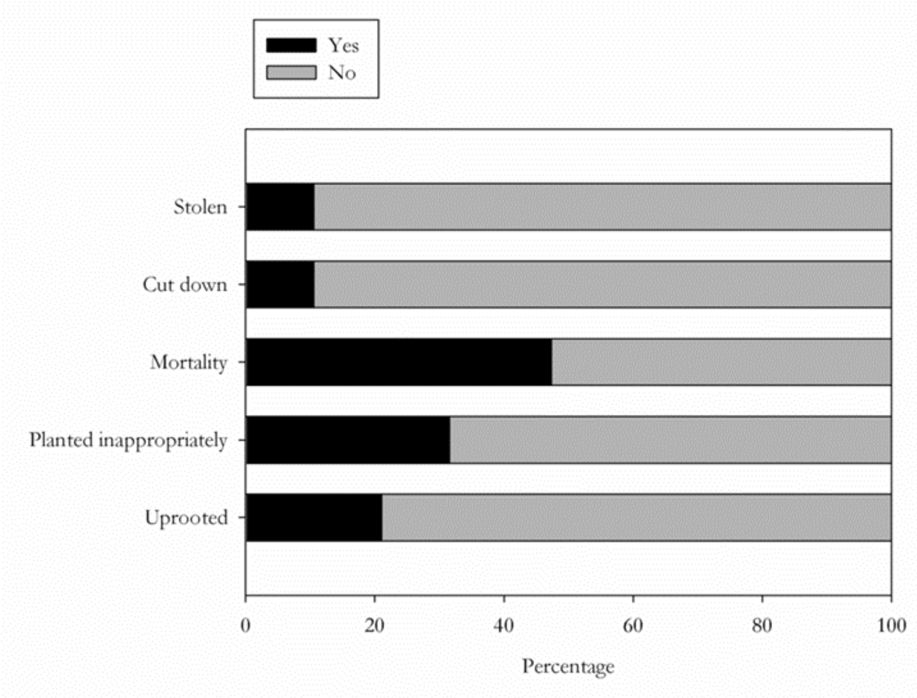


Figure 4.5: Plant Mortality Reason when Planted for Reforestation Programs

4.7 Constraints Faced by the Swamp Nurseries

A standard nursery should have basic structures such as germination shed, potting shed, transplanted shed, and hardening bed to grow quality seedlings. Unfortunately, most of the observed nurseries do not have these facilities (Figure 4.6). In addition to that, most of the nursery owner's pointed out the lack of funds, technical skills, support from the government, and non-government. Organization, lack of access to high-quality germplasm are of major concern for profitable and successful nursery operations and business (Figure 4.7).

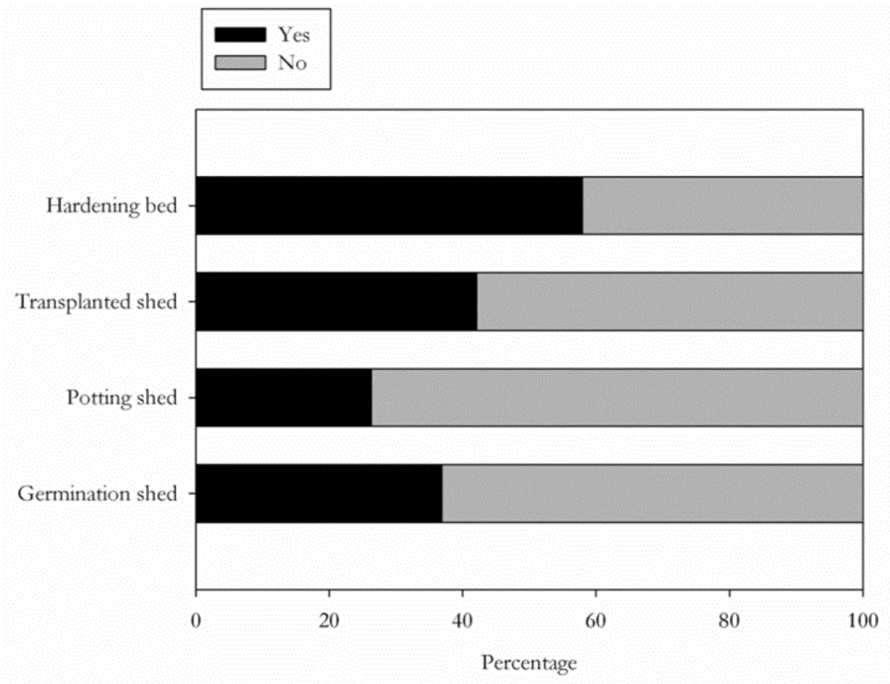


Figure 4.6: Available Necessary Structures in Swamp Nurseries

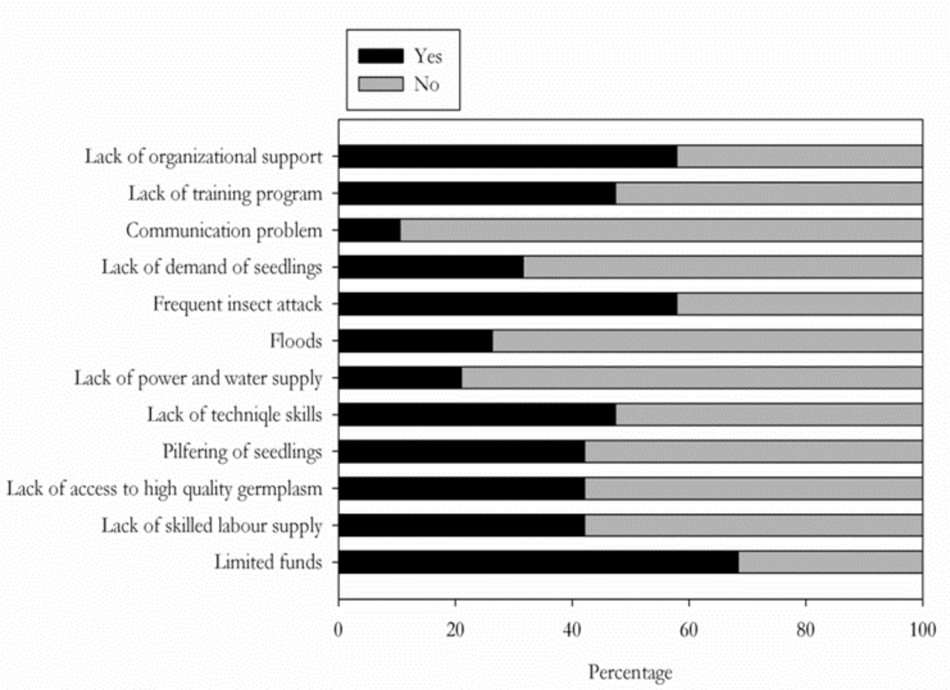


Figure 4.7: Constraints that were Commonly Encountered by the Nursery Owners

5. Evaluation of Best Land Utilization Practices by Crop Diversification in *Haor* Areas

5.1 Present Constrains

As mentioned earlier *haor* area is very prone to natural calamities. These hazards create many problems which ultimately converted to crop yield loss. Four major constraints are identified by the respondents during KII and FGDs. They highlighted pest infestation as the major constrain for crop production followed by flash flood. Major constraints identified by the respondents are presented in Figure 5.1 by percentage.

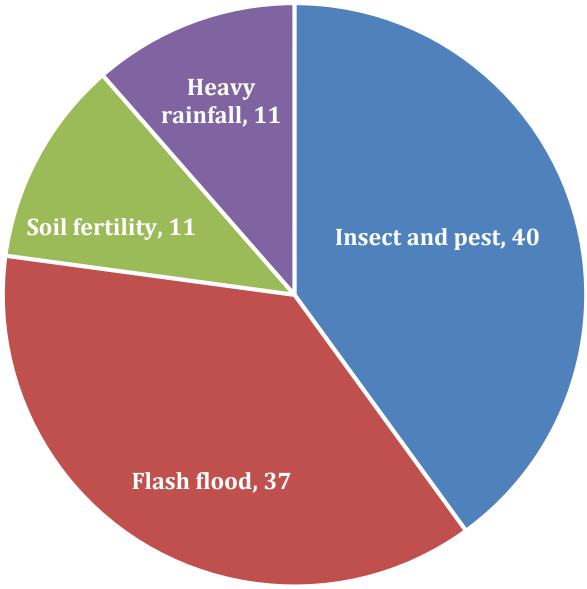


Figure 5.1: Major Constrains Highlighted by the Respondents

5.2 Present Practice

Presently non rice crops dominant in the homestead level of *haor* area. Mostly spices dominate in these area where water requirement is very low. Dwellers also grow different kind of vegetables at homestead level. Moreover, a small portion of maize cultivation is also found in the sampling areas. The crops grown in the sampling area is presented in Figure 5.2.

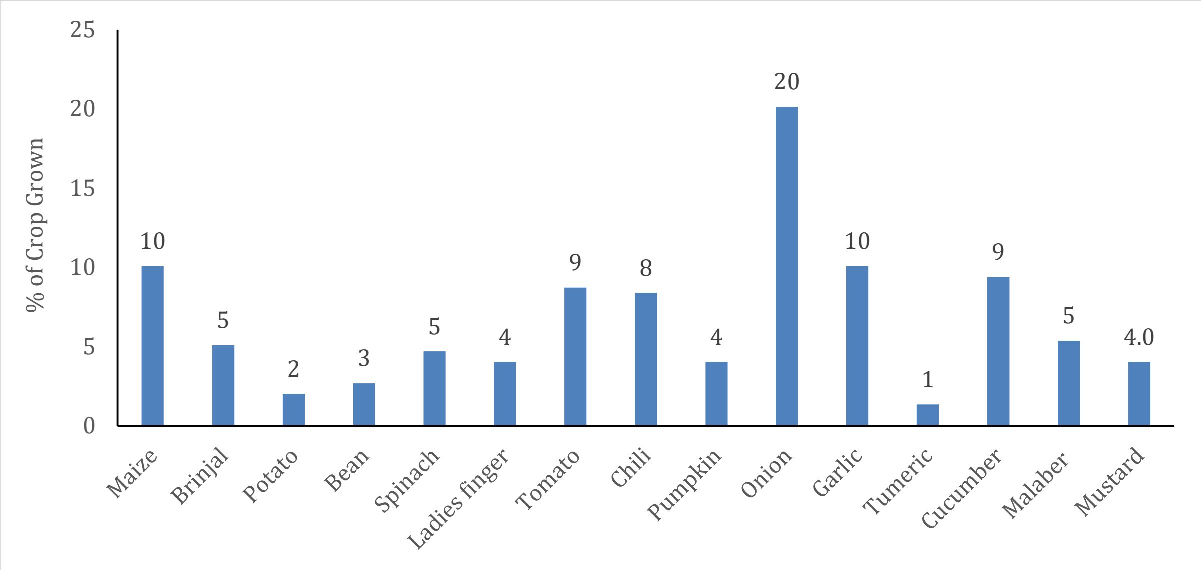


Figure 5.2: Percentage of Crop Grown in the Sampling Area (at Homestead Level)

5.3 Innovative Ideas

Crop cultivation is constraining during monsoon due to excessive water and less cultivable land area. To manage this problem mainly four ideas are highlighted during KII and FGDs. The innovative ideas identified by the FGDs are presented in Figure 5.3 by percentage.

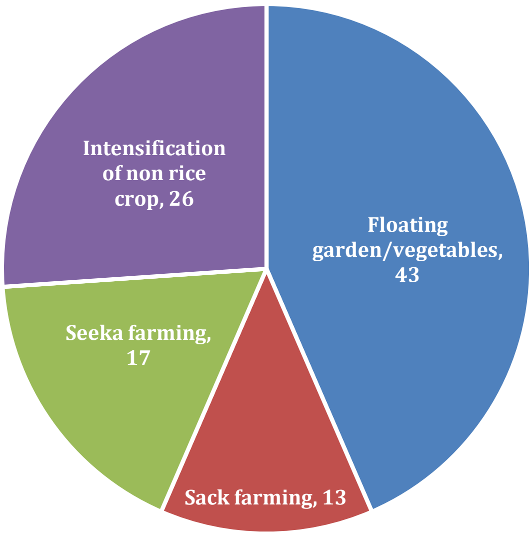


Figure 5.3: Innovative Ideas to Increase Crop Production in the Sampling Area (%)

5.4 Crop Suitability Analysis

Crop suitability analysis was carried out for two different segments. These are-

- Homestead level; and
- *Haor* base level;

5.4.1 Homestead Level Crop

For homestead level, crop suitability was assessed according to *haor* types (Deeply flooded *haor*, Foothill Haor, and Floodplain). As settlement categories and surrounding areas are largely dependent on *haor* classifications. Homestead of deeply flooded *haor* areas are clumsy where very little space is found to bring under cultivation. Thus, vegetables, especially which could grow in the backyards or rooftops of rural settlements, are the only choice. Several vegetables could be grown in these areas-

- Bean, Spinach, Pumpkin, Cucumber, Malaber Spinach, Water Gourd, Snake Gourd, Red Amaranth, Squash Gourd, Bitter Gourd, Sponge Gourd and Brinjal.

A sample is presented in Figure 5.4.

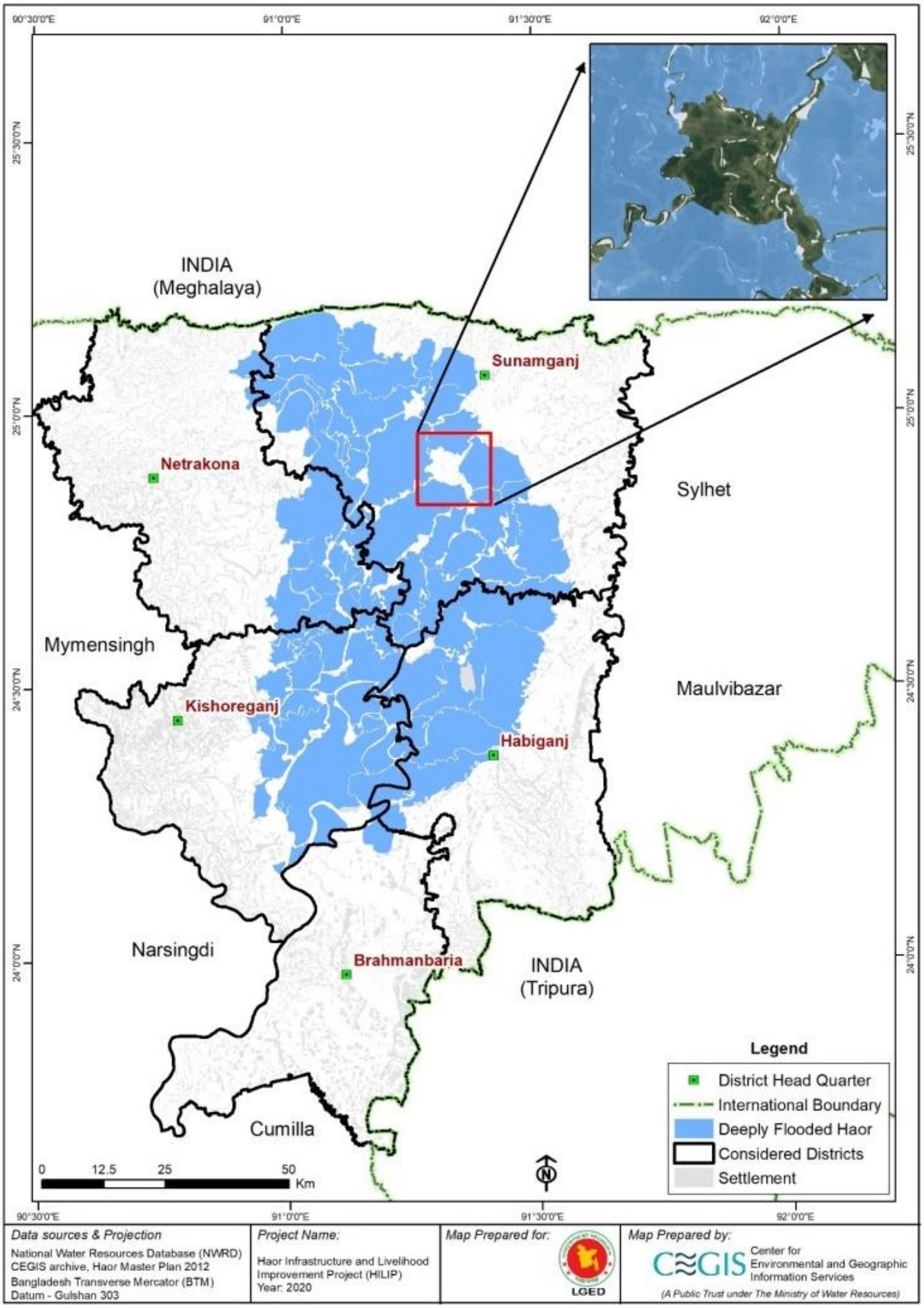


Figure 5.4: Crops Ground in Homestead Level in Deeply Flooded *Haor*

Foothills are relatively high ground in *haor* areas where water recession occurred before deeply flooded *haor*. In the dry season, some free space is found in and around the homestead. This allows for growing more crops in this area. So the crop choice is also enlarged than that of deeply flooded *haor*. A sample is presented in Figure 5.5. List of crops is- Brinjal, Bean, Spinach, Ladies finger, Tomato, Chilli, Pumpkin, Turmeric, Cucumber, Malabar, Spinach, Water Gourd, Snake Gourd, Red Amaranth, Squash Gourd, Bitter Gourd, Sponge Gourd.

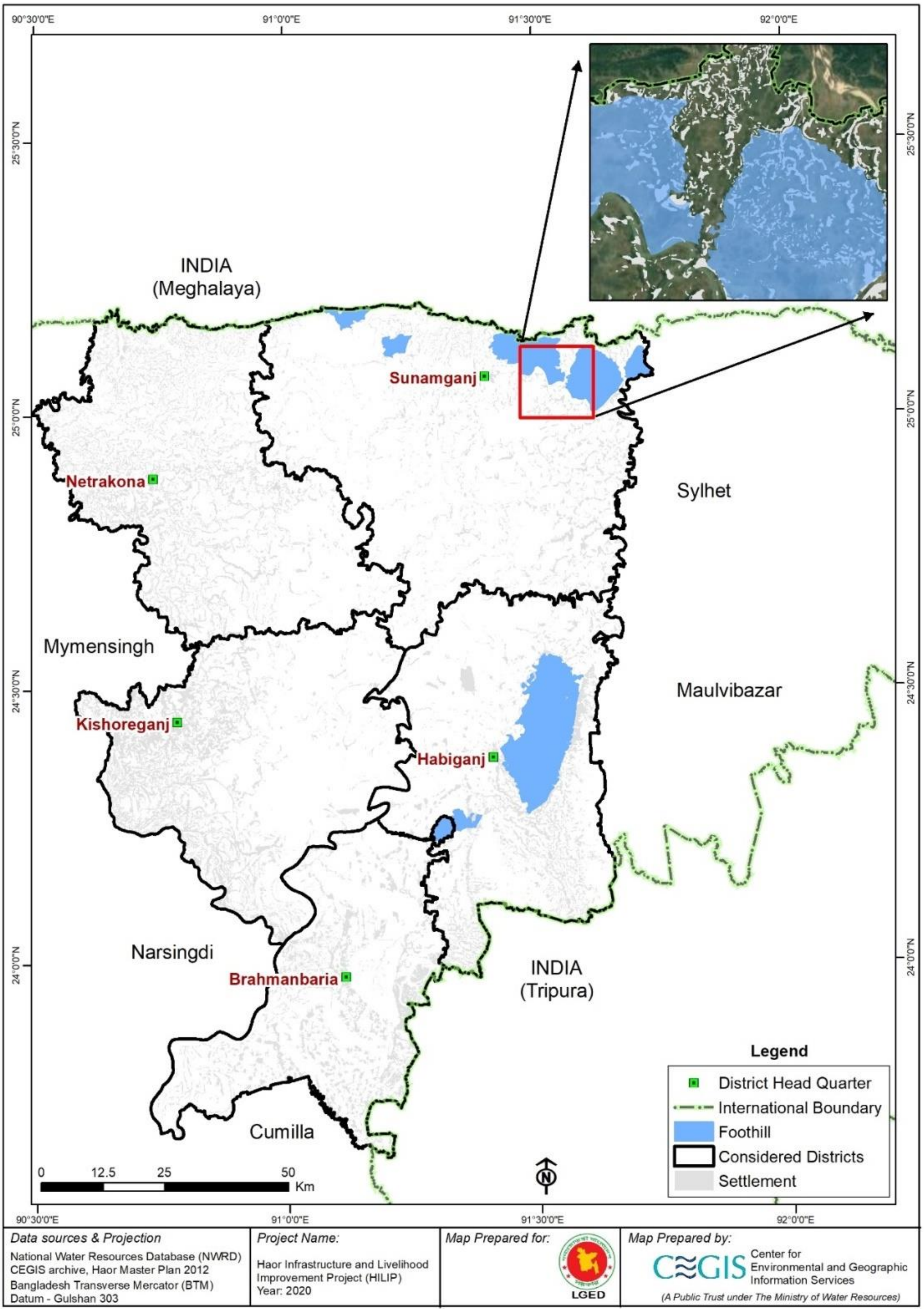


Figure 5.5: Crops Ground in Homestead Level in Foothill *Haor*

Floodplain *haors* are situated at the edges of the *haor* areas. Both water recession and flooding occur late in these areas. So, a wide range of crops could be grown here. Some of these are orchards and field crops. A sample is presented in Figure 5.6. List of crops is- Brinjal, Potato, Bean, Spinach, Ladies finger, Tomato, Chilli, Pumpkin, Onion, Garlic, Turmeric, Cucumber, Malabar Spinach, Maize, Water Gourd, Lemon, Snake Gourd, Red Amaranth, Squash Gourd, Bitter Gourd, Sponge Gourd.

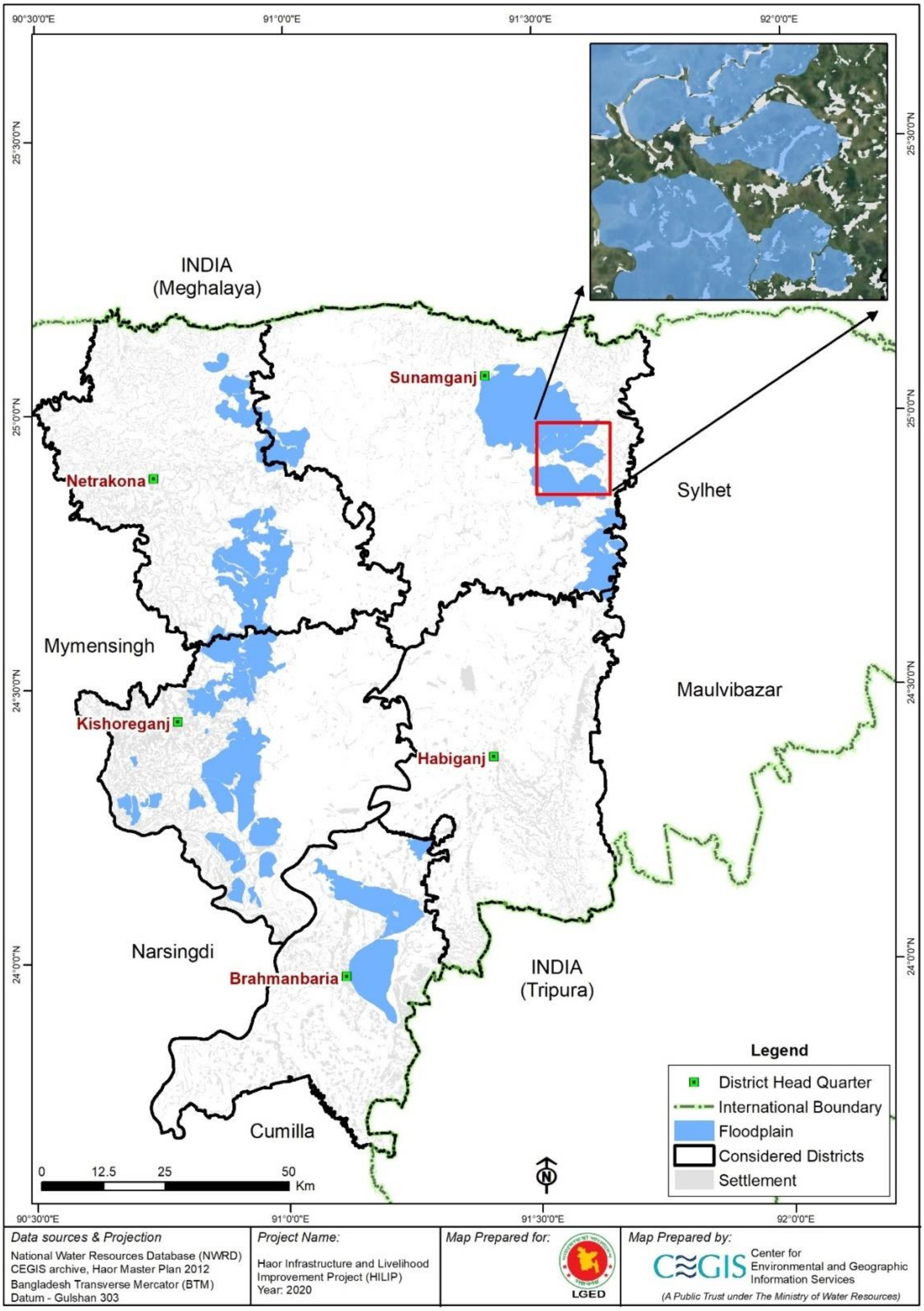


Figure 5.6: Crops ground in Homestead Level in Floodplain *Haor*

5.4.2 Haor Basin Level

Agricultural practice in *haor* areas is mainly dependent on flooding and water recession. So, waterlogged areas of deeply flooded *haors* have very little choice of crop diversification. According to the crop suitability analysis, broadcasting Aus and local Aman suitability is high for cultivation. As mentioned earlier, the diversification of HYV varieties remains limited due to uncertainties of water recession and the threat of natural calamities. A bunch of crops is selected for *haor* basin level cultivation. Their suitability analysis for the entire study area is presented in Figures 5.7-5.20 and the percentage of suitability is presented in Table 5.1. It is to be noted that the study area is vast, so district-wise crop suitability is for the specific crop is presented in Appendix 9.

Table 5.1: Percentage of Different Crops Suitability at Study Area (*Haor* base level)

Crop Name	Suitable	Moderately Suitable	Not Suitable	Total
Broadcasting Aus	19	36	45	100
T. Aus (without Irrigation)	6	28	66	100
T. Aus (with Irrigation)	6	29	65	100
T. Aman (with Irrigation)	3	31	66	100
T. Aman (without Irrigation)	2	32	66	100
Lt Aman (Without Irrigation)	5	49	45	100
HYV Boro	6	73	21	100
Jute_capsularis	29	26	45	100
Jute_Olitorious	7	27	65	100
Potato (with Irrigation)	11	43	46	100
HYV Mustard	11	33	55	100
Onion	10	33	57	100
Radish	8	37	56	100
Snake Gourd	3	13	84	100

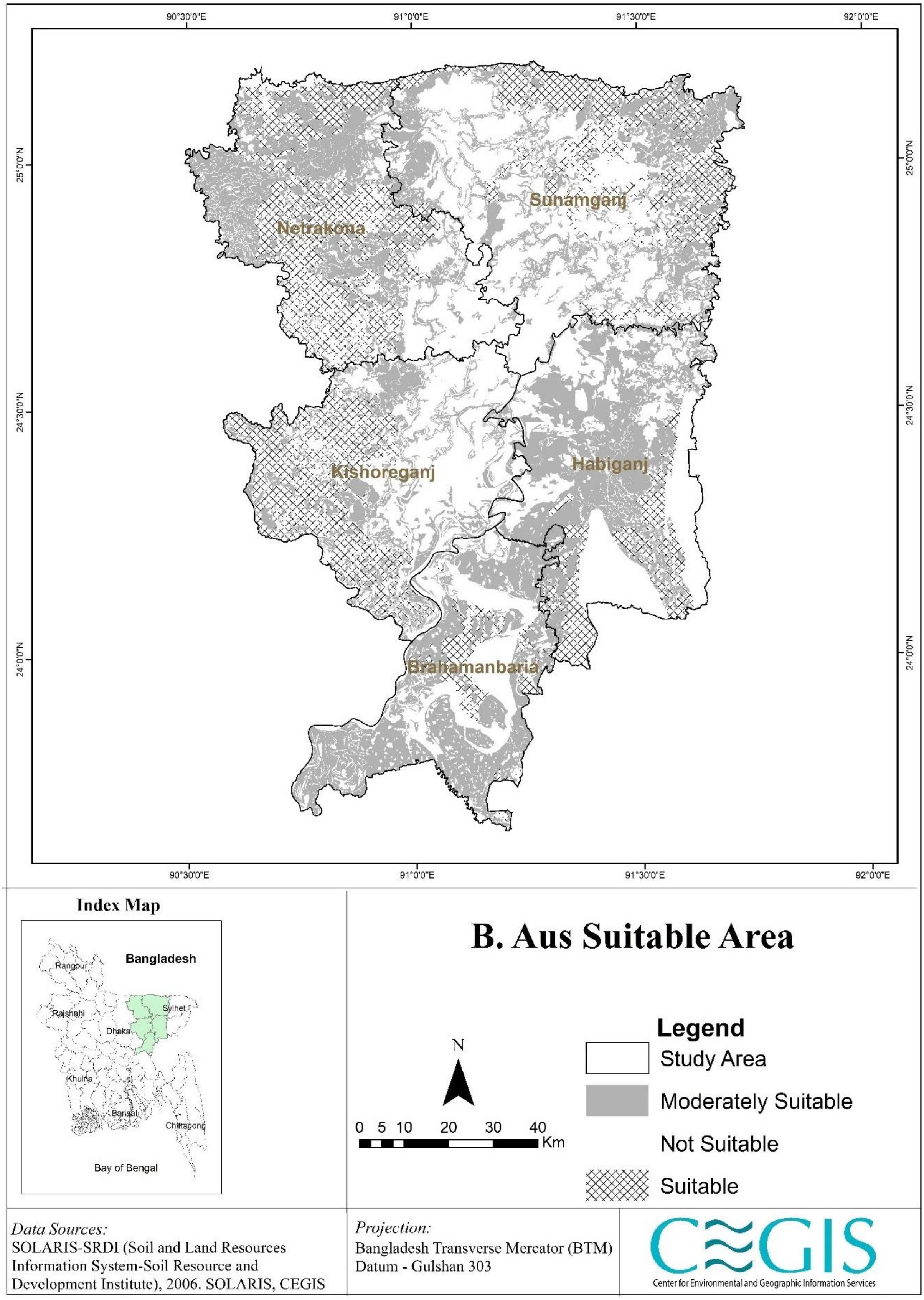


Figure 5.7: B. Aus Suitable Areas

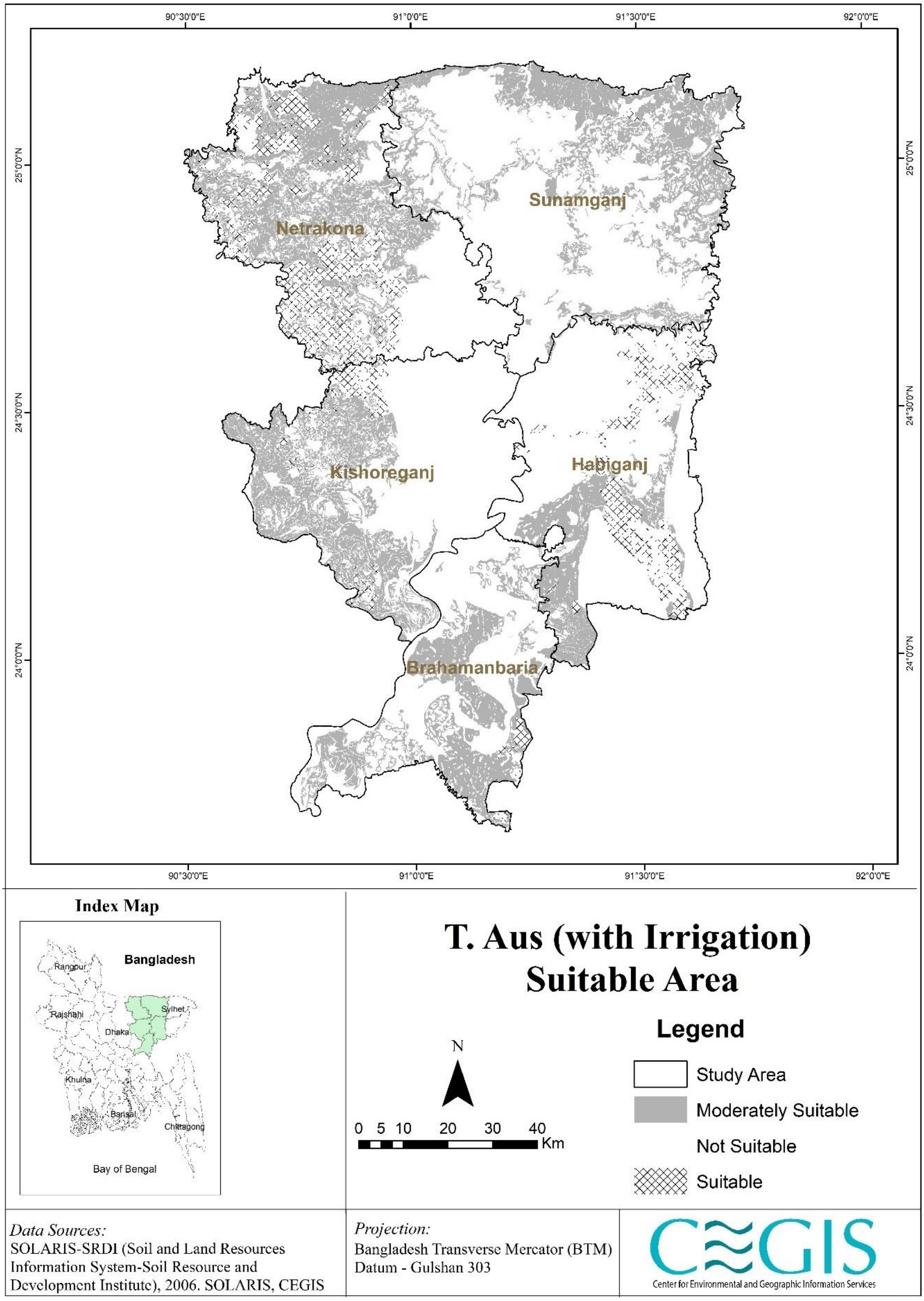


Figure 5.8: T. Aus (with Irrigation) Suitable Areas

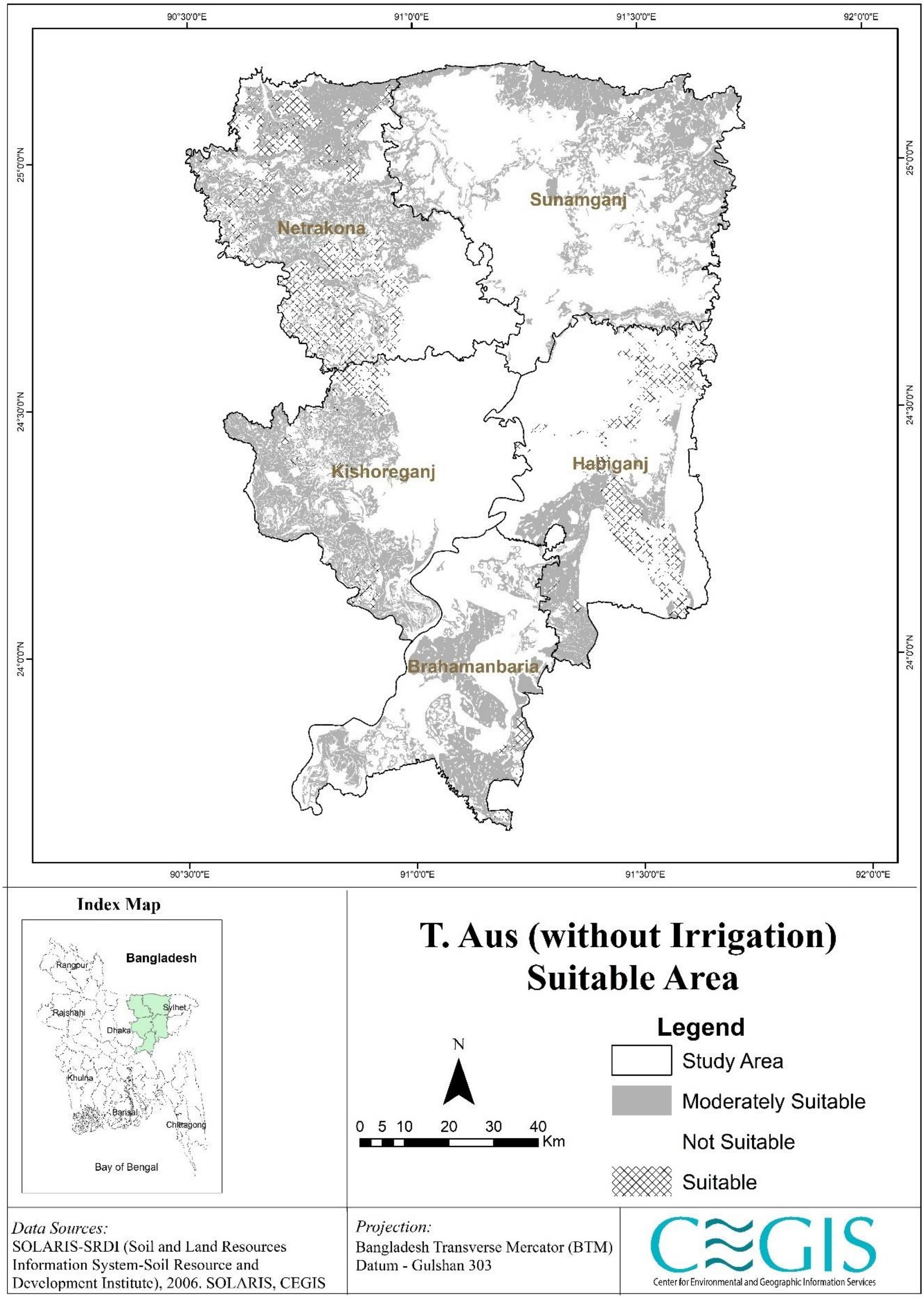


Figure 5.9: T. Aus (without Irrigation) Suitable Areas

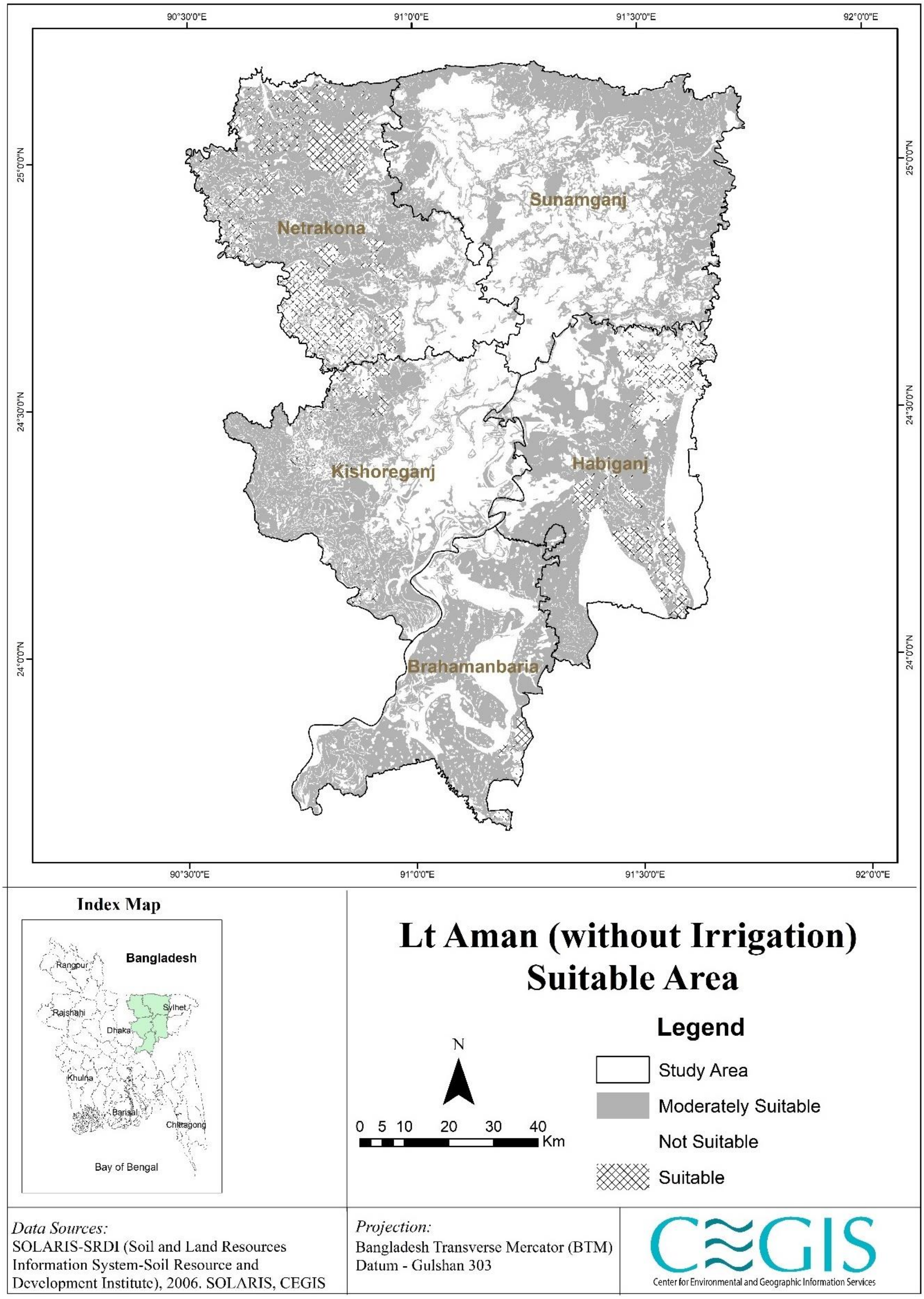


Figure 5.10: Local Aman (without Irrigation) Suitable Areas

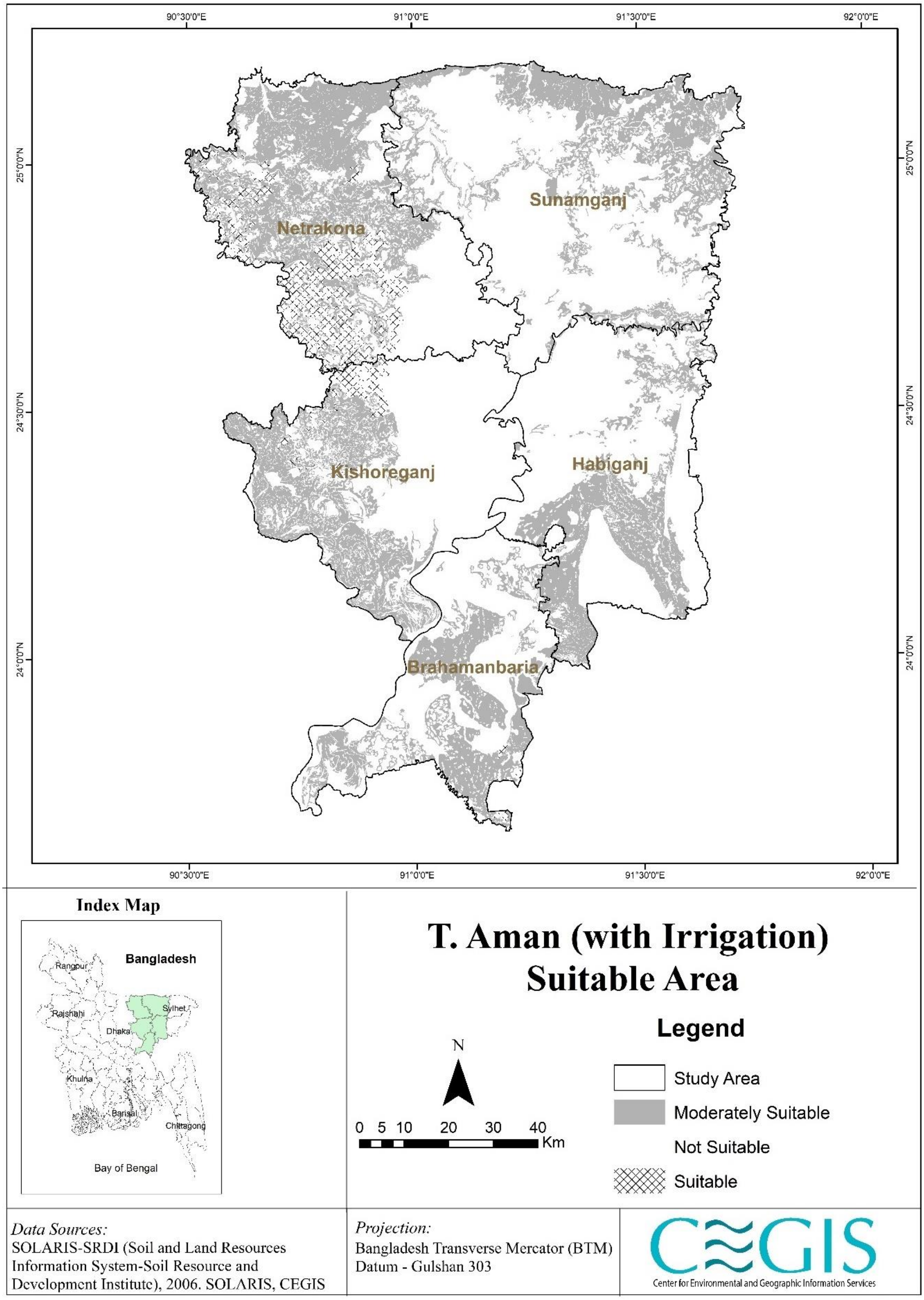


Figure 5.11: T. Aman (with Irrigation) Suitable Areas

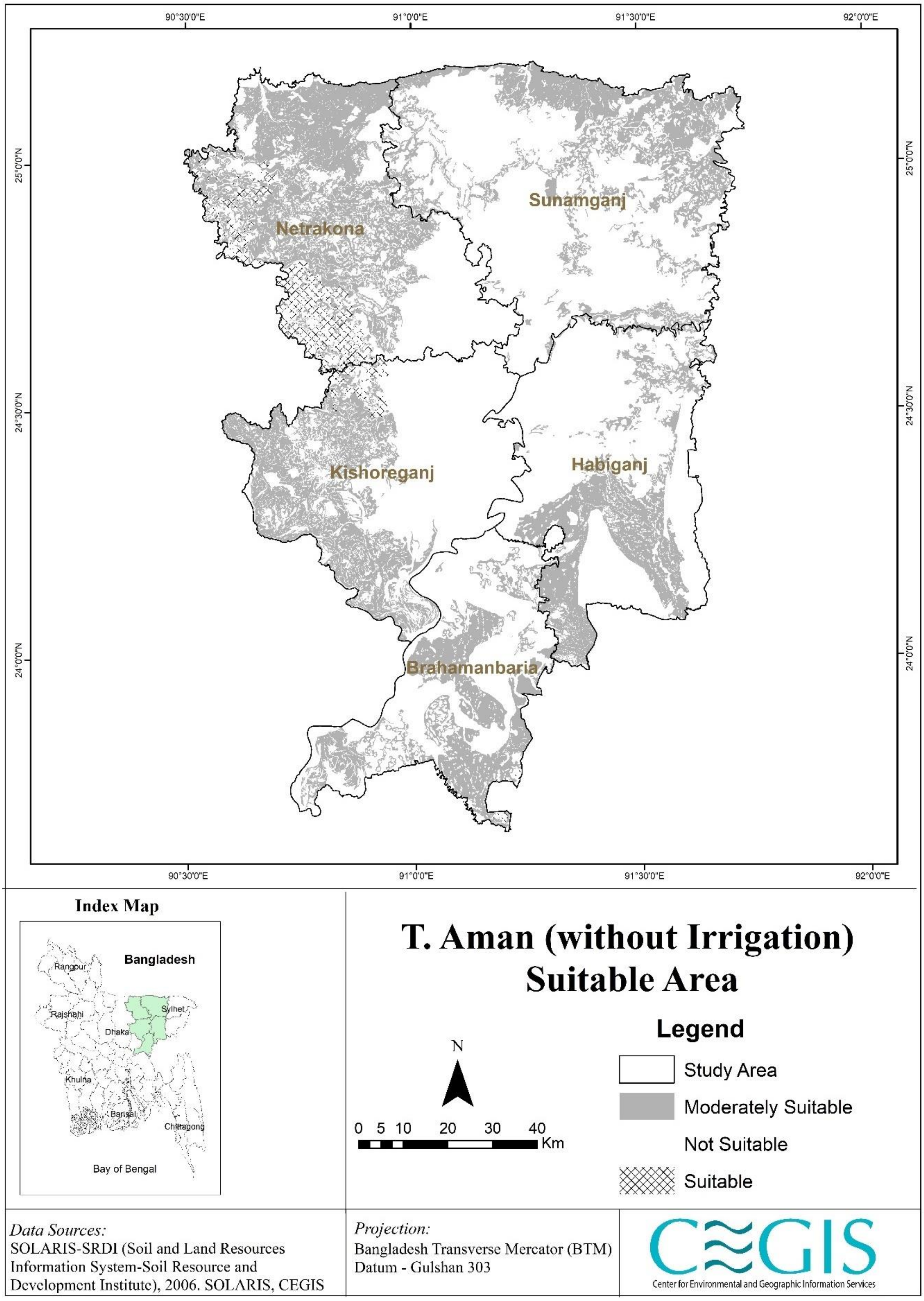


Figure 5.12: T. Aman (without Irrigation) Suitable Areas

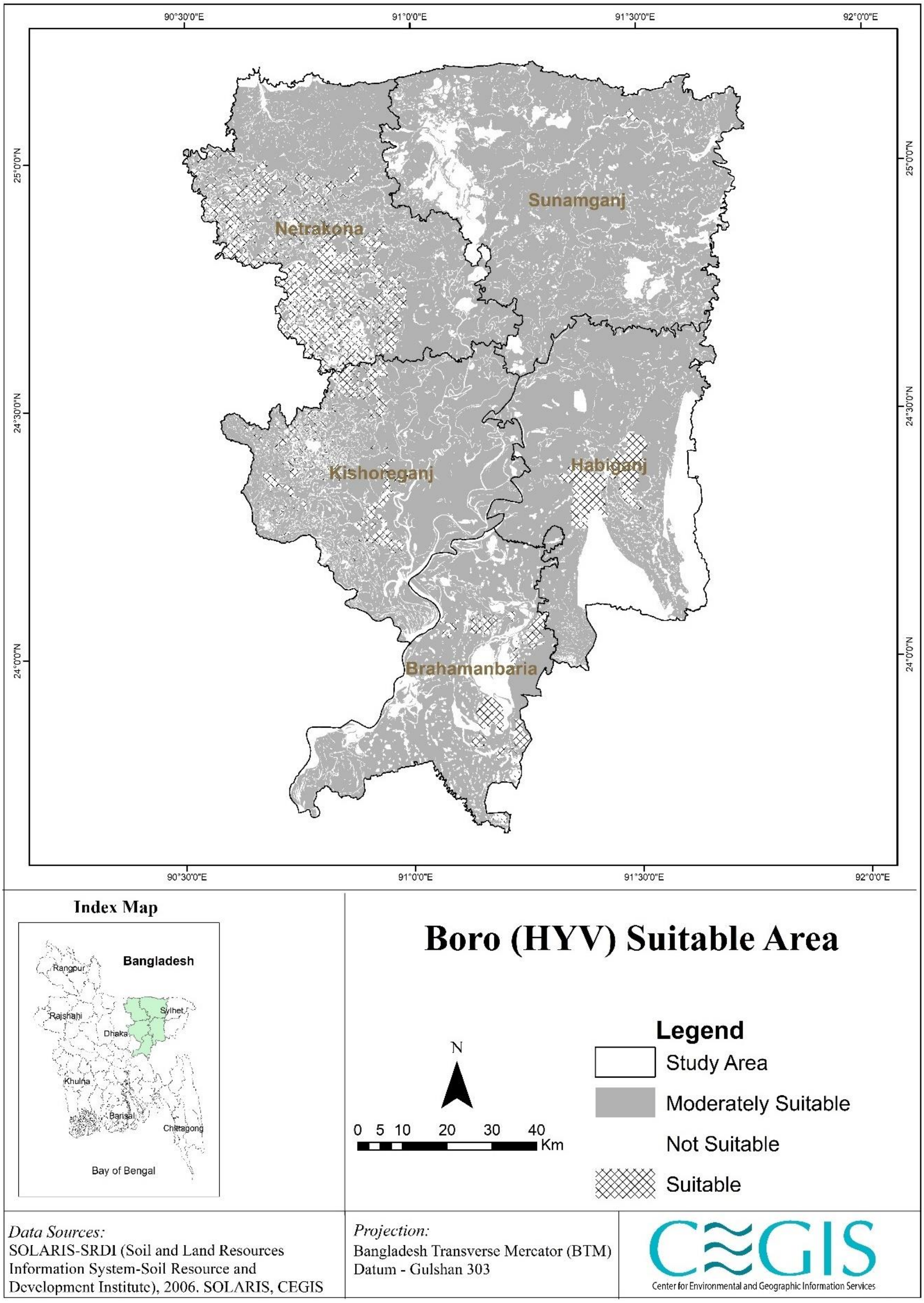


Figure 5.13: HYV Boro Suitable Areas

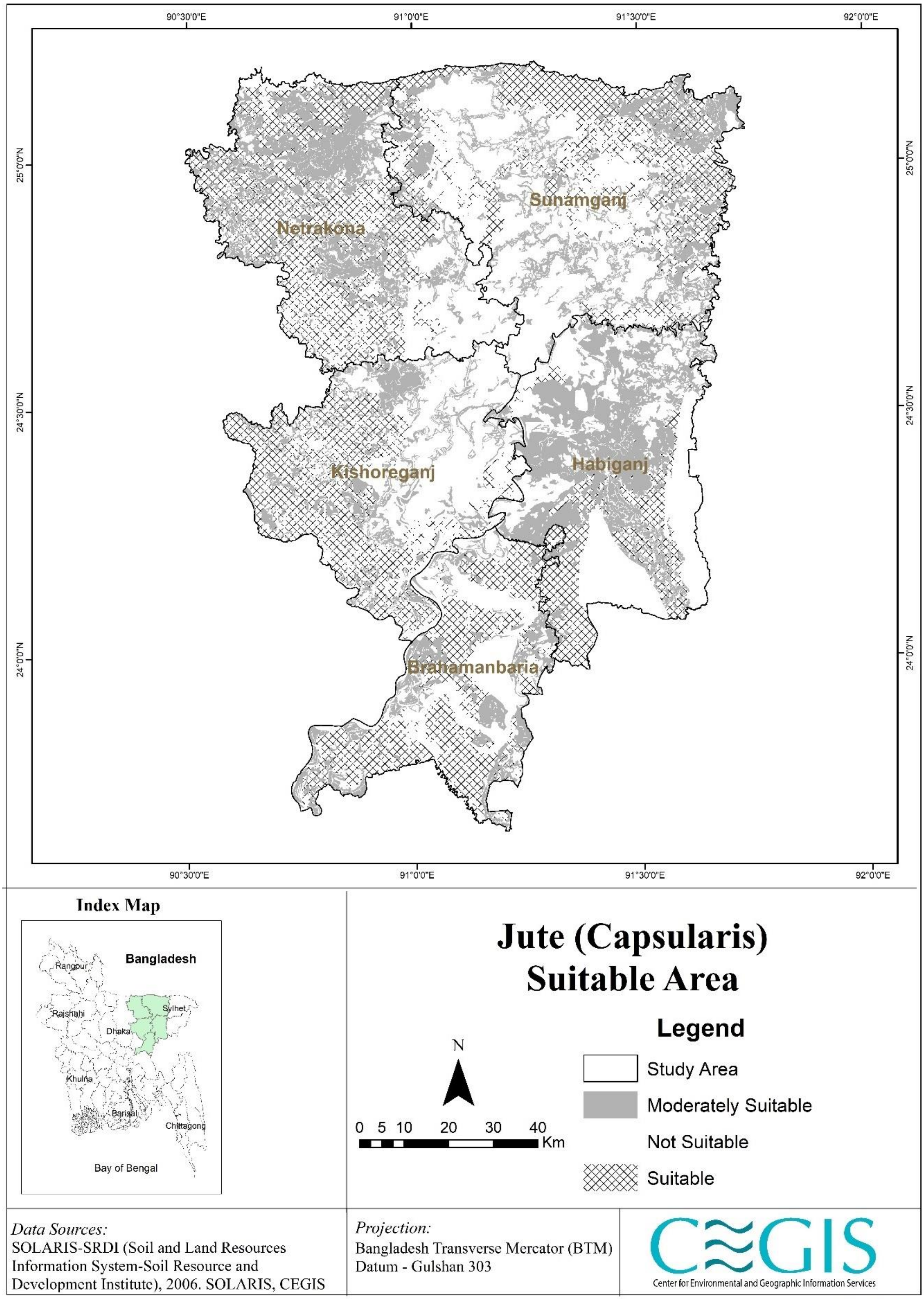


Figure 5.14: Jute (Capsularis) Suitable Areas

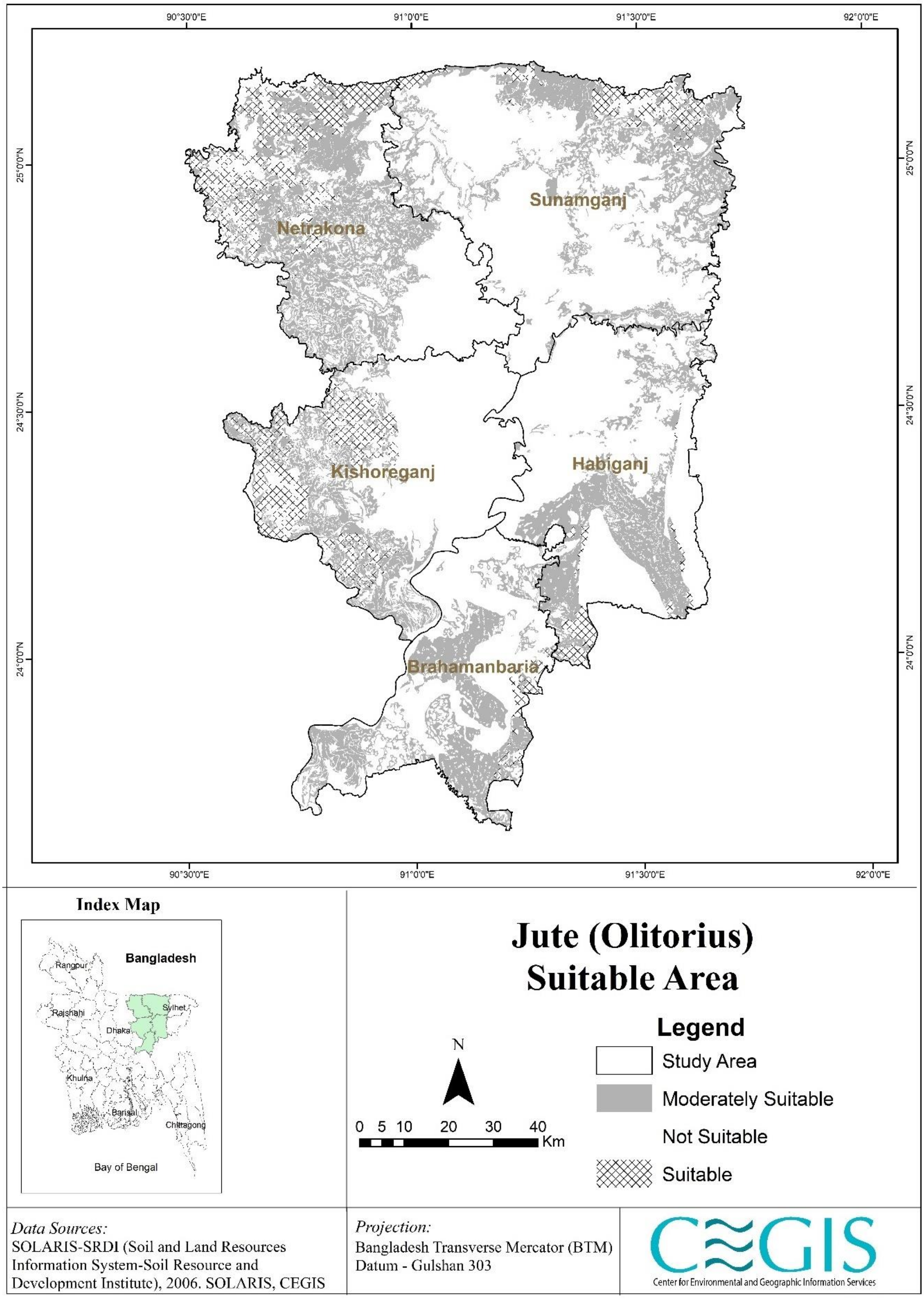


Figure 5.15: Jute (Olitorious) Suitable Areas

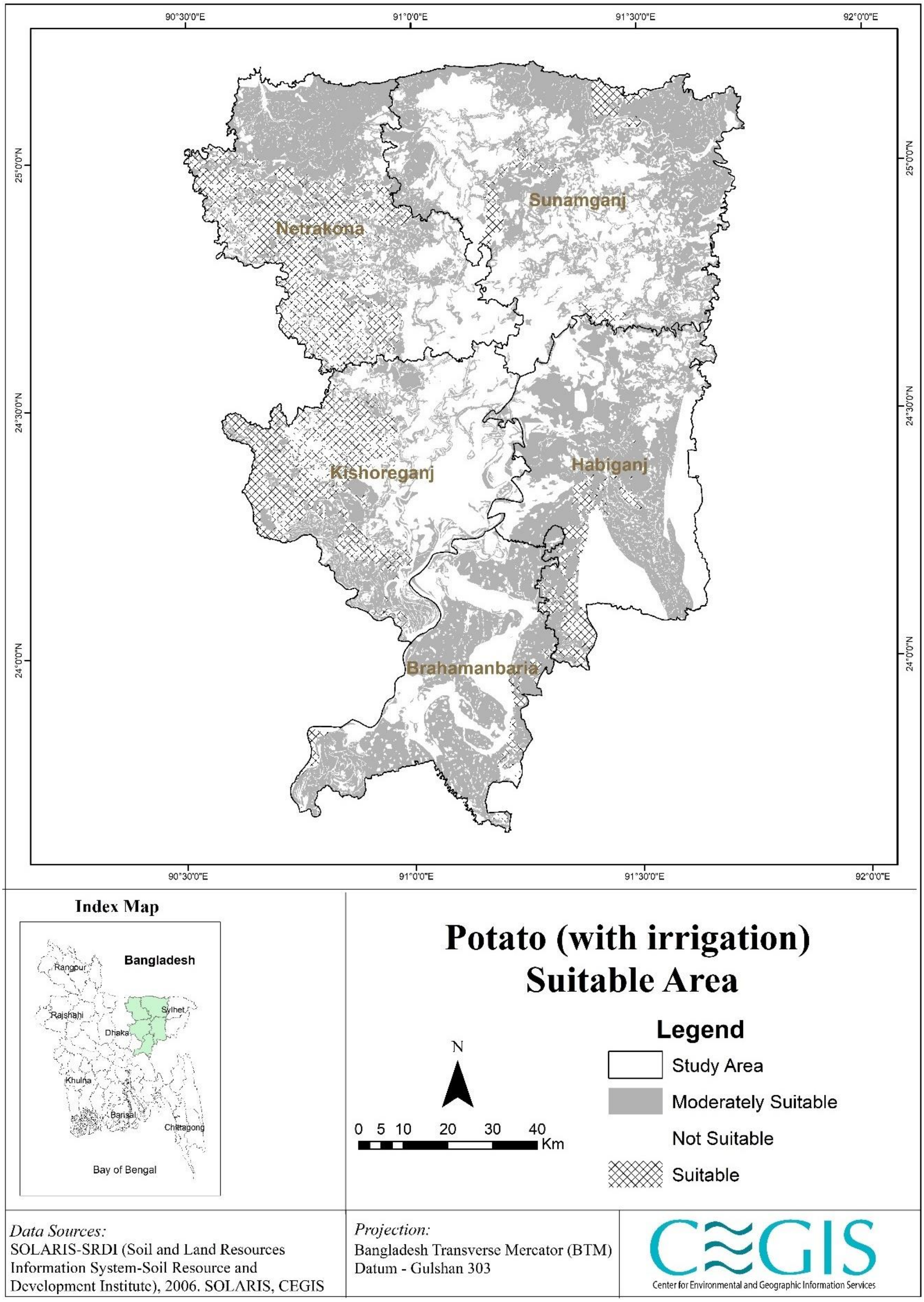


Figure 5.16: Potato (with Irrigation) Suitable Areas

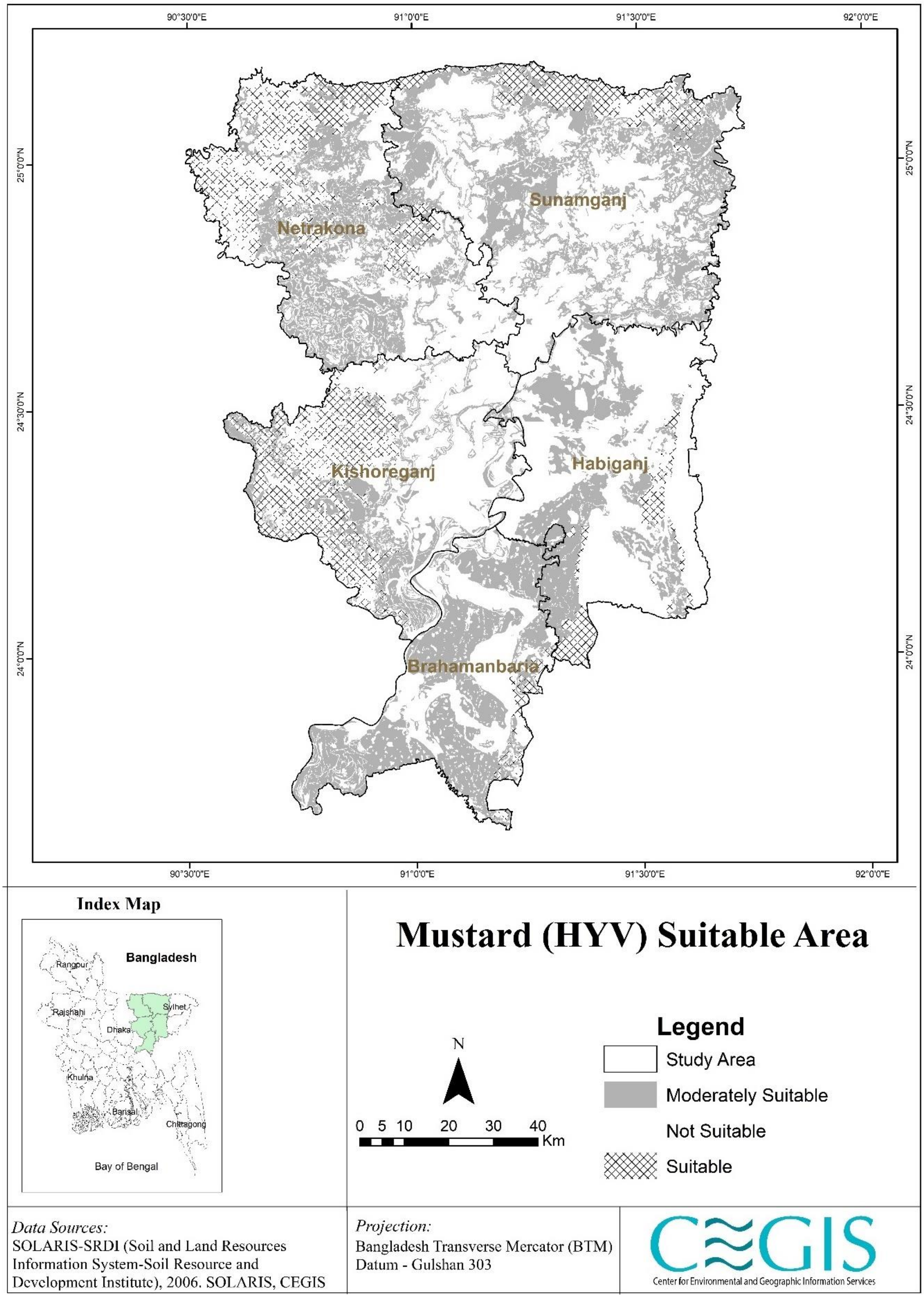


Figure 5.17: HYV Mustard Suitable Areas

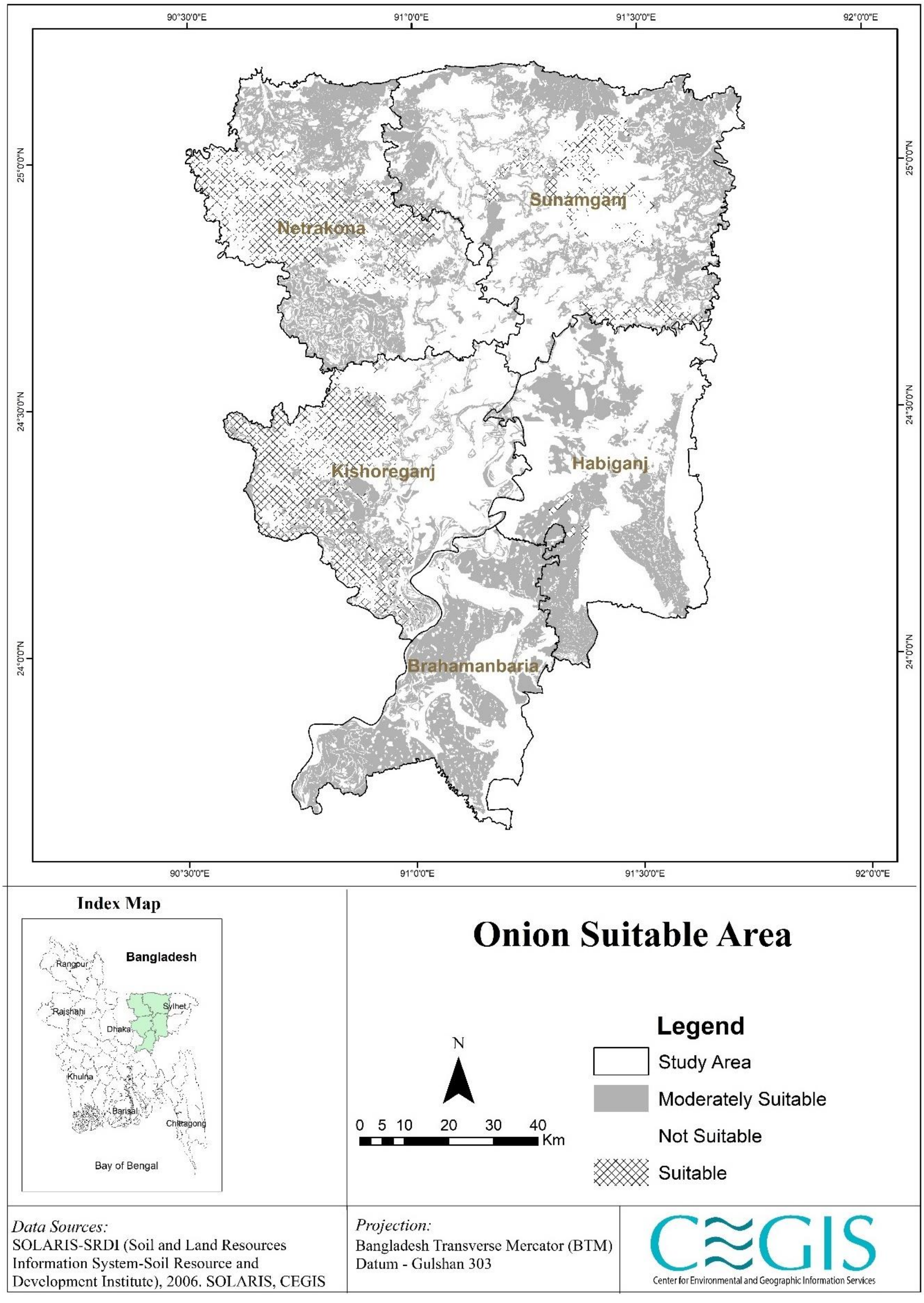


Figure 5.18: Onion Suitable Areas

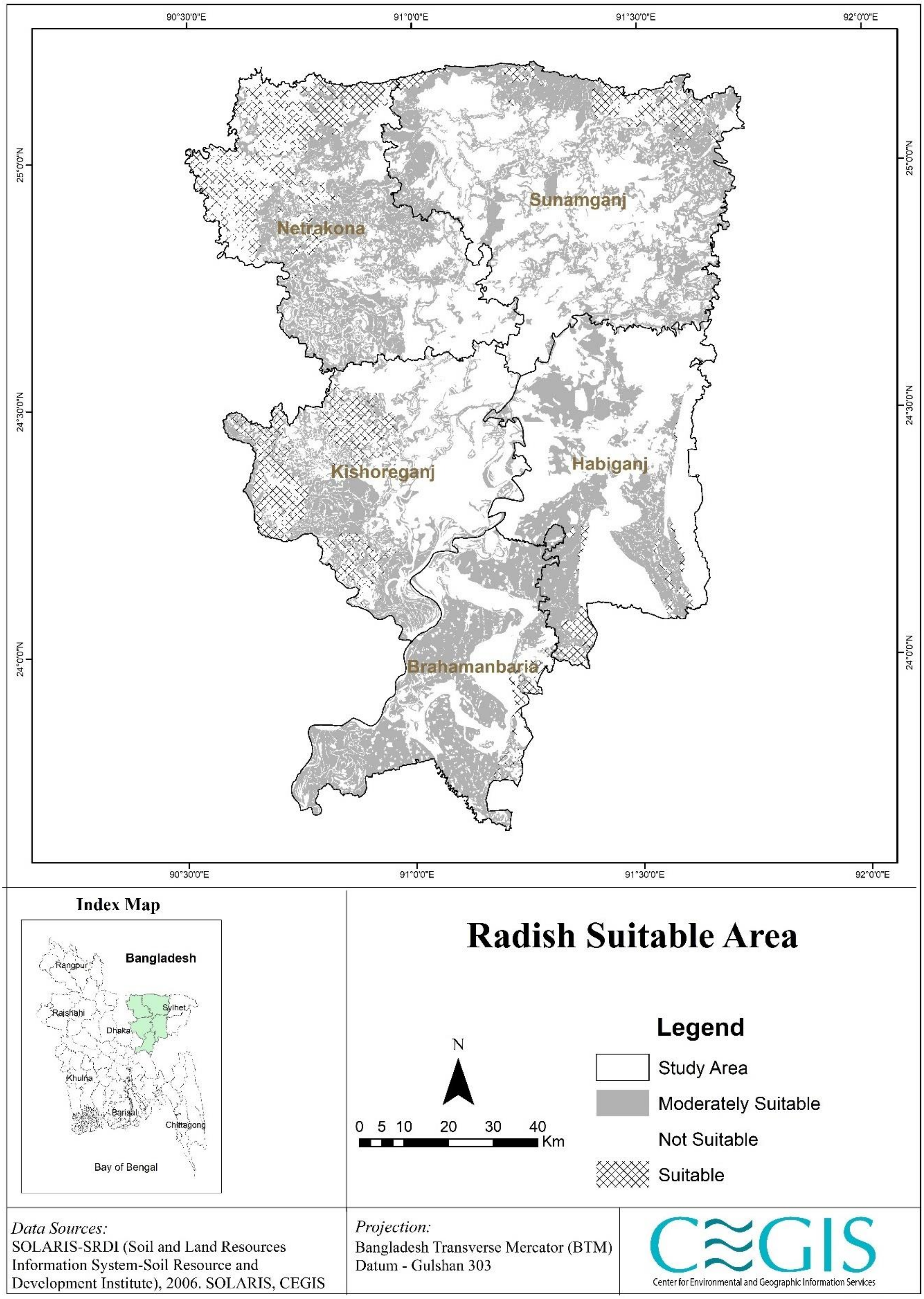


Figure 5.19: Radish Suitable Areas

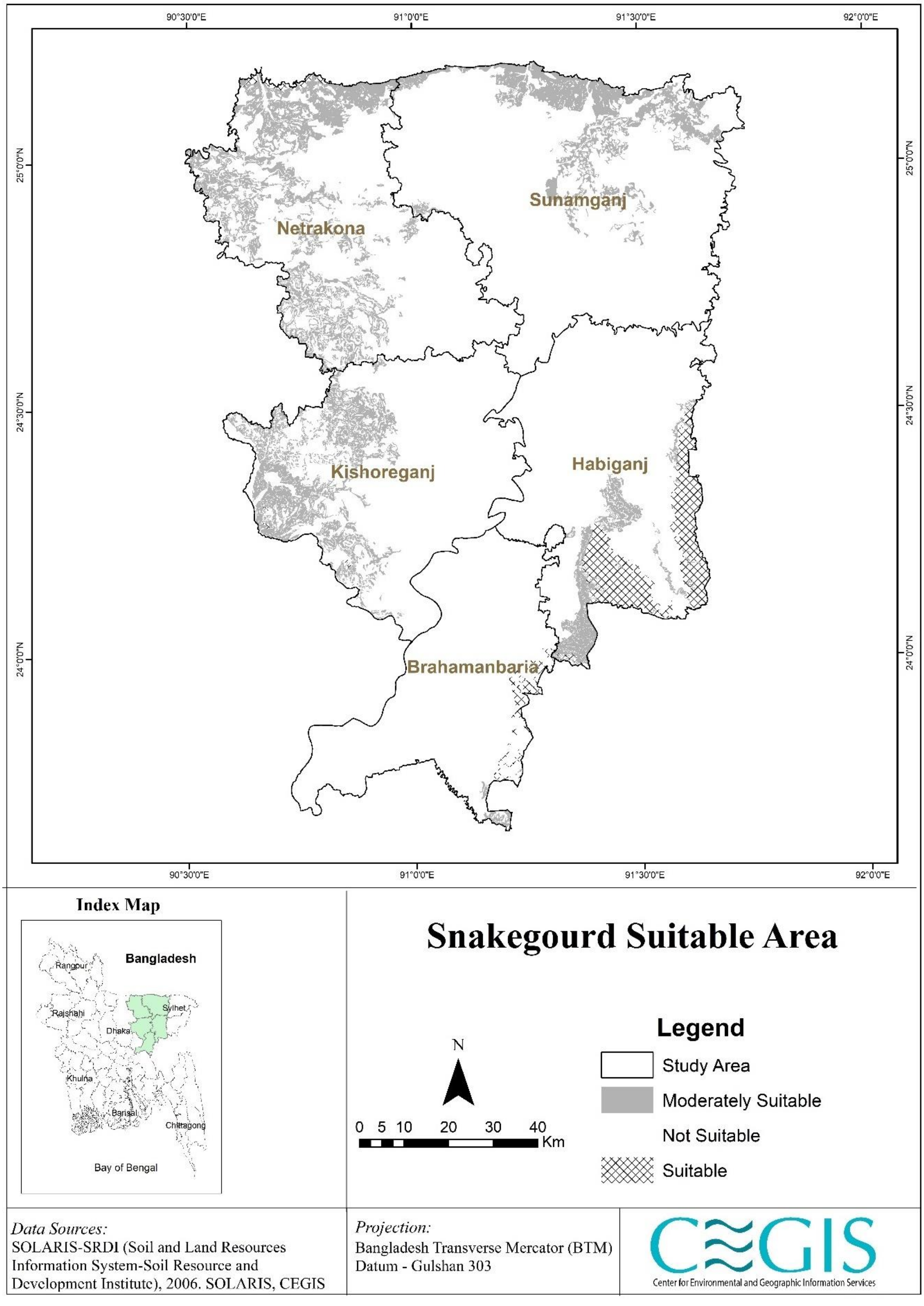


Figure 5.20: Snake Gourd Suitable Areas

6. Impacts of Swamp Afforestation on Flood Flow/Wave Force Reduction

6.1 Swamp Vegetation Capacity in Reducing Flood Flow/Wave Force Reduction

Estimates of major swamp vegetation resistance to water flow at different planting densities and forest widths are crucial for plantation design. Manning's roughness coefficients are widely used for vegetation resistance against water flow. Table 6.1 shows changes in Manning's number with changes in planting density of the selected swamp species at different water depths. The calculation shows that resistance of swamp vegetation to water flow increases with high-density vegetation, which is expected. For Vetiver Grass (*V. nemoralis*) at 2m spacing, for example, Manning's numbers are 2.71, 3.39, 4.74, 6.18 for water depths of 3.5m, 2.5m, 1.5m, and 1m, respectively which shows high resistance against water flow compared to other species observed in this study. Manning's number calculation further indicates that there are no significant differences in resistance against water flow among Hijol (*B. acutangula*), Koroch (*P. pinnata*) and Pitali (*T. nudiflora*) regardless of vegetation density and water depth (Table 6.1).

Table 6.1: Manning's Number for Root and Trunk System of Selected Swamp Vegetation

Water Depth (m)	Hijol (*B. acutangula*) (Existing)		Hijol (*B. acutangula*) (20m width & 5km afforestation)		
	Root System	Root + Trunk System	Root System	Root + Trunk System	
				2m Spacing	4m Spacing
3.5	21.14	17.50	21.14	5.26	9.67
2.5	20.15	17.90	20.15	6.44	11.27
1.5	18.27	17.34	18.27	8.47	13.21
1	16.44	16.02	16.44	9.96	9.96

Water Depth (m)	Koroch (*P. pinnata*) (Existing)		Koroch (*P. pinnata*) (20m width & 5km afforestation)		
	Root System	Root + Trunk System	Root System	Root + Trunk System	
				2m Spacing	4m Spacing
3.5	21.14	10.00	21.14	5.26	9.74
2.5	20.15	11.61	20.15	6.50	11.35
1.5	18.27	13.48	18.27	8.54	13.27
1	16.44	13.92	16.44	10.03	13.79

Water Depth (m)	Borun *(C. magna)* (Existing)		Borun *(C. magna)* (20m width & 5km afforestation)		
	Root System	Root + Trunk System	Root System	Root + Trunk System	
				2m Spacing	4m Spacing
3.5	21.30	19.64	21.14	4.55	8.53
2.5	20.31	18.86	20.15	5.60	10.09
1.5	18.45	17.34	18.27	7.48	12.20
1	16.63	15.81	16.44	8.99	13.06

Water Depth (m)	Pitali *(T. nudiflora)* (Existing)		Pitali *(T. nudiflora)* (20m width & 5km afforestation)		
	Root System	Root + Trunk System	Root System	Root + Trunk System	
				2m Spacing	4m Spacing
3.5	21.30	18.15	21.14	4.87	9.04
2.5	20.30	18.40	20.15	5.98	10.64
1.5	18.50	17.66	18.27	7.93	12.68
1	16.60	16.28	16.44	9.44	13.39

Water Depth (m)	Vetiver Grass (*V. nemoralis*) (Existing)		Vetiver Grass (*V. nemoralis*) (20m width & 5km afforestation)		
	Root System	Root + Trunk System	Root System	Root + Trunk System	
				1m Spacing	1.5m Spacing
3.5	38.41	26.90	38.41	2.71	4.05
2.5	38.40	29.78	38.41	3.39	5.06
1.5	38.2	33.07	38.16	4.74	7.05
1	37.70	34.90	37.71	6.18	9.12

7. Swamp Afforestation Site Suitability Assessment

7.1 Water Tolerance of Plant Species

Based on water stagnancy duration and water depth, identified swamp vegetation were grouped into 'high', 'medium', and 'low' water-tolerant species (Table 7.1). A total of 35 native swamp vegetation were grouped considering both variables (Figure 7.1). It was observed that water stagnancy duration varies from 1-14 weeks and water depth 1-6ft for different species. High water-tolerant species can tolerate waterlogging conditions for an average of 13 weeks, followed by medium water-tolerant species with the capacity to tolerate for seven weeks and low water-tolerant species having the capacity to tolerate for two weeks (Figure 7.1a). In the case of species water depth tolerance, a high water-tolerant group can tolerate an average of 4ft water height followed by a medium group at a height of 2.5ft water and low water tolerant group at a height of 1ft water (Figure 7.1b). Using water tolerance categories, one can decide which species to consider for plantation in which Sites. It is important to note that no species were found that can tolerate water all time.

Table 7.1: Swamp Vegetation Suitability based on Water Stagnant duration and Inundation Depth

Species	Vegetation type	IUCN Global Status	Water stagnant duration (week)*	Water depth (Ft)*	Cluster*	Water tolerance class	Habitat**
Borun (*Crataeva magna*)	Tree	NA	12	3	C-1 [duration: 12-16 & depth: 3-6]	High Water Tolerant species	K, PW, R, BA
Ikor Ghas (*Sclerostachya fusca*)	Herb	NA	16	6			R, H
Hijol (*Barringtonia acutangula*)	Tree	LC	12	4			K, PW, R, BA, K, KA
Khagra (*Phragmites Kakra*)	Herb	NA	16	6			K, PW, R
Murta (*Schumannianthus dichotoma*)	Shrub	NA	14	3			K, PW, R, BA, K, KA
Koroch (*Pongamia pinnata*)	Tree	LC	12	3			K, PW, R, BA
Arjun (*Terminalia arjuna*)	Tree	NA	8	2	C-2 [duration: 4-10 & depth: 2-4]	Moderate Water Tolerant species	H, R
Jali bet (*Calamus tenuis*)	Shrub	LC	8	2			K, BA, H
Mandar (*Erythrina variegata*)	Tree	LC	10	2			R, PW
Jarul (*Lagerstroemia speciosa*)	Tree	NA	6	2			K, PW, R
Painnya Mandar (*Erythrina fusca*)	Tree	LC	10	2			K, PW, BA
Pitali (*Trewia nudiflora*)	Tree	LC	6	2			K, PW, BA
Shundi bet (*Calamus guruba*)	Shrub	NA	8	2			K, BA, H
Babla (*Acacia nilotica*)	Tree	NA	4	4			H, RA
Vetiver grass (*Vetiveria zizanioides*)	Herb	NA	6	4			R, H
Bonlata (*Ficus Heterophylla*)	Shrub	NA	4	2		Low Water Tolerant species	PW, K
Bat (*Ficus benghalensis*)	Tree	NA	1	1			R, K
Bohera (*Terminlia bellirica*)	Tree	NA	1	1			R
Chalta (*Dillenia indica*)	Tree	LC	2	1			H, R, K
Chundal (*Tetrameles nudiflora*)	Tree	LC	2	1			R, H
Debdaru (*Polyalthia longifolia*)	Tree	NA	1	1			R, H
Desi gab (*Diospyros peregrina*)	Tree	NA	2	1			R, H
Dumur (*Ficus hispida*)	Tree	LC	1	1			K

Species	Vegetation type	IUCN Global Status	Water stagnant duration (week)*	Water depth (Ft)*	Cluster*	Water tolerance class	Habitat**
Goda (*Vitex pinnata*)	Tree	LC	2	1	C-3 [duration: 1-4 & depth: 1-2]		K
Jagdumur (*Ficus racemusa*)	Tree	NA	1	1			R
Kadam (*Athocephalus chinensis*)	Tree	NA	2	2			R, H, PW
Horina (*Vitex glabrata*)	Herb	LC	3	1			R, H
Kalahuja (*Cordia dichotoma*)	Tree	LC	3	2			H
Kalajam (*Syzygium cumini*)	Tree	LC	3	1			R, H, K
Kath badam (*Termenalis catappa*)	Tree	NA	2	1			R, H
Pani hijol (*Salix tetrasperma*)	Tree	LC	3	1			K
Pitraj (*Aphanamixis polystachya*)	Tree	LC	1	1			K, PW
Shutogola (*Vatica lanceaefolia*)	Tree	CR	2	1			H
Sonalu (*Cassia fistula*)	Tree	LC	2	1			R

*N.B. Flood inundation and depth data were obtained from the field and Choudhury (2005). **Habitat type: Kanda=K, Kua=KA; perennial water bodies=PW, Roadside=R, Beel area=BA, Homestead=H). ***NA=not available, LC=least concern, CR= Critically Endangered.*

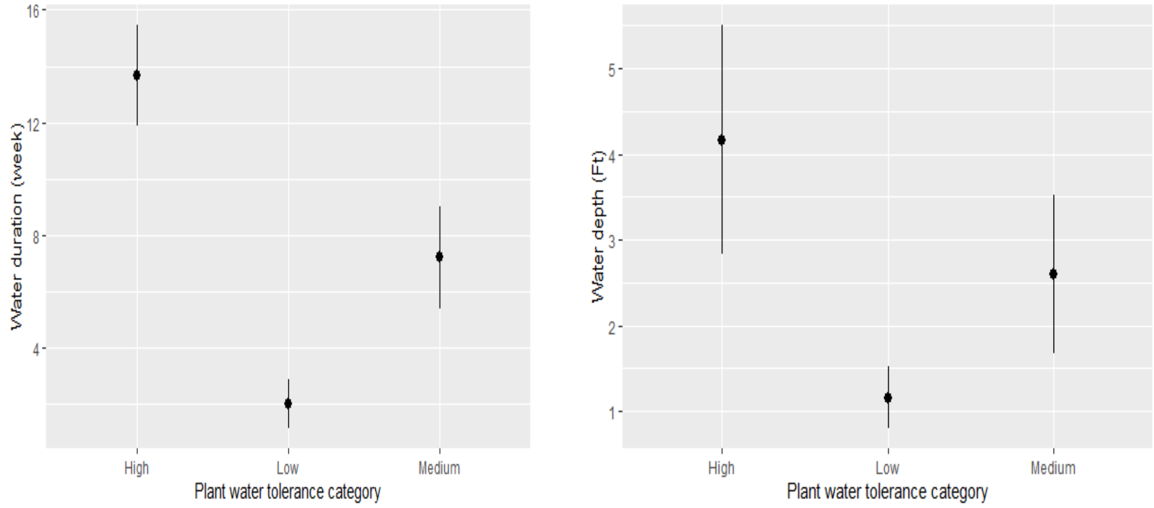


Figure 7.1: Plant Water Tolerance Range (a) Water duration (Week) (b) Water Depth (Ft)

7.2 Swamp Species Dominance in Reforestation Programs

The species accumulation curve shows the species richness for combinations of plantation Sites. These curves portray the average pooled species richness when all Sites are combined. The output indicates that the average richness for all possible combinations of 28 Sites is 9 (Figure 7.2a). Koroch was the dominant species among all the plots, which was confirmed by the Rank-abundance curves followed by Hijol and Pitali (Figure 7.2b).

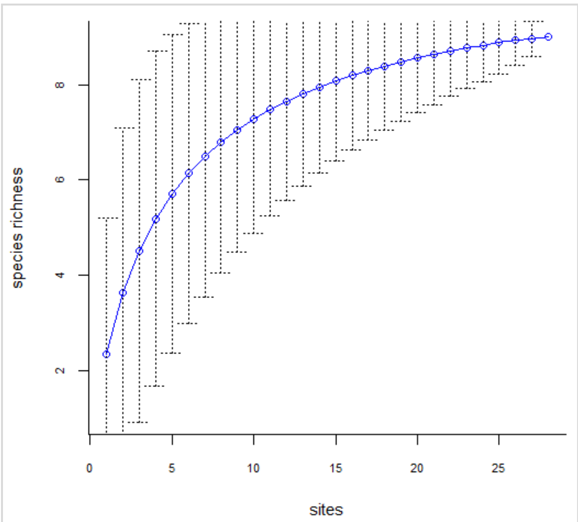


Figure 7.2 (a): Species Accumulation Curve

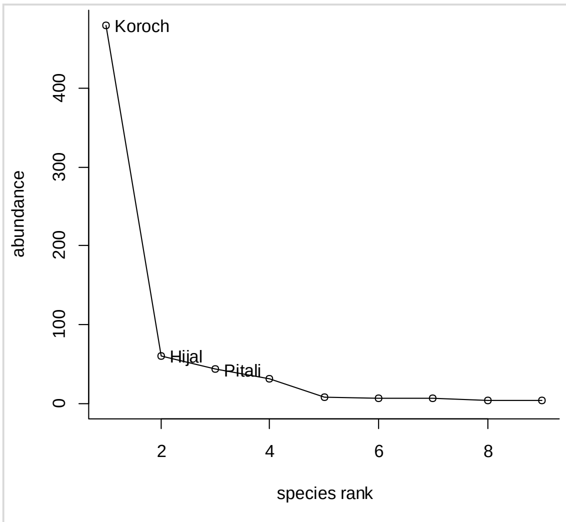


Figure 7.2 (b): Rank Abundance Curve

7.3 Dominant Swamp Tree Species Habitat Range Modeling for Reintroduction

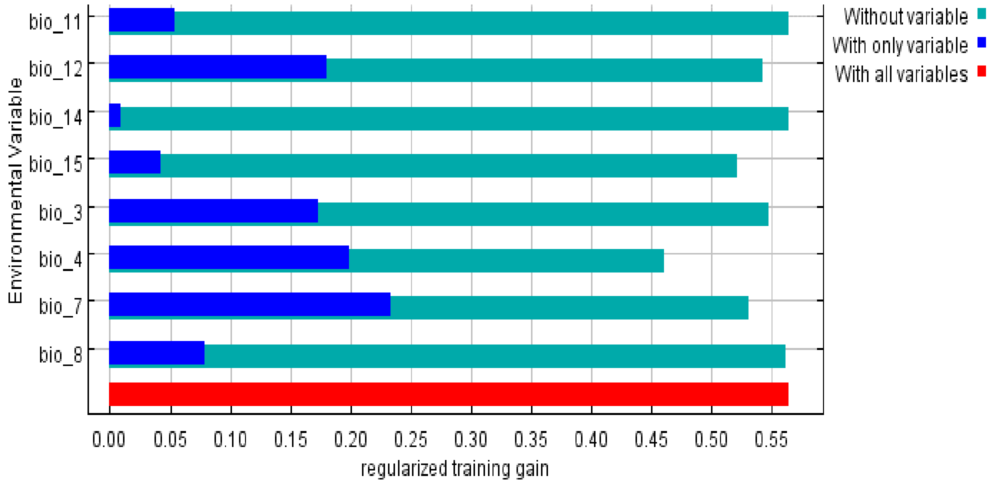
7.3.1 Model Evaluation

The AUC values were uniformly high for all four species where *Crataeva nurvala* has AUC=0.904 followed by *Pongamia pinnata* AUC=0.858, *Barringtonia acutangula* (0.853), and *Trewia nudiflora* AUC=0.747, suggesting that the bioclimatic variables used for the model explained the predicted distribution very well. The jackknife test showed that BIO7 (annual temperature range) was the most influential variable for Hijol, Koroch, and Pitali. In contrast, BIO3 (Isothermality) was the most influential climate variable in

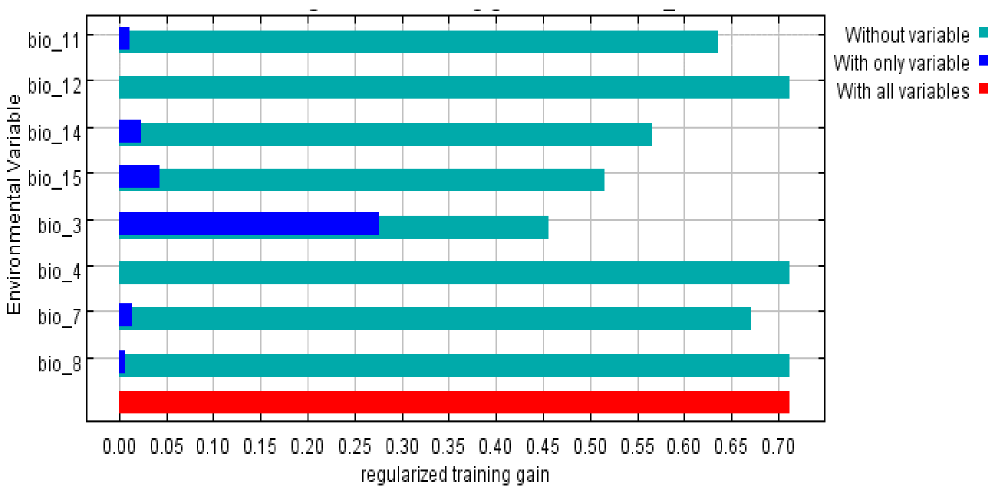
Borun's distribution (Figure 7.3). Increases in both of these variables lead to a decline in the suitable habitat of all the four major species (Figure 7.4).

7.3.2 Species Response and Habitat Suitability under Present Climatic Conditions

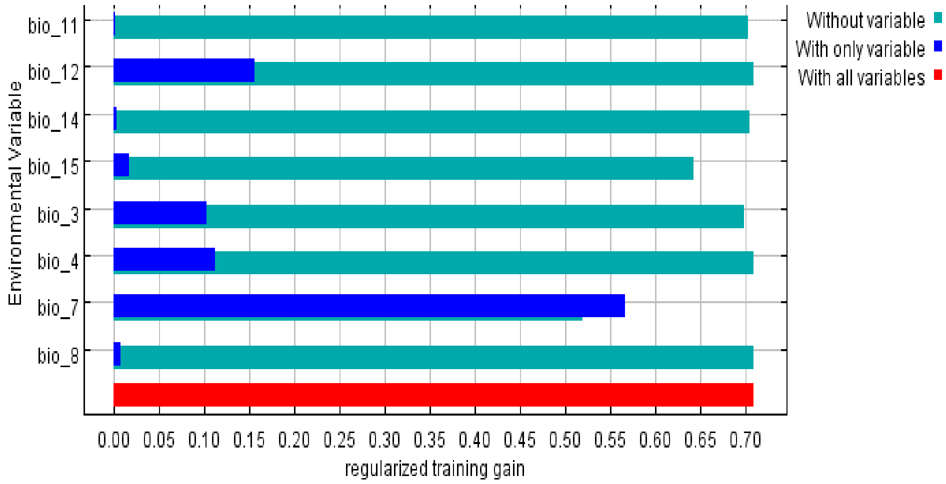
The predicted current distribution of four dominant swamp species under current climatic conditions is shown in Figure 7.5. Red colors indicate a highly suitable area for future plantations whereas deep blue colors indicate areas that are not suitable for plantations. Based on our model, more than 50% of the study area is 'highly suitable' for plantations for Hijol, Koroch and Pitali. However, suitable areas for Borun in less than 50% of the whole *Haor* areas (Figure 7.5).



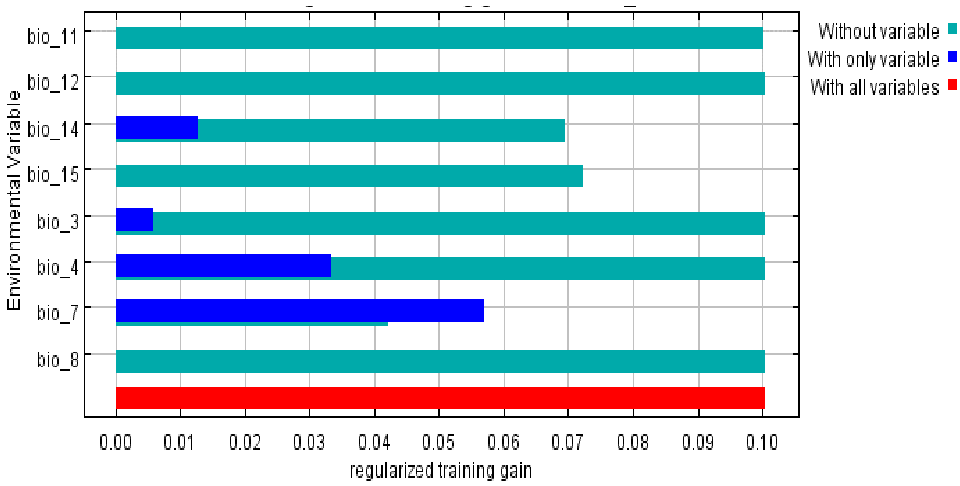
Hijol (*Barringtonia acutangula*)



Borun (*Crataeva magna*)



Koroch (*Pongamia pinnata*)



Pitali (*Trewia nudiflora*)

N.B: BIO3=Isothermality, BIO7=temperature annual range; BIO8=mean temperature of wettest; BIO12=quarter annual precipitation; BIO14=precipitation of driest month and BIO15= precipitation seasonality

Figure 7.3: The Jackknife Test for Evaluating the Relative Importance of Climate Variables for Four Dominant *Haor* Species

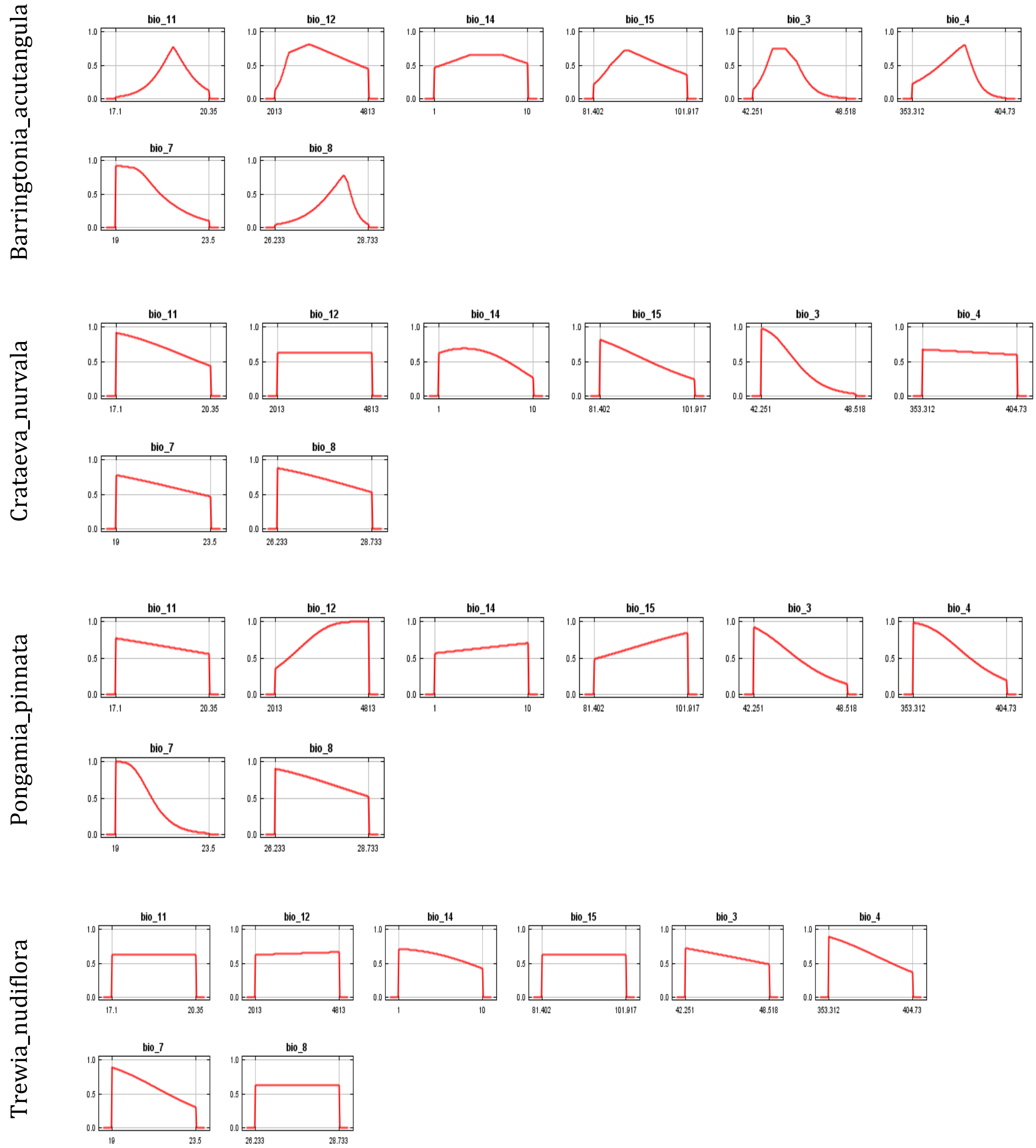
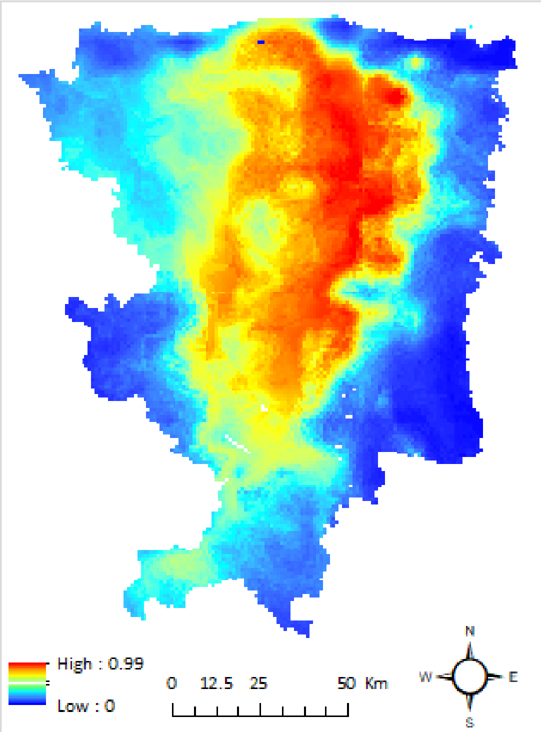
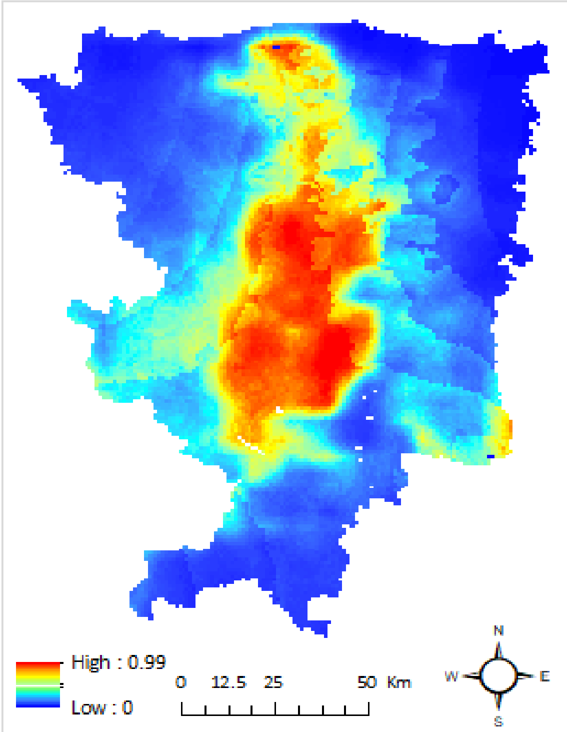


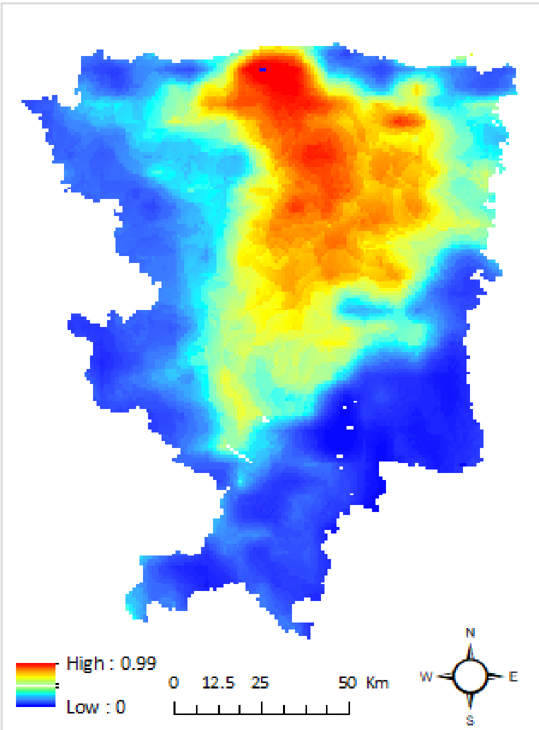
Figure 7.4: Response Curves for the Predictors of the MaxEnt Model



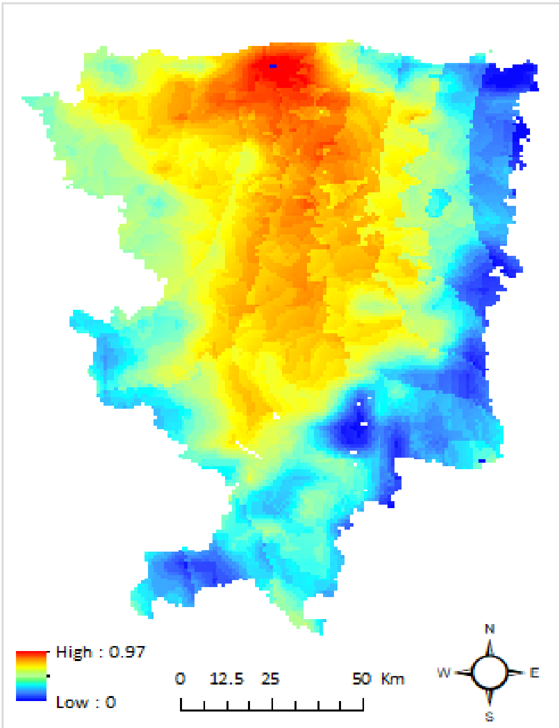
Hijol (*Barringtonia acutangula*)



Borun (*Crataeva magna*)



Koroch (*Pongamia pinnata*)



Pitali (*Trewia nudiflora*)

N.B: Red colors indicate a highly suitable area for future plantations whereas deep blue colors indicate areas that are not suitable for plantations.

Figure 7.5: Predicted Current Potential Distribution of Hijol, Koroch, Pitali and Borun under Current Bioclimatic Conditions

8. Swamp Forest Resilience Indicators and Contribution of Swamp Tree in Climate Resilience

8.1 'Resilience' Concept

The concept of 'resilience' is largely applied in the field of 'ecology' (Holling, 1973; Westman, 1978; Hill, 1987). The concept is now widely practiced in other disciplines, including natural and physical sciences, socioecological, and social science systems (Adger, 2006; Folke et al., 2010). Hence, the 'resilience concept has acquired multiple ecological, biological, physical, social, and socio-economic dimensions and various links to other concepts such as equilibrium, thresholds, tipping points, recovery, and adaptive capacity (Tooth, 2018). Because of variation among disciplines, resilience attributes also largely vary. This synthesis aims to discuss seasonally flooded freshwater swamp forest dynamics and its resilience attributes because conceptual development has not kept pace with changes in the processes that alter and control seasonally flooded swamp forests.

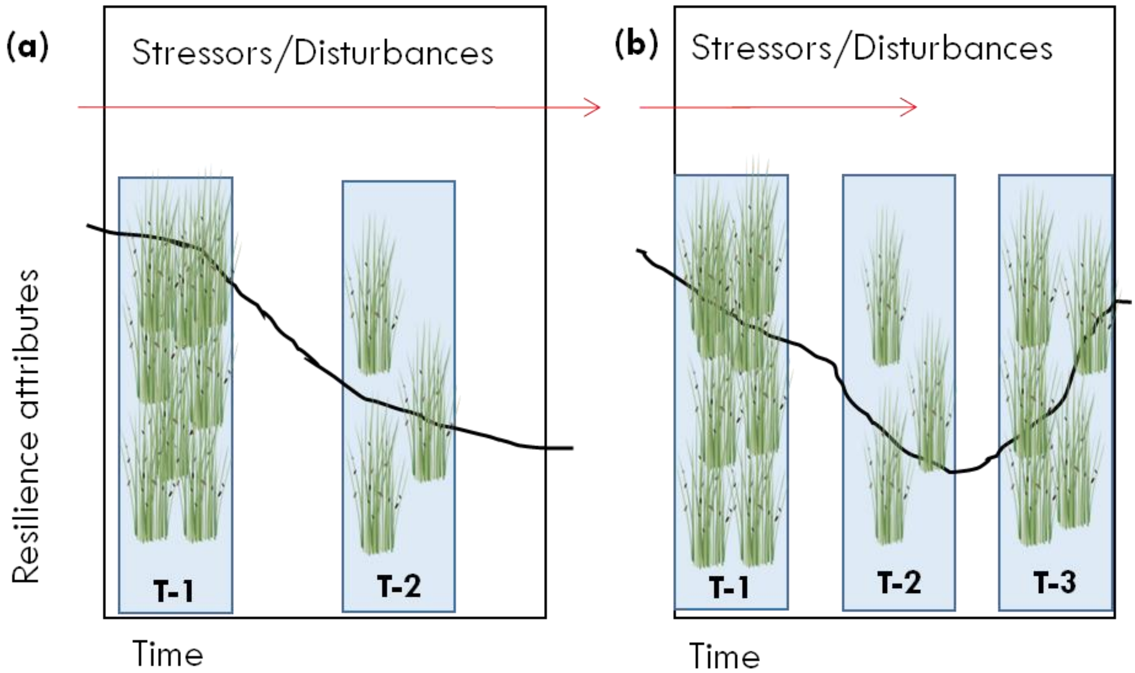
Globally, freshwater swamp forests occur in Southeast Asia, Africa, and South America, with the largest proportion in the Amazon basin (Richards, 1996). However, the decline of swamp species is rapid and even exceeding that of tropical rainforests. If this scenario continues, swamp forests and their related vegetation will be extinct in the near future. Here, integrating "resilience" concepts and their related attributes could help improve restoration and monitoring efforts. Resilience approaches to restoration can increase the adaptive capacity of the ecosystem in this Anthropocene (Galassi et al., 2014; Everard et al., 2020; Somers et al., 2019) because it incorporates concepts of dynamic feedbacks, unpredictable change, and variation of ecosystem function and structures (Holling, 1996; Parrish, 2003).

A full review of resilience and related concepts of all the swamp forests across the globe is beyond the scope of this report. Therefore, the seasonally flooded swamp forest of Bangladesh is considered for this synthesis. The swamp forests in Bangladesh that once used to be common in *Haor* areas have become rare due to clearing, cutting, and other anthropogenic pressures. The natural regeneration of this forest type is hardly visible in the wetland. The reed beds have also been severely reduced because of continued over-harvesting for fuel and converting land into agricultural fields. As a result, certain aquatic species that used to be common in the area became very rare. This process threatened the integrity of the *haor* ecosystem as a whole. Degradation of the conditions of swamp forests and reed beds had led to several impacts on resource use and livelihoods of the local people. Swamp forest provides food and shelter for the fish population and, therefore, a reduction in fish production; species diversity and the waterfowl population were observed over the past few decades (Choudhury, 2005). To understand how resilience attributes can be integrated into the restoration of the swamp forest ecosystem, resilience attributes and their scale of application were identified from relevant literature. We further classified these attributes according to their ecological scale of application. We provide guidelines on how practitioners can select resilience attributes that are appropriate for specific management applications. Finally, we outline general strategies for integrating resilience into restoration planning and monitoring. Therefore, this study aims to identify resilience attributes that facilitate the seasonally flooded swamp forest ecosystem (i.e. *Haor* ecosystem of Bangladesh) function. More precisely, this investigates the ecological, hydrological, and physical attributes contributing to the resilience of the seasonally flooded swamp forest ecosystem.

Resilience' determines the persistence of relationships within the ecosystem and is an ability to absorb changes and persist (Figure 8.1) (Holling, 1973). From an ecological or biological perspective, the concept of resilience is especially applicable to natural systems that adapt to different degrees of disturbance while maintaining the same processes and structures that reinforce each other (Krosby et al., 2010; Suding and Gross 2006). However, it is not possible to return to its pristine condition because, in general terms, the systems are altered (by humans or by other natural processes) in one way or another, so that their return to a pristine state may be a goal that is significantly outside the realms of possibility.

Hizol and Koroch in Haor Region

Murta and Vetiver in Haor Region



N.B: The black lines indicate the time series observed of the Swamp forest ecosystem and the red lines represent disturbances over time (a). In this hypothetical example, overexploitation (disturbance) of swamp vegetation will cause biodiversity loss (parameter/indicator) (b). If swamp degradation stops (disturbance stops) and restoration initiative, taken swamp biodiversity may recover (Source: Md. Shawkat I. Sohel).

Figure 8.1: Scheme of the Swamp Forest Resilience through the Temporal Evolution of Resilience Attributes

The transition from one phase to another (state change or regime shift) occurs through thresholds; and the new regime or state is characterized by a different set of processes and structures (Allen et al., 2014). Regime or state changes are typically associated with significant consequences in processes or structures (e.g., a change in swamp vegetation composition that leads to a loss of associated biodiversity), and do not always occur suddenly but may be the result of long system periods (Eason et al., 2016) or slow and progressive changes (Miller, et al., 2010). The scope of the concept of ecosystems resilience is broader than initially considered. When discussing ecosystems alone, resilience is closely related to sustainability (Folke et al., 2002; Thomas et al., 2017). Scheffer et al., (2001) report that a loss of ecosystem resilience generally paves the way for a change to an alternative state and suggest that sustainable management should be directed towards maintaining ecosystem resilience (Scheffer et al., 2001).

8.2 Indicators Used to Assess Resilience

Resilience attributes can be categorized into species, population, community, ecosystem and abiotic factor specific (Table 8.1). Detailed descriptions are as follows:

8.2.1 On Seed Dispersal and Hydrological Connectivity

Seed dispersal by water – is an important mechanism, particularly in riparian environments, and may influence seed bank structuring and riparian composition (Groves et al., 2007; Gurnell et al., 2008; Goodson et al., 2003). Seeds are released into the water where they can be dispersed downstream at great distances from parent trees or onto higher elevations during flooding, depending on flow magnitude (Naiman et al., 1988). Lateral connectivity between the channel and floodplains and timing of seed release, for example, with receding flood flows, influence whether seeds are transported to Sites with favorable germination conditions. Seed dispersal is also influenced by flow regime, including flow magnitude, flow variability, rate of flow change, magnitude, and frequency of flow conditions (Richter et al., 1996).

8.2.2 On Habitat Connectivity

Connectivity among various habitat types helps maintain species that use various aquatic and terrestrial habitats for feeding, reproduction, refuge, and migrating (Thom et al., 2012). In riverine systems, ecological connectivity is important for maintaining natural variability and supporting productivity (Bisson et al., 2009). Ecosystem connectivity is also critical to help regulate essential abiotic and biotic processes such as flow, temperature, water quality, aquatic and terrestrial interactions, and food webs (Timpane-Padgham et al., 2017). Removal of anthropogenic barriers to migration can help increase the resilience of aquatic biota to climate change impacts such as changing flow regimes (Milner et al., 2013).

8.2.3 On Plant Water Tolerance Trait

In the Anthropocene, swamp forest structure and function have been heavily degraded by anthropogenic activities such as the construction of flood control structures, road and settlement infrastructure. These artificial structures significantly alter water movement and create water logging in some parts of the landscape that significantly affect plant water tolerance. Therefore, knowledge of swamp vegetation water tolerance limits is essential to increase the resilience of degraded swamp forests. Water tolerance of swamp vegetation varies from species to species. For example, freshwater swamp forest of Bangladesh, high water-tolerant species can tolerate waterlogging conditions for an average of 13 weeks, followed by seven weeks by medium water-tolerant species and two weeks by low water-tolerant species. In the case of species water depth tolerance, the high water-tolerant group can tolerate an average of 4ft water followed by 2.5ft water by medium and 1ft by low water tolerant group (Figure 8.2).

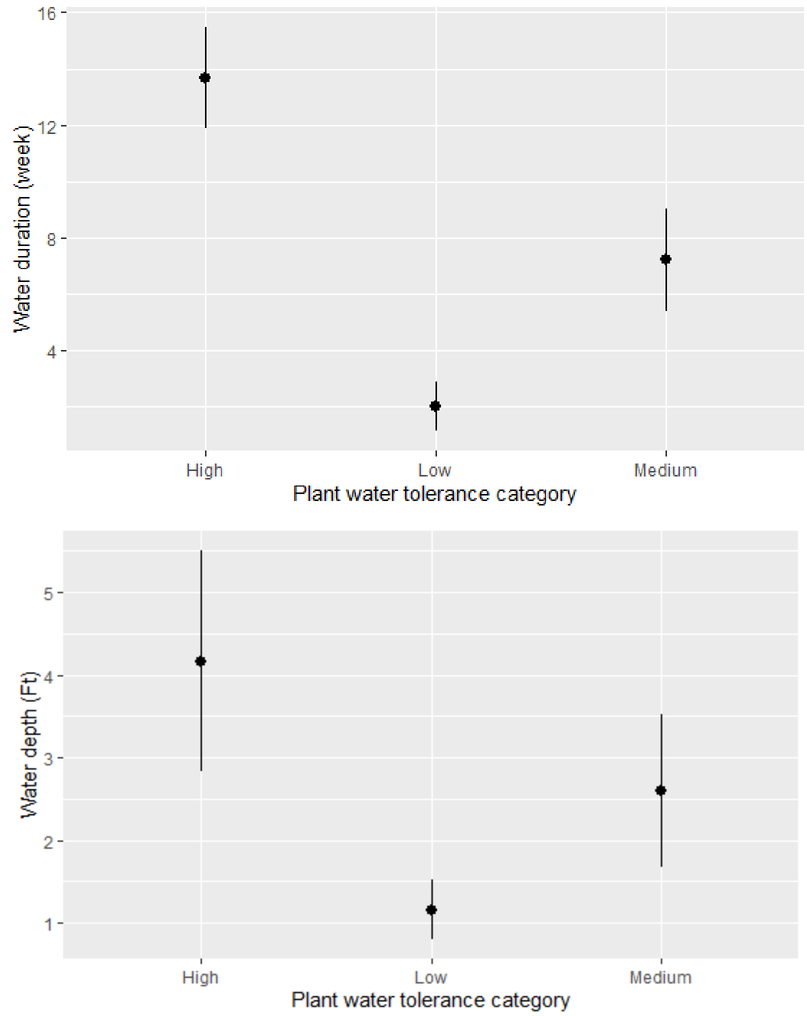


Figure 8.2: Plant Water Tolerance Range (a) Water Duration (Week) (b) Water Depth (Ft)

8.2.4 On Plant Functional Trait

Surface water flow regulation is mostly influenced by plant functional traits such as tree size (diameter and height), root structure, density, and growth (Gurnell, 2014). Large Leaf Area (LAI) (Falster et al., 2011) can also synergistically increase flow resistance. Woody plants show higher surface flow resistance than herb or shrub vegetation (Dosskey et al., 2010). Protection from erosion or soil stabilization also depends on root architecture, depth, and root tensile strength (Bardgett et al., 2014).

Table 8.1: Resilience Attributes for Seasonally Flooded Swamp Forest

Resilience Attribute	Specific Attribute	Restoration focus (Species, ecosystem/habitat)	References
Species specific	Seed dispersal potential	Species, ecosystem/habitat	Beechie et al., 2010; Soons et al., 2017; von Behren and Yeakley, 2020
	Growth form	Species	Scarano, 2006
	Water tolerance (water depth and duration tolerance)	Species	Ingvalson et al., 2020; Bratkovich, et al., 1994; De Jager et al., 2012
	Plant root structure	Ecosystem/habitat	Bau' et al., 2021; Bardgett et al., 2014
	Plant height	Ecosystem/habitat	Marapara, 2016; Moor et al., 2017

Resilience Attribute	Specific Attribute	Restoration focus (Species, ecosystem/habitat)	References
	Plant density	Species, ecosystem/habitat	Moor et al., 2017
	Regeneration rate	Species, ecosystem/habitat	Moor et al., 2017
	Genetic diversity	Species, ecosystem/habitat	Stubbington and Datry 2013; Downing and Leibold, 2010
	Connectivity between populations	Species, ecosystem/habitat	Rittenhouse and Peterman, 2018
	Species diversity	Species, ecosystem/habitat	Bouchard et al., 2007
Population specific	Connectivity among community	Species, ecosystem/habitat	Rittenhouse and Peterman, 2018
	Spatiotemporal variability in habitat structures	Species, ecosystem/habitat	Seki et al., 2018; Liu et al., 20104
Community specific	Connectivity between different habitats/vegetation patches	Species, ecosystem/habitat	Naiman et al., 1993; Rittenhouse and Peterman, 2018
	Sedimentation	Species, ecosystem/habitat	Wang et al., 2014
Ecosystem specific	Flow regime	Species, ecosystem/habitat	Moor et al., 2017; Rittenhouse and Peterman, 2018
	Water stagnant duration	Species, ecosystem/habitat	Ingvalson et al., 2020; De Jager et al., 2012
Abiotic factors	Water depth	Species, ecosystem/habitat	Ingvalson et al., 2020; De Jager et al., 2012
	Hydrologic connectivity		Maltby, 2009; Maltby and Acreman, 2011; Rittenhouse and Peterman, 2018

8.3 Resilience and Restoration at the Local Scale: Examples from *Haor* Ecosystem

The seasonally flooded freshwater swamp forest of Bangladesh is now under threat of being lost because of anthropogenic and nature-originated pressure. To reverse this trend reforestation program is taking place. Integration of resilience attributes into reforestation programs can enhance reforestation success. Local people's perception is crucial in this regard. Local stakeholders opined that Bole/Trunk structure, seed dispersal potential, reproductive strategy, root structure vegetation density, and connectivity between populations and community vegetation are important resilience attributes we may need to consider during reforestation. Among all these indicators, most of the local people who participated in the FDGs emphasized ecological and hydrological connectivity, vegetation density, and the root structure of swamp vegetation (Table 8.2).

Table 8.2: People's Perception towards Fresh Water Swamp Forest Resilience Indicators

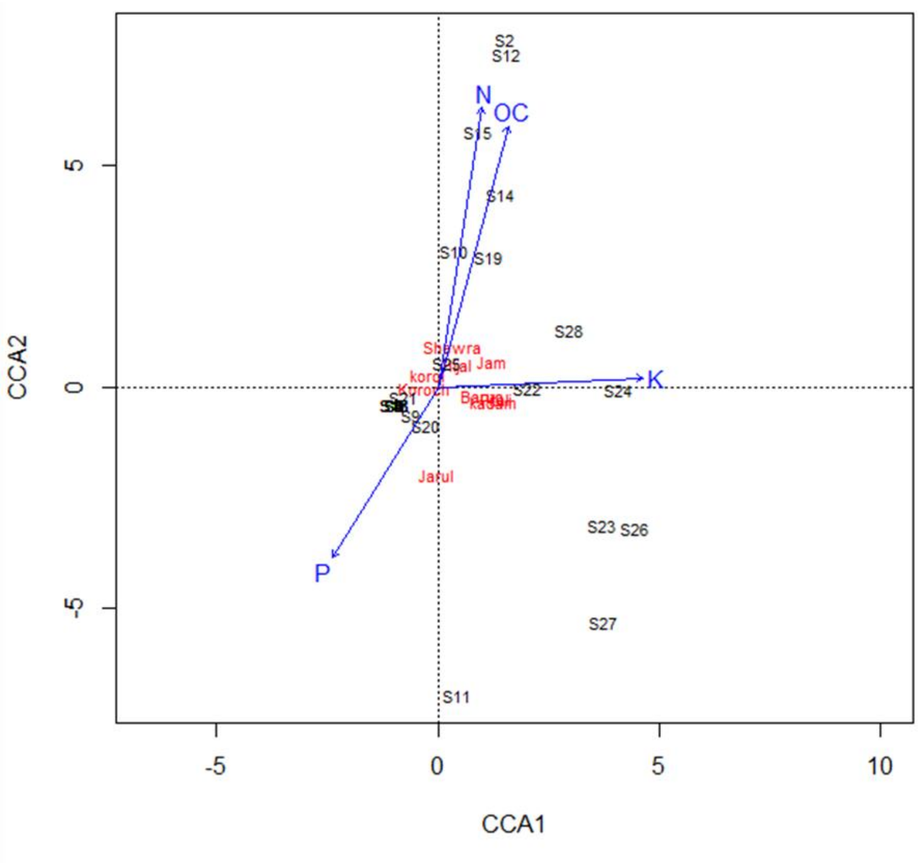
Resilience Indicators	Remarks	High resilience*	Medium resilience *	Low resilience *
Seed dispersal potential	Plants with seed dispersal ability has high resilience	3	14	4
Reproductive strategy	Plants having natural reproductive strategies through flower, fruit and seed has high resilience	4	11	6
Coppicing ability	Vegetation with coppicing ability can enhance swamp ecosystem resilience	5	4	12
Bole/Trunk trait (Buttressed, cylindrical trunk)	Buttressed trunk or large size bole/truck can reduce wave action. Thus, increase resilience	9	7	7
Root structure and depth	– Fibrous root structure can reduce wave action and reduce soil erosion; – Deep vertical root structure can give more strength against wave action;	13	7	1
Population density	High density of species can increase resistance against wave force	13	7	1
Connectivity between populations and community vegetation	– More culmed patches of swamp vegetation can increase connectivity resilience; – Hydrological connectivity among vegetation patches can increases swamp forest resilience against disturbances;	12	7	2

**Numbers under each resilience class indicates consensus made in each FGDs. In total, 21 FGDs were conducted in Haor areas.*

8.4 Vegetation Diversity and Their Interaction with Environmental Variables

A species accumulation curve shows the species richness for combinations of Sites. These curves portray the average pooled species richness when all Sites are combined. The output shows that the average richness for all possible combinations of 28 Sites is 9. Koroch was the dominant species among all the plots which were confirmed by the Rank-abundance curves followed by Hijol and Pitali. Vegetation species richness has been identified through Shannon and Simpson indices, both indices show poor vegetation diversity in most Sites. Only 7 Sites (Site ID: 10,11,14,19,22,24,27) have good diversity compare to the remaining Sites (Chapter 2: Table 2.1).

The CCA model shows that Shewra, Jam, Hijol, Korch, Koroi had large abundance within the plantation Sites where soils were enriched with organic carbon, nitrogen, and potassium content indicating a positive relationship. The abundance of Jarul was high where the soil was enriched with phosphorus. The abundance of Borun and Kadam exhibited no correlation with the soil variables (Figure 8.3).



N.B: K=Potassium, P=Phosphorus, N=Nitrogen, and OC=Organic carbon

Figure 8.3: Canonical Correspondence Analysis (CCA) of Dominant Swamp Tree Species and Environmental Variables in 28 Reforested Sites

8.5 Tree Biomass and Carbon Stocks in Swamp Vegetation

Table 8.3 shows the total biomass and organic carbon stock in the studied swamp vegetation plot. The total estimated biomass and carbon stock in swamp trees was 303373.42 kg/ha and 151686.71 kg/ha consecutively. Altogether only nine swamp vegetation were used for plantation in the observed study Sites. Only Koroch shows promising carbon stock in the studied Sites which store approximately 128.04 t/ha carbon. This is because of the high tree density (585 trees/ha). The remaining species' carbon stock was extremely low, which ranges from 0.31-8 t/ha. Vegetation density was extremely poor in most of the study sites, which significantly affected the carbon capture capacity of swamp vegetation (Table 8.4). It was evident that with the increases in tree density, carbon stock also increases (Figure 8. 4).

Table 8.3: Biomass and Carbon in Trees of Swamp Plantations

Biomass	Amount (kg/ha)	Carbon	Amount (kg/ha)	Amount (Ton/ha)
Above ground Biomass	263802.981	Above ground carbon	131901.4906	131.901
Below ground Biomass (without soil)	39570.4472	Below ground carbon	19785.22359	19.785
Total Biomass	**303373.42**	**Total carbon**	**151686.71**	**151.686**

Table 8.4: Species wise Biomass and Carbon Stock

Species	MAGB (kg/tree)	MBGB (kg/tree)	MTB (kg/tree)	MAGC (kg/tree)	MBGC (kg/tree)	Mean TC (kg/tree)	Tree/ ha	TC (t/ha)
Borun	333.61	50.04	383.65	166.80	25.02	191.82	37.80	7.25
Hijol	183.82	27.57	211.39	91.91	13.79	105.69	75.61	7.99
Jam	232.22	34.83	267.05	116.11	17.42	133.52	9.76	1.30
Jarul	109.23	16.39	125.62	54.62	8.19	62.81	4.88	0.31
Kadam	160.46	24.07	184.53	80.23	12.03	92.27	7.32	0.68
Koroch	380.41	57.06	437.47	190.20	28.53	218.73	585.37	128.04
Koroi	89.57	13.44	103.01	44.79	6.72	51.50	7.32	0.38
Pitali	176.65	26.50	203.14	88.32	13.25	101.57	52.44	5.33
Shewra	197.80	29.67	227.47	98.90	14.84	113.74	3.66	0.42
Mean	**207.09**	**31.06**	**238.15**	**103.54**	**15.53**	**119.07**	**87.13**	**16.85**

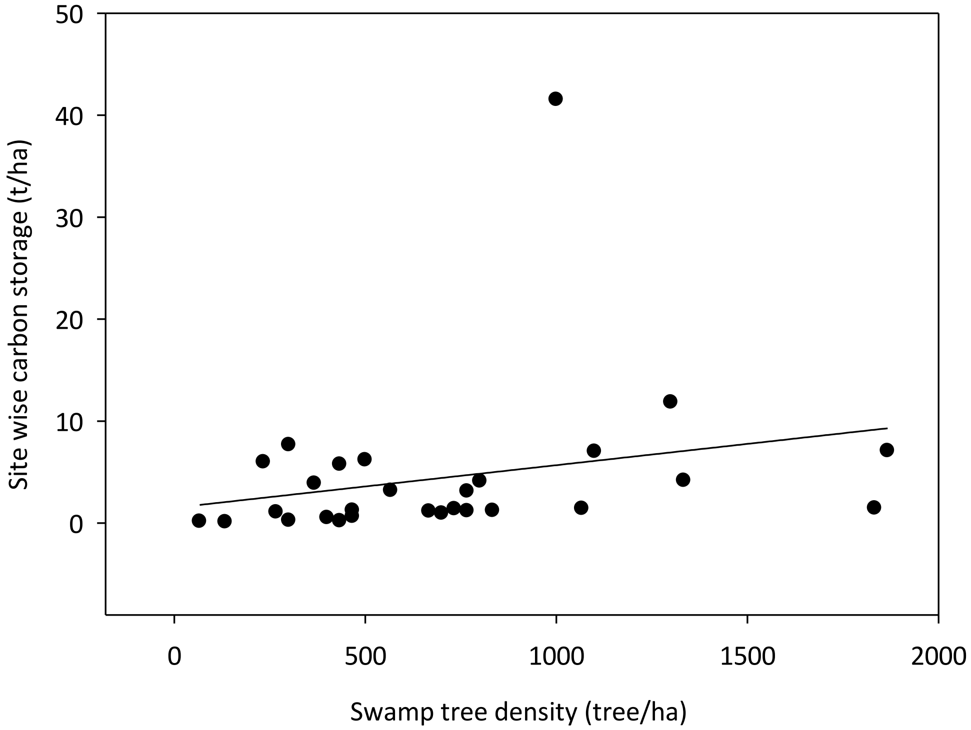
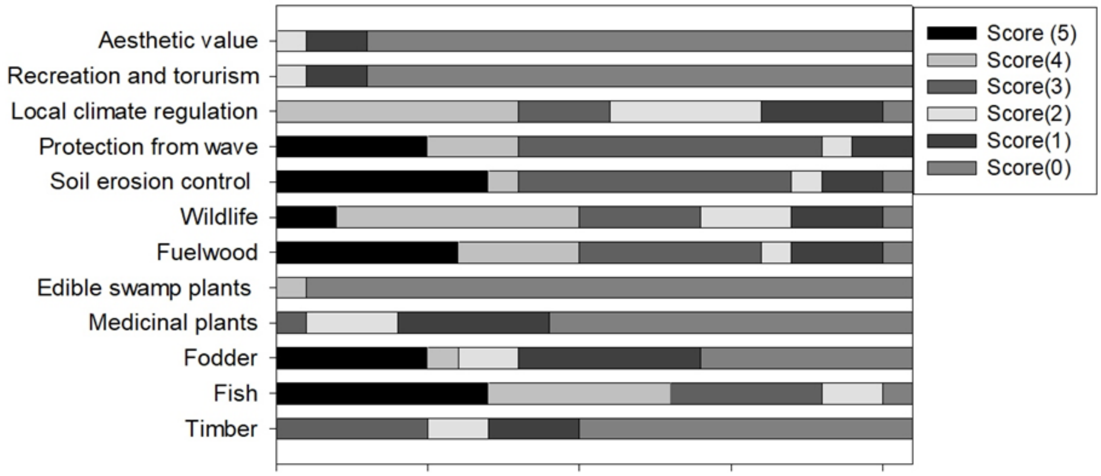


Figure 8.4: Correlation between Carbon Storage in Swamp Trees and Tree Density

9. Ecosystem Functions and Resilience's Assessment Tool

9.1 Ecosystem Services Recorded

The highest significant positive contribution of swamp reforestation provisioning service was the provision of fish (score 5=7 Sites) followed by fuelwood collection (score 5=6 Sites). Soil erosion control (score 5=7 Sites) and protection from waves (score 5=5 Sites) were also significant because of swamp plantations. However, cultural services have not improved significantly due to plantation activities. The second highest contribution from swamp reforestation was a fish provision (score 4=6 Sites) and fuelwood collection (score 4=4 Sites). Regulation of local climate (score 4=8 Sites), habitat for wildlife (score 4=8 Sites) and protection from waves (score 4=3 Sites) all made a positive contribution at more than two-thirds of all the field Sites. Recreation, tourism (score 0=18 Sites) and aesthetic value (score 0=18 Sites) did not contribute to cultural services (Figure 9.1). Poor communication systems might be the reason.

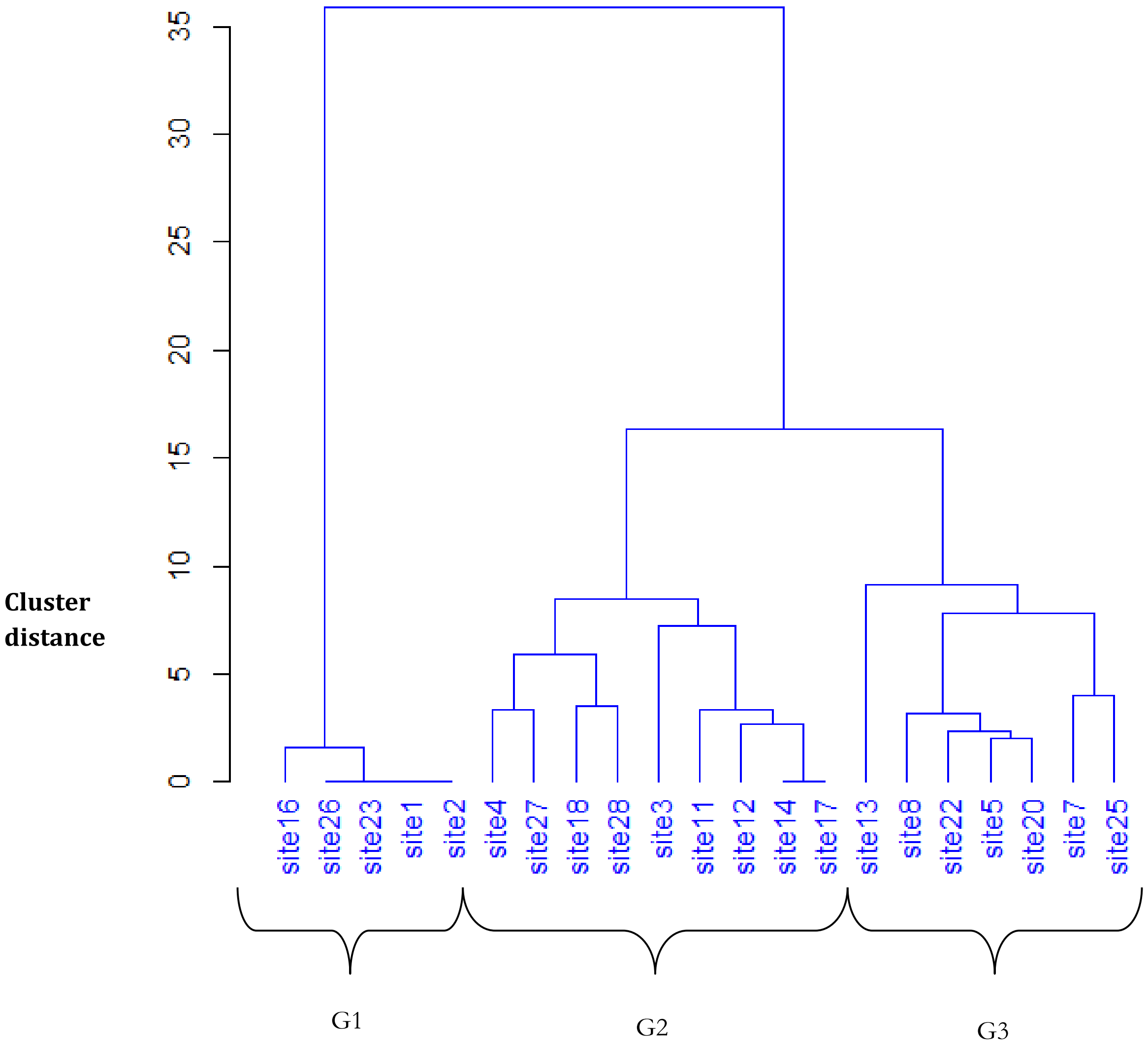


N.B: 0=no relevant capacity; 1=low relevant capacity; 2=relevant capacity; 3=medium relevant capacity; 4=high relevant capacity; and 5=very high relevant capacity.

Figure 9.1: Relative Importance of Individual Ecosystem Services from All Field Assessment Sites (n=21)

9.2 Classifying Sites by Ecosystem Services

Clustering analysis shows that there are three distinct groups of Sites based on their ES traits. The Smallest cluster (G1) that includes Sites 1,2,16,23,26 swamp plantations have made a significant positive contribution towards fish, fodder provision, wildlife provision, soil erosion control, and protection from wave action. The main differences in the remaining two clusters are the provision of fish, fodder, and timber provision. G3 provides more of these services compared to G2 Sites. Among all the Sites, 2,12,14,23,26 provide highest provisioning services (average score=>5). Whereas Site 1,2,8,18,23,26,27 provides highest regulating services (average score=>4) (Figure 9.2 and Table 9.1). Cultural services were negligible for most of the Sites.



N.B: Distance or height of each cluster indicates similarities and dissimilarities among sites.

Figure 9.2: Dendrogram Shows Hierarchical Clustering of Field Sites based on Their Ecosystem Services

Table 9.1: Site Cluster base on Their Ecosystem Service Provision

Cluster	Sits	Timber	Food (Fish)	Fodder	Medicinal plants	Edible swamp plants	Fuelwood	Total Provisioning Services	Wildlife	Soil erosion control	Protection from wave	Local climate regulation	Total Regulating Services	Recreation and tourism	Aesthetic Value	Total Cultural Services	Mean DBH (cm)	Mean Height (m)
G1	Site1	0	5	5	0	0	5	**2.5**	4	5	5	4	**4.5**	0	0	**0**	23.90	7.92
	Site2	0	5	5	0	0	5	**5.0**	4	5	5	4	**4.5**	0	0	**0**	14.25	5.38
	Site23	0	5	5	0	0	5	**5.0**	4	5	5	4	**4.5**	0	0	**0**	25.00	14.15
	Site26	0	5	5	0	0	5	**5.0**	4	5	5	4	**4.5**	0		**0**	13.15	5.19
G2	Site3	0	0	0	1	0	1	**4.16**	5	4	4	4	**2.0**	0	0	**0**	18.32	5.51
	Site4	2	4	0	1	0	4	**2.33**	4	5	3	4	**0.25**	0	0	**0**	81.11	6.06
	Site11	0	3	1	1	0	3	**2.33**	2	3	3	3	**2.0**	2	2	**0**	34.00	10.18
	Site12	0	4	0	2	0	3	**5.16**	3	3	3	2	**2.25**	0	0	**0**	23.36	5.15
	Site14	0	3	0	2	0	3	**5.66**	3	3	3	3	**2.25**	1	1	**0**	25.61	5.72
	Site16	0	5	5	0	0	5	**3.83**	4	5	4	4	**2.5**	0	0	**0**	15.00	5.21
	Site17	0	3	0	2	0	3	**3.0**	3	3	3	3	**1.25**	1	1	**0**	32.00	5.26
	Site18	3	2	1	0	0	4	**1.66**	4	3	3	1	**4.25**	0	0	**0**	22.00	9.43
	Site27	0	5	0	0	0	5	**2.16**	4	5	5	4	**4.0**	0	0	**0**	15.39	5.44
	Site28	1	4	0	0	0	4	**3.16**	5	3	2	2	**2.75**	0	0	**2**	26.50	6.40
G3	Site5	2	3	1	1	0	3	**2.83**	1	3	3	1	**2.75**	0	0	**0**	19.19	5.14
	Site7	1	2	1	0	0	0	**2.83**	0	0	1	0	**3.0**	0	0	**1**	21.95	5.16
	Site8	3	4	2	0	0	1	**3.83**	1	2	4	1	**4.25**	0	0	**0**	85.29	5.64
	Site13	3	3	4	3	4	4	**3.83**	3	1	3	2	**3.0**	0	0	**1**	19.52	5.05
	Site20	3	4	2	1	0	3	**3.0**	1	3	3	2	**2.75**	0	0	**0**	32.51	5.50
	Site22	3	4	1	0	0	2	**3.33**	2	3	3	2	**4.5**	0	0	**0**	15.46	9.28
	Site25	1	5	1	0	0	1	**3.16**	2	1	1	1	**3**	0	0	**0**	32.13	5.65

10. *Haor* Land Use Pattern and Projection

10.1 Historical Land Use Pattern Observations

Land cover analysis from the year 2000 to 2019 using satellite images shows that *Haor* regions of the proposed study sites were blessed with diversified land classes such as Pond and Aquaculture, Baor, Built-up areas, Cultivated Trees, Agri-Crop, Rivers and Khals, Rural Settlement, Perennial water bodies. Among all these land covers, agricultural crop practices in the dry season are dominant, followed by rural settlement and perennial water bodies. Surprisingly swamp vegetation in *Haor* areas was extremely low for the last twenty years. (Table 10.1 to 10.5 and Figure 10.1-10.5).

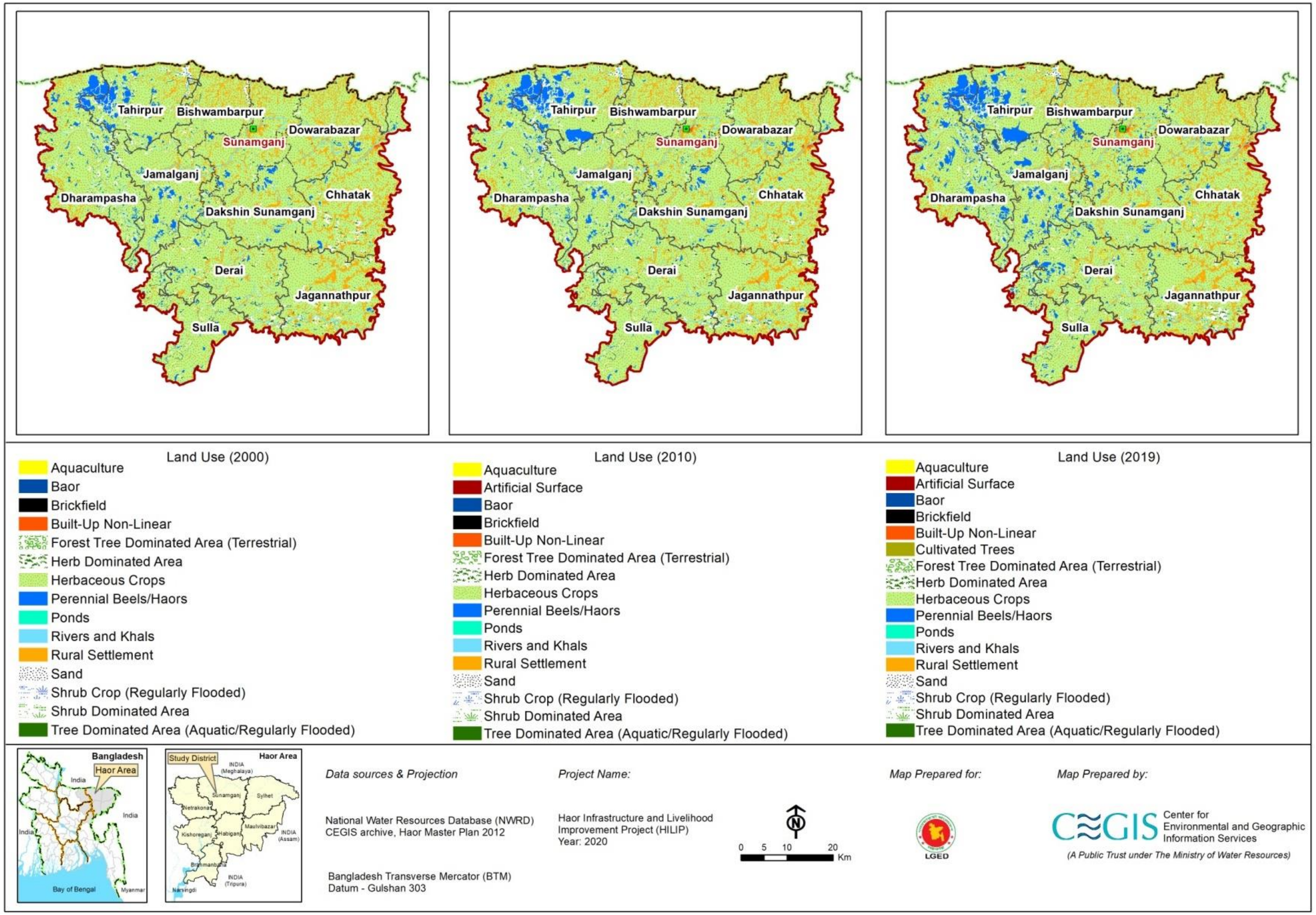


Figure 10.1: Land Uses of Sunamganj *Haor* Areas in 2019

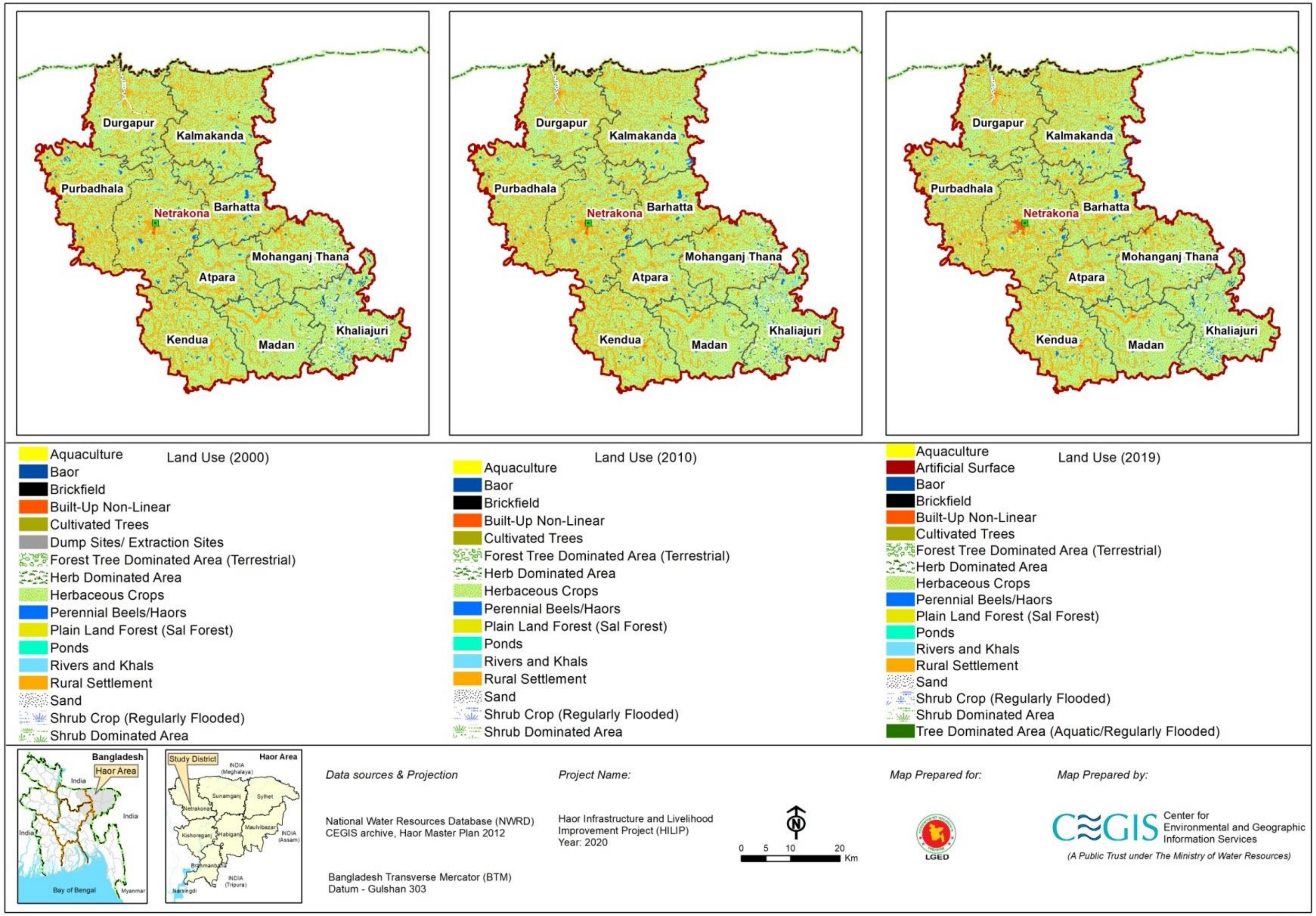


Figure 10.2: Land Uses of Netrokona *Haor* Areas in 2019

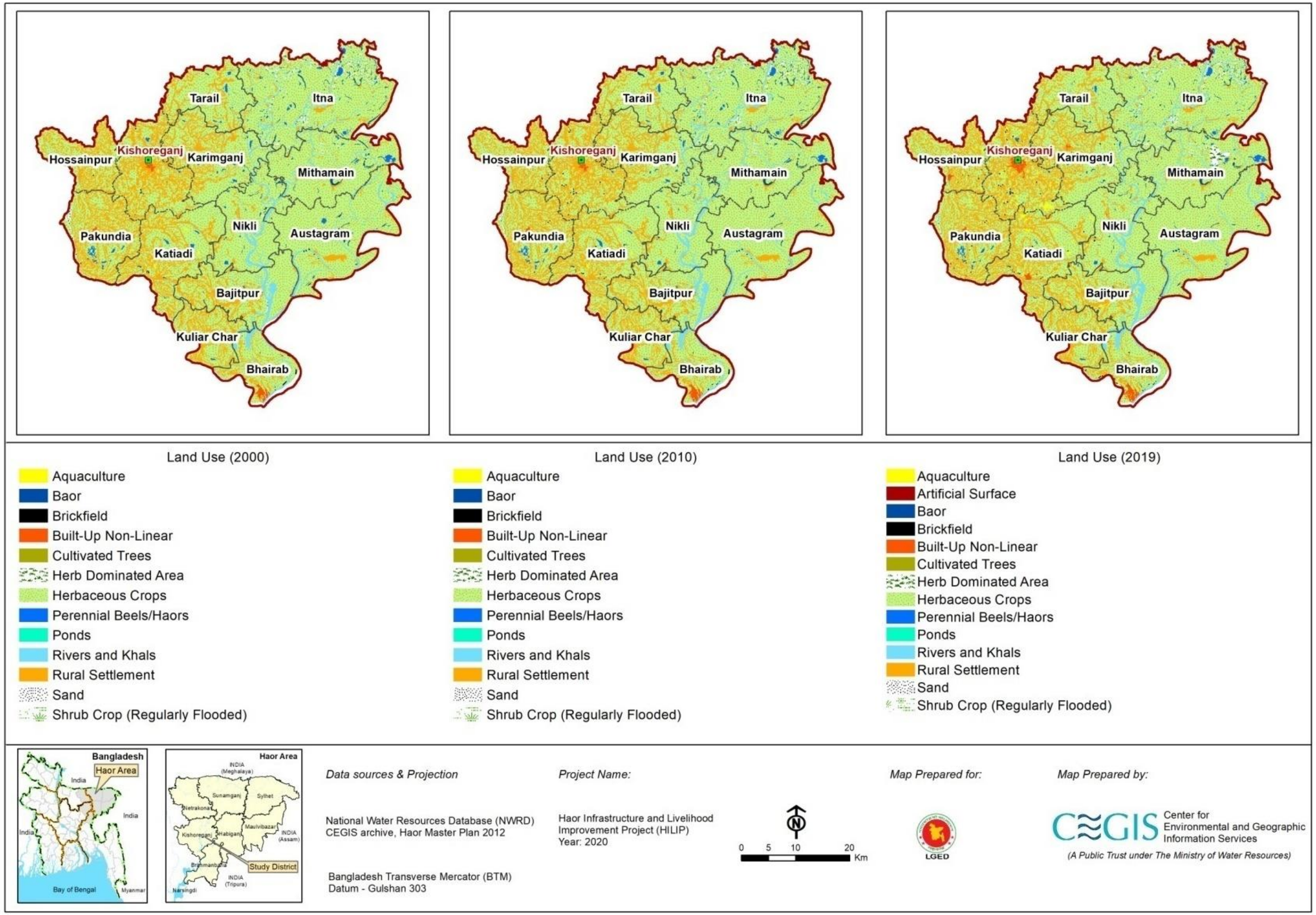


Figure 10.3: Land Uses of Kishoreganj *Haor* Areas in 2019

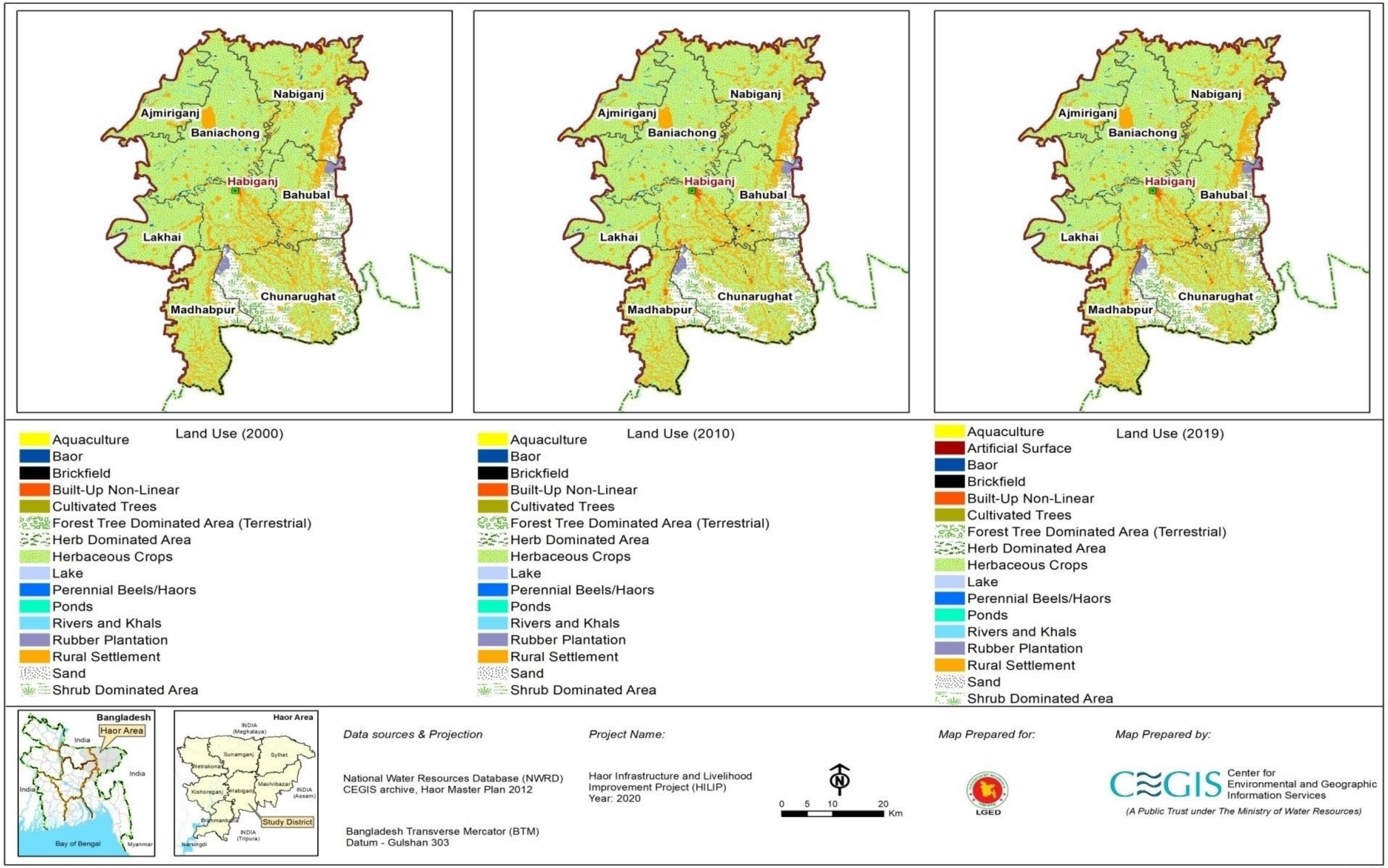


Figure 10.4: Land Uses of Habiganj *Haor* Areas for 2019

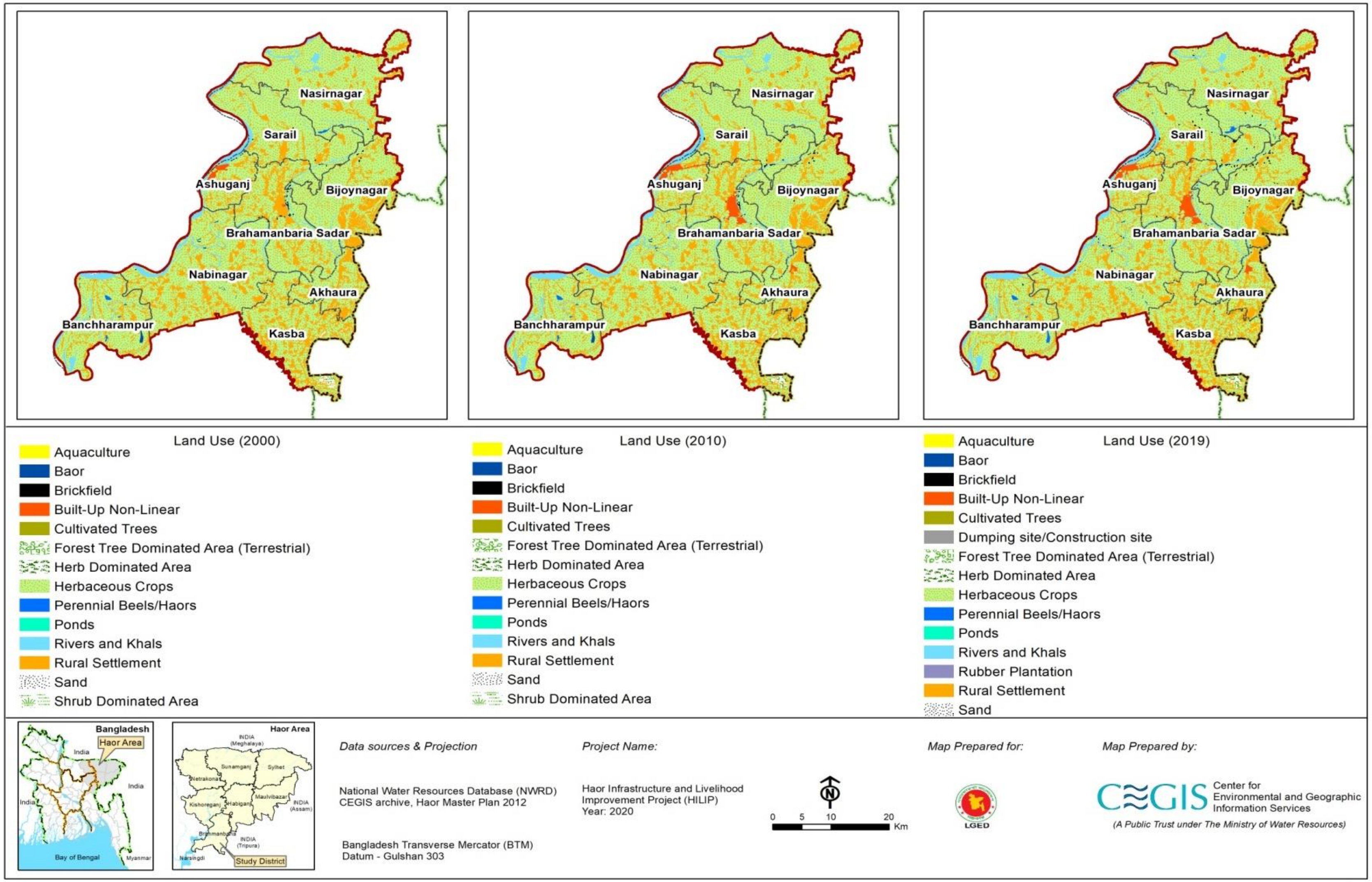


Figure 10.5: Land Uses of Brahmanbaria *Haor* Areas for 2019

Land use analysis for the recent year is presented in following Tables 10.1 to 10.5.

Table 10.1: Land Uses of Brahmanbaria *Haor* Areas for 2000, 2010 and 2019

Land Class	Area (Ha)		
	2000	2010	2019
Aquaculture	26	51	703
Baor	227	221	76
Brickfield	279	340	676
Built-Up Non-Linear	467	1,819	2,388
Cultivated Trees	158	288	664
Forest Tree Dominated Area (Terrestrial)	101	449	5
Herb Dominated Area	53	82	602
Herbaceous Crops	142,485	141,019	37
Perennial *Beels*/*Haors*	198	130	138,540
Ponds	5	16	387
Rivers and *Khals*	9,393	10,344	44
Rural Settlement	38,713	37,737	10,288
Sand	47	2	17
Shrub Dominated Area	496	151	38,218
Dumping site/Construction site	-	-	5
Rubber Plantation	-	-	1
Grand Total	**192,648**	**192,648**	**192,653**

Table 10.2: Land Uses of Habiganj *Haor* Areas for 2000, 2010 and 2019

Land Class	Area (ha)		
	2000	2010	2019
Aquaculture	107	725	725
Baor	811	716	716
Brickfield	84	311	311
Built-Up Non-Linear	216	1,498	1,498
Cultivated Trees	50	906	906
Forest Tree Dominated Area (Terrestrial)	7,497	10,056	10,056
Herb Dominated Area	485	676	676
Herbaceous Crops	182,388	177,766	177,766
Lake	76	61	61
Perennial *Beels/Haors*	513	516	516
Ponds	56	148	148
Rivers and *Khals*	3,268	4,694	4,694
Rubber Plantation	2,155	2,722	2,722
Rural Settlement	36,769	37,213	37,213
Sand	32	78	78
Shrub Dominated Area	23,723	20,106	20,106
Artificial Surface	-	36	36
Grand Total	**258,231**	**258,231**	**258,231**

Table 10.3: Land Uses of Kishoreganj *Haor* Areas for 2000, 2010 and 2019

Land Class	Area (ha)		
	2000	2010	2019
Aquaculture	162	302	1,438
Baor	1,375	1,172	902
Brickfield	207	306	393
Built-Up Non-Linear	552	591	1,555
Cultivated Trees	22	16	167
Herb Dominated Area	1,575	1,567	2,531
Herbaceous Crops	193,352	191,731	189,149
Perennial *Beels/Haors*	2,294	2,071	1,885
Ponds	31	52	192
Rivers and *Khals*	10,742	12,170	11,817
Rural Settlement	43,491	43,967	43,896
Sand	277	129	113
Shrub Crop (Regularly Flooded)	32	39	32
Artificial Surface			42
Grand Total	**254,113**	**254,113**	**254,113**

Table 10.4: Land Uses of Sunamganj *Haor* Areas for 2000, 2010 and 2019

Land Class	2000	2010	2019
Aquaculture	35	238	791
Baor	1,474	1,190	1,211
Brickfield	70	69	71
Built-Up Non-Linear	79	368	378
Forest Tree Dominated Area (Terrestrial)	12	12	99
Herb Dominated Area	12,928	10,561	86
Herbaceous Crops	292,609	288,454	12,677
Perennial *Beels/Haors*	12,056	15,349	279,156
Ponds	3	9	21,569
Rivers and *Khals*	9,980	12,367	4
Rural Settlement	35,428	35,485	12,103
Sand	1,049	901	36,651
Shrub Crop (Regularly Flooded)	1,868	2,537	809
Shrub Dominated Area	178	190	1,760
Tree Dominated Area (Aquatic/ Regularly Flooded)	1	1	34
Artificial Surface		37	286
Tree Dominated Area (Aquatic/Regularly Flooded)	-	-	83
Grand Total	**367,768**	**367,768**	**367,769**

Table 10.5: Land Uses of Netrokona *Haor* Areas for 2000, 2010 and 2019

Land Class	Area (ha)		
	2000	2010	2019
Aquaculture	38	162	779
Baor	817	594	925
Brickfield	73	101	194
Built-Up Non-Linear	174	216	908
Cultivated Trees	34	33	167
Dump Sites/ Extraction Sites	24	-	-
Forest Tree Dominated Area (Terrestrial)	520	585	383
Herb Dominated Area	4,365	4,305	4,167
Herbaceous Crops	213,843	211,424	208,966
Perennial *Beels/Haors*	3,595	3,112	3,840
Plain Land Forest (Sal Forest)	127	127	104
Ponds	29	23	8
Rivers and *Khals*	5,345	8,094	7,409
Rural Settlement	48,881	49,273	50,002
Sand	782	649	672
Shrub Crop (Regularly Flooded)	152	152	165
Shrub Dominated Area	374	323	450
Artificial Surface	-	**-**	**30**
Tree Dominated Area (Aquatic/Regularly Flooded)	-	-	4
Grant Total	**279,173**	**279,173**	**279,173**

10.2 Future Land Use Projection

10.2.1 Land Use Change Analysis for the Projection

Haor region has a unique land use pattern including bowl shaped wetlands, cropland, forest, plantation, orchards and settlements etc. The area statistics of land use class of 2010 and 2019 is shown in Table 10.6. In this study, the national land use map of 2019 was prepared using the Landsat 8 images, 2019. The spatial resolution of Landsat 8 is 30 meters. Following the IPCC guideline and considering the significance of some land use classes in the *haor* region, the land use classes that were defined are:

1. Cropland
2. Forestland
3. Grassland
4. Orchard and other plantation
5. Other lands
6. River and *khals*
7. Settlements
8. Wetlands
9. Other lands

According to the statistics (Table 10.6), area of crop land, forest land and rivers & *khals* are decreasing. Rivers and *khals* has decreased by 1,406.07 ha, Cropland decreased by 19,886.19 ha and Forest land decreased by 703 ha only. A significant change can be noticed in cropland. In ten years about 1.47% (19,886.19 Ha) of cropland in *haor* area has decreased which is very concerning. However, aquaculture, grassland, orchard and plantation, settlements and other land are showing increasing trend. In recent times, development works has changed the appearance of the *haor* where some wetlands or agricultural lands have been converted into built-up areas including settlements, roads, industries etc.

Table 10.6: Analysis of Land Use Changes from 2010 to 2019

Major Classes	Area 2019 (Ha)	2019 (%)	Area 2010 (Ha)	2010 (%)	Changes	Changes (%)
Aquaculture	4437.15	0.33%	1062.20	0.08%	3374.95	0.25%
Crop land	995535.16	73.64%	1015421.36	75.11%	-19886.19	-1.47%
Forest land	34632.10	2.56%	35335.26	2.61%	-703.15	-0.05%
Grass land	20087.46	1.49%	16949.36	1.25%	3138.09	0.23%
Orchard and other plantations	2003.20	0.15%	382.27	0.03%	1620.91	0.12%
Rivers and *Khals*	46311.89	3.43%	47771.96	3.53%	-1460.07	-0.11%
Settlements	212707.84	15.73%	206864.11	15.30%	5843.73	0.43%
Wetlands	32484.11	2.40%	25335.58	1.87%	7148.52	0.53%
Other lands	3734.02	0.28%	2811.61	0.21%	922.40	0.07%
Grand Total	**1351932.94**	**100%**	**1351933.73**	**100%**		

Source: Based on RS calculation done by CEGIS

10.2.2 Scenario Analysis

Productive Scenario

The Productive scenario is characterized by moderate water conditions, stabilizing population growth and an increase of per capita Gross Domestic Production (GDP) growth as a result of fast economic growth and a continuous transition of Bangladesh towards a diversified economy which will be moderately affected by climate change. While portraying land use changes under this scenario, it is assumed that aquaculture will be high due to application of modern technology. Croplands, grasslands and wetlands are expected to be decreased due to significant increase of settlement area. Rivers and *khals* will be increased due to restoration and conservation initiatives taken by the government, non-government and other agencies. Other land uses and Orchard and other plantation areas may increase due to investment in technology, enhanced development activities and given the condition of transition to a diversified economy. Diversified economy will create more opportunities for employment. Crop loss will be less influenced by the mild climate change. The overall assumption expresses an increasing trend in the land uses of aquaculture, settlements, orchards and other plantations, river and *khals* which is compensated by cropland, grassland and wetland areas within limited resources.

Resilient Scenario

The Resilient scenario is characterized by extreme water conditions due to rapid climate change and a stable increase of GDP per capita, driven by favorable economic conditions leading to a transformation to a fully diversified economy. Due to advancements in research and technology, aquaculture will develop rapidly and agricultural production will be high. Although the production has a chance to be interrupted by natural hazards and climatic conditions, economic growth ensures high investment to apply technology and develop infrastructures for the protection from disasters. Settlement areas will expand replacing cropland and grassland areas but the process will not be as fast as in a productive scenario. Due to technological adaptation and sustainability to cope with the harsh climatic conditions, other land uses such as orchards and other plantations will slowly increase. Moreover, restoration and conservation initiatives will highly support the increase of wetlands, rivers and *khals*. Employment opportunities and women empowerment will improve slowly under this scenario. The scenario portrays the development activities through adaptation with climate change and implementation of standards for environmental protection.

Moderate Scenario

The Moderate scenario is characterised by a slower GDP per capita growth, due to moderate economic growth and a fast-growing population in combination with moderate climate changes. Climate change in Bangladesh is relatively mild under this scenario. The development in aquaculture will be a slow process due to lack of investment in technology and effects of climate changes. The settlement area will expand slowly and, therefore, less cropland and grassland areas will be converted allowing more arable land for agricultural production. Due to lack of initiatives in restoration and conservation, rivers, *khals* and wetlands will begin to decrease slowly. Orchards and other plantations will keep increasing since plantations can be initiated at low investment, and forest land will remain the same. However, the overall scenario portrays slow progress in land use transformations, less diversified economy and scarce opportunities for employment.

Active Scenario

The Active scenario depicts unfavourable economic growth conditions and an exponential growing population, together with extreme water variability due to climate change and adverse upstream developments. The combination of frequent events of climate change and low economic growth hinders the development activities and resists the investments in technology, maintenance and operation which portrays the worst scenario unlike others. The development in aquaculture will not be as significant as in other scenarios. The expansion of settlement areas will be a slow process due to lack of financial strength for investment. Rivers and *khals*, wetlands, grasslands and cropland will decrease slowly which can be ignorable initially. Orchards and other plantations will keep increasing in this scenario since it requires very low investment throughout the process. There is less chance of diversified economy that will not allow creating employment opportunities and support women empowerment.

10.2.3 Future Projection

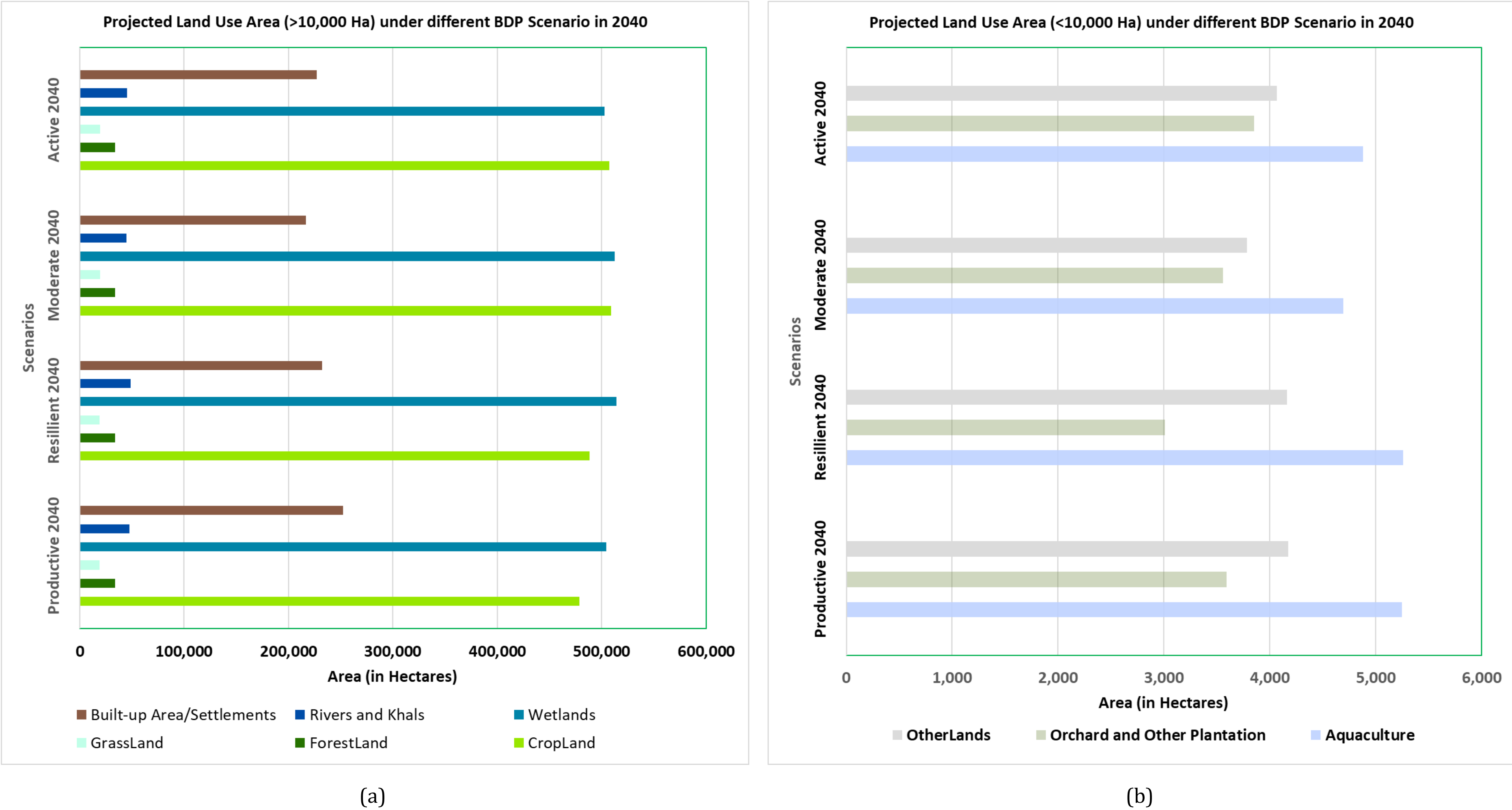
The land use of the *haor* districts has been projected for the year 2040. The rationale behind selecting 2040 as the projection year is that 2040 target year by which the government aims to become a developed country by fulfilling Vision 2041. It is also prudent to consider a long period (minimum of 20 years from the base year) to visualize any changes that might occur in the ecosystem.

Modelling Result Analysis - 2040

Following Table 10.7 and Figure 10.6 show the predicted change in land use classes with respect to baseline values in 2019. It is observed that the Orchards and Other plantation class exhibits most rapid changes. Croplands and Grasslands show a general trend in the decline for all scenarios.

Table 10.7: Projected Land Use Change in 2040 with Respect to Baseline (2019) Values

Major Land Use Classes	Base 2019	Productive 2040		Resilient 2040		Moderate 2040		Active 2040	
	Area (in Ha)	Area (in Ha)	Change	Area (in Ha)	Change	Area (in Ha)	Change	Area (in Ha)	Change
Aquaculture	4404	5250	19.21%	5258	19.39%	4691	6.52%	4878	10.76%
Crop Land	511970	478726	-6.49%	488132	-4.66%	509119	-0.56%	507038	-0.96%
Forest Land	34027	34027	0.00%	34027	0.00%	34027	0.00%	34027	0.00%
Grass Land	20035	18875	-5.79%	19118	-4.58%	19502	-2.66%	19681	-1.77%
Orchard and Other Plantation	1956	3589	83.49%	3008	53.78%	3558	81.90%	3851	96.88%
Other lands	3733	4174	11.81%	4165	11.57%	3782	1.31%	4066	8.92%
Wetlands	513839	504255	-1.87%	513939	0.02%	512471	-0.27%	502791	-2.15%
Rivers and Khals	45967	47673	3.71%	48774	6.11%	44601	-2.97%	45225	-1.61%
Built-up Area /Settlements	212657	252010	18.51%	232167	9.17%	216837	1.97%	226811	6.66%



(a) LU Classes with area over 10,000 Hectares (b) LU Classes with area under 10,000 Ha

Figure 10.6: Projected Land Use Area under Different BDP Scenarios in 2040

Productive 2040

The assumptions under Productive scenario enable rapid socioeconomic progress and subsequent change in Land Use by 2040. Growth in Aquaculture (20%), Orchards and Other Plantations (>65%) and Settlements/Built-up Areas (9%) (Figure 10.7) underpins these assumptions. The increase in Rivers and Khal areas illustrate development is likely to encompass natural preservation of the river ecosystem. Little reduction in the wetlands indicate very limited encroachment in the wetlands. In this scenario, the model outputs show that decrease in Croplands, Other lands and Grass land is likely to account for meeting the increase in demand for aforementioned land use classes. It is evident from the maps that change in Land Use classes occur mostly in Habiganj and Sunamganj districts.

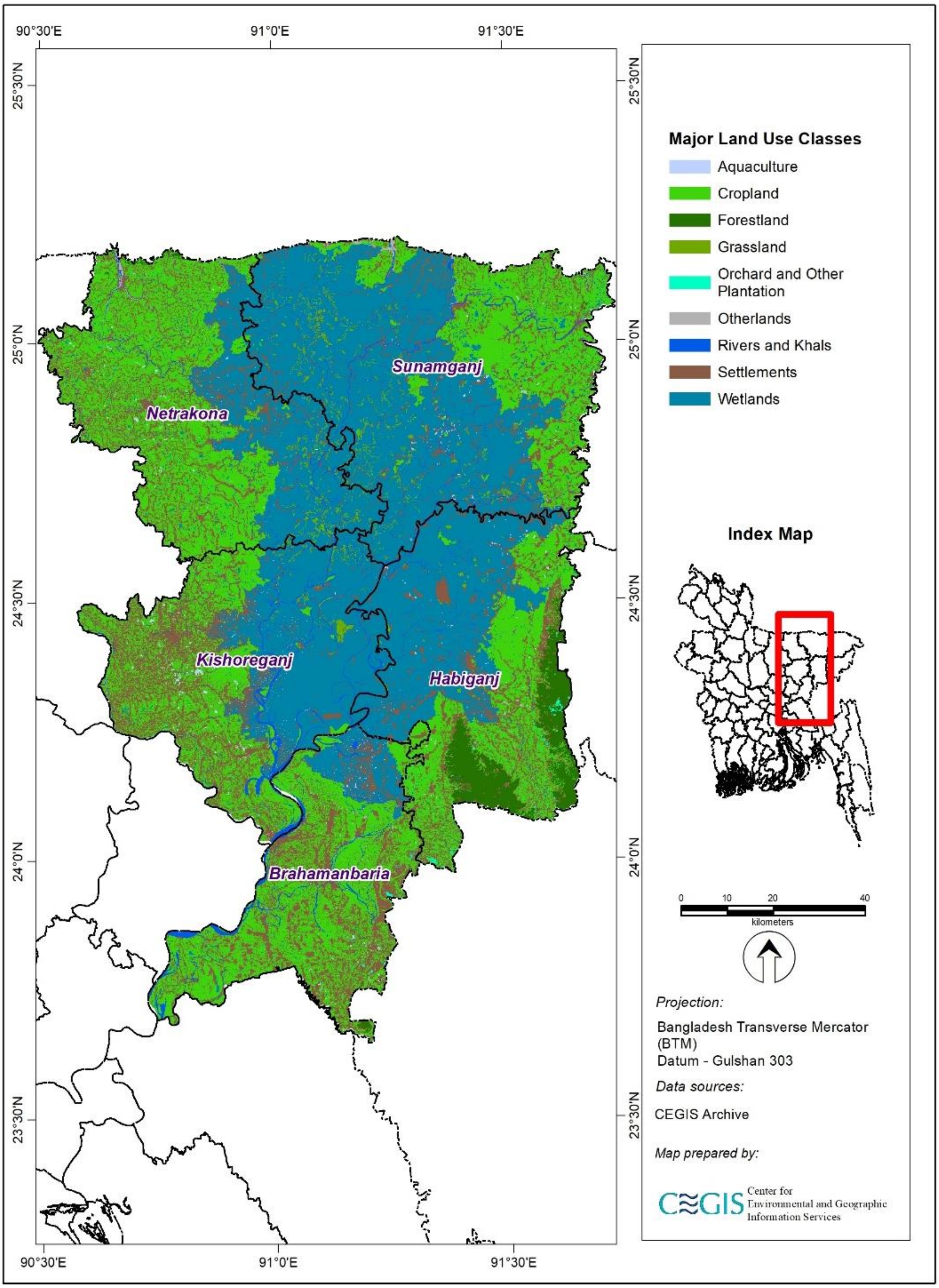


Figure 10.7: Projected Land Use in Productive 2040 Scenario

Resilient 2040

This scenario emphasizes on restoration and preservation of ecosystem and sustainable reaping of ecosystem services. The model outputs hold up to the assumptions. No reduction in Wetlands area (Figure 10.8) depicts that the wetlands would be preserved as much as possible under this scenario. Very slight increase (0.5%) in Rivers and *Khals* indicate restoration of rivers and excavation of *khals*. Increase in settlements/built-up areas (11%) and other lands is envisaged after high economic growth (in line with perspective plan 2021 and Vision 2041) has been achieved. Croplands and Grasslands are likely to be converted for meeting the land use demand. The changes are likely to occur mostly in Habiganj and Sunamganj districts in this scenario as well.

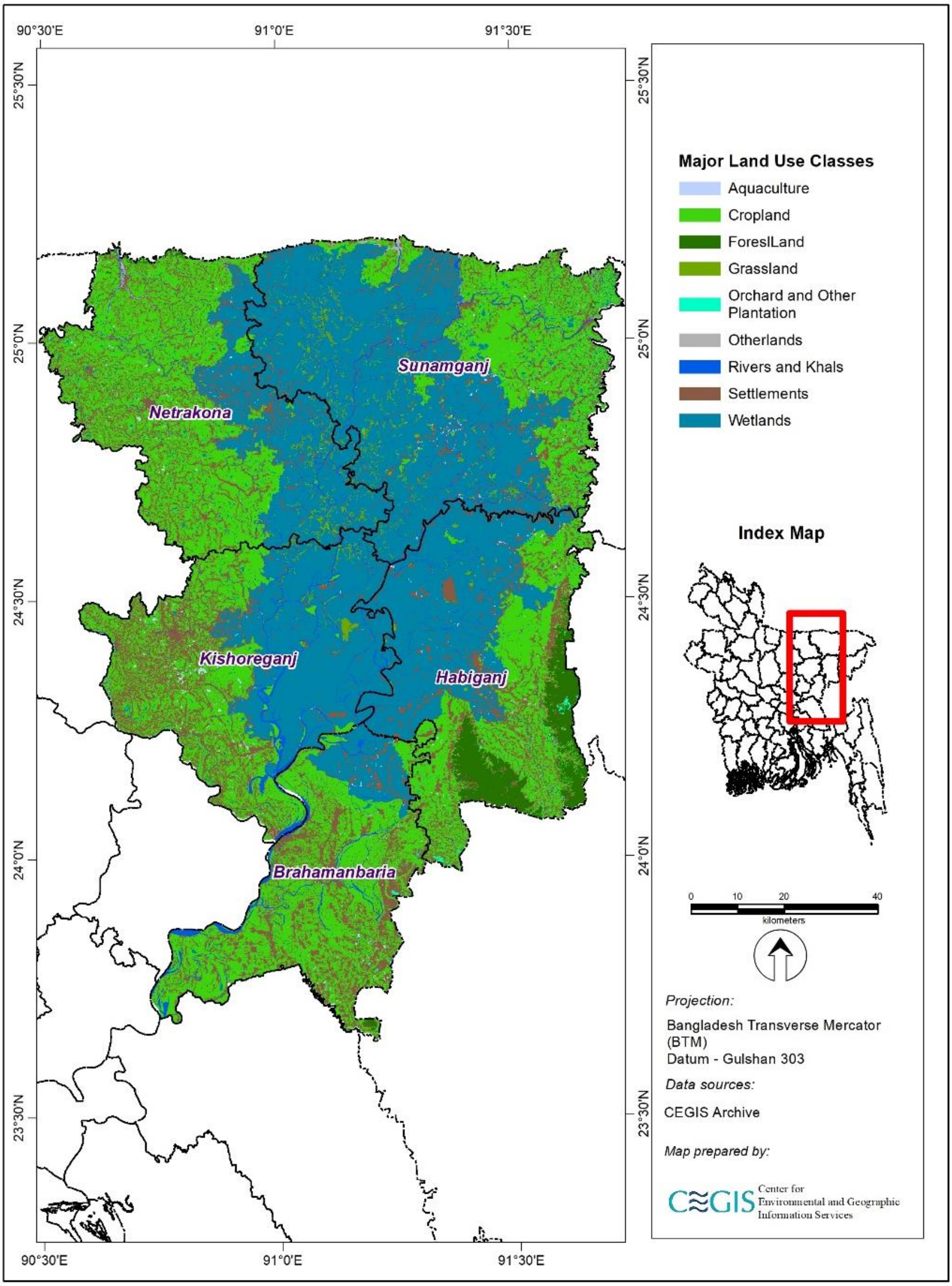


Figure 10.8: Projected Land Use in Resilient 2040 Scenario

Moderate 2040

This scenario was designed to replicate the current trend of change in land use observed in the *haor* region. The growth rates used in this scenario follow the business-as-usual case considered in view of the Perspective plan 2021 and Eighth Five-Year Plan. From the historical land use change analysis, it is observed that land use change in the *haor* region shows upwards conversion of croplands to aquaculture and orchards (mostly betel leaf cultivation). This trend is assumed to continue (Figure 10.9) with 6.5% rise in Aquaculture and >80% rise in Orchards and other Plantations. Poor economic growth is likely to influence less urban development, which is illustrated by only 2% increase in the settlement areas. Infinitesimal decrease in rivers and *khals* indicate encroachment of rivers (adjacent areas) for conversion into other land use classes. Lesser decrease in Croplands compared to other scenarios depict low economic growth leading to less conversion of croplands.

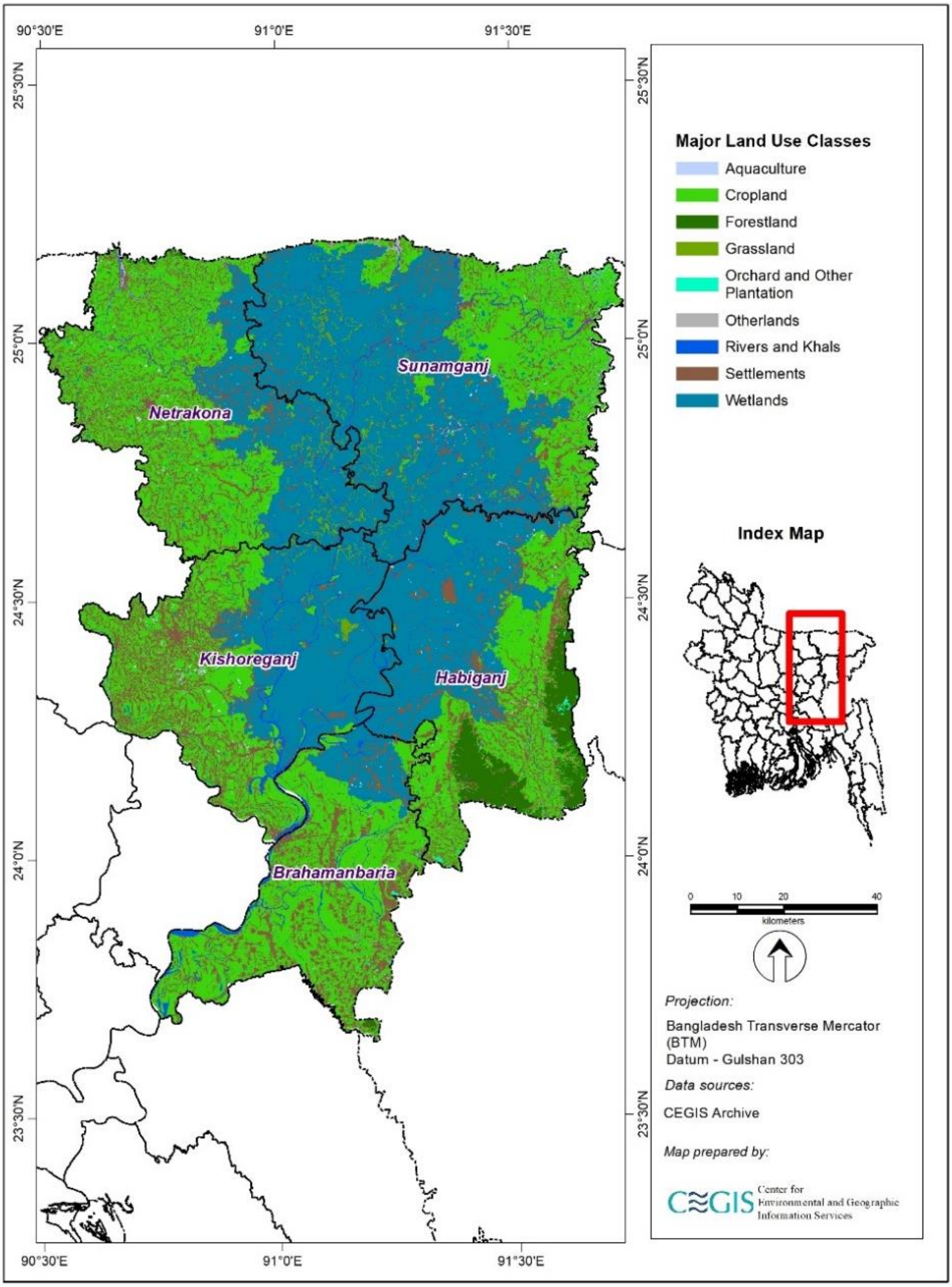


Figure 10.9: Projected Land Use in Moderate 2040 Scenario

Active 2040

Storyline of this scenario reflects high climate change and low economic growth (adverse conditions developed within the narrative of Vision 2041), to induce land use change for development. Only 1% reduction in croplands indicate prevalence of agrarian economy in this region. Wetlands area is predicted to be reduced by 1.6% (Figure 10.10) which illustrates poor maintenance of wetland ecosystem. Reduction in rivers and *khals* depict encroachment of rivers for conversion into settlement and other lands. Orchards and other plantations are also predicted to increase by a significant margin. 6.7% growth in settlements/built-up areas is likely to meet the demand for urban and industrial sprawl.

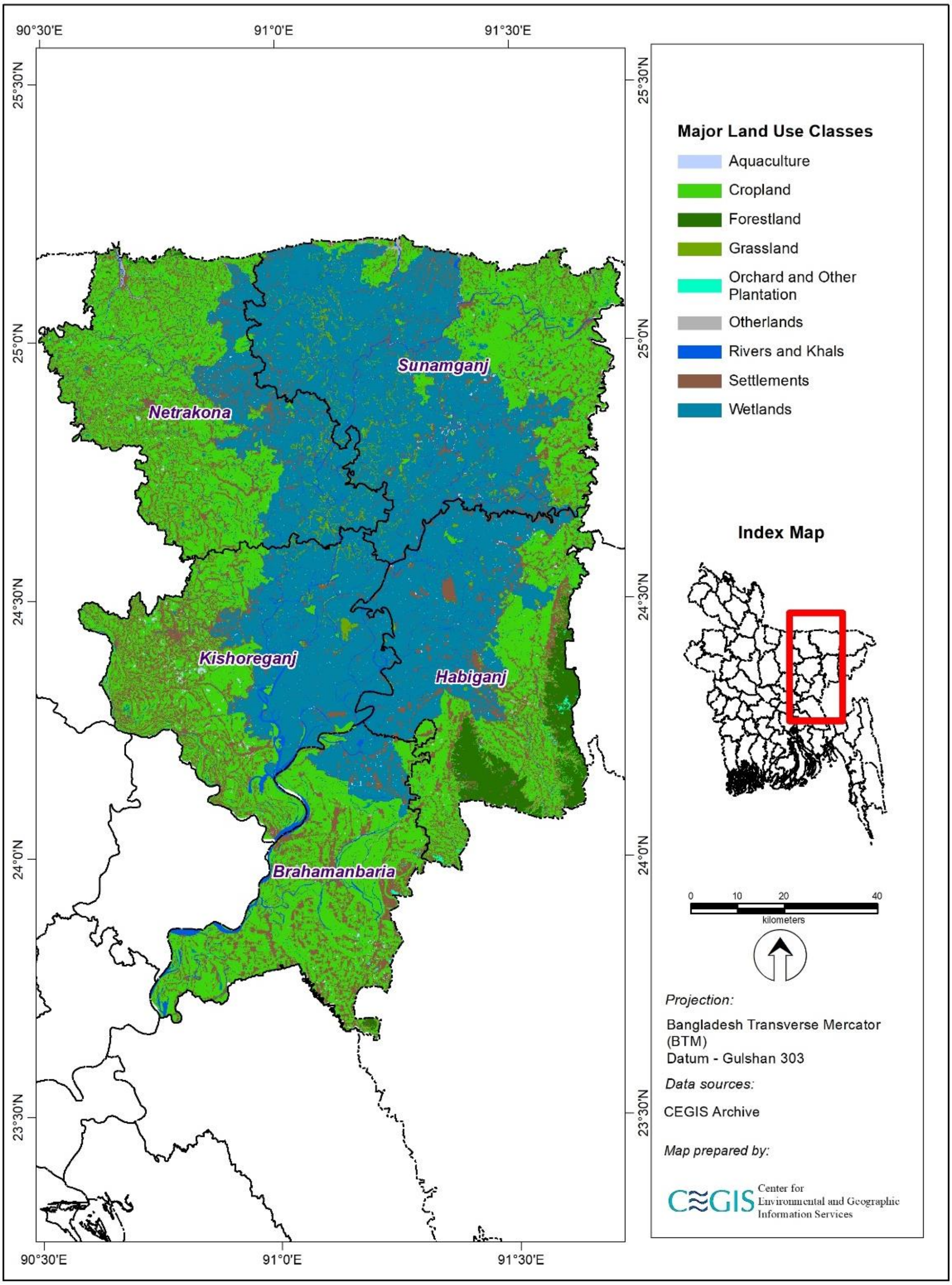


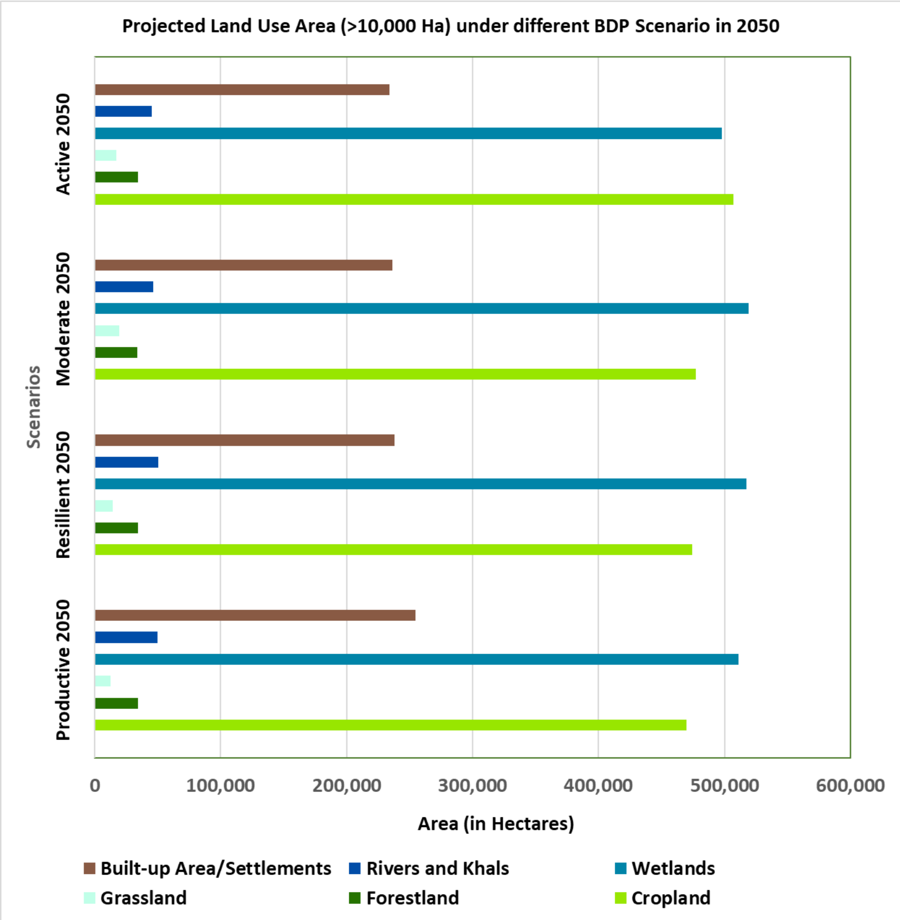
Figure 10.10: Projected Land Use in Active 2040 Scenario

Modelling Results Analysis – 2050

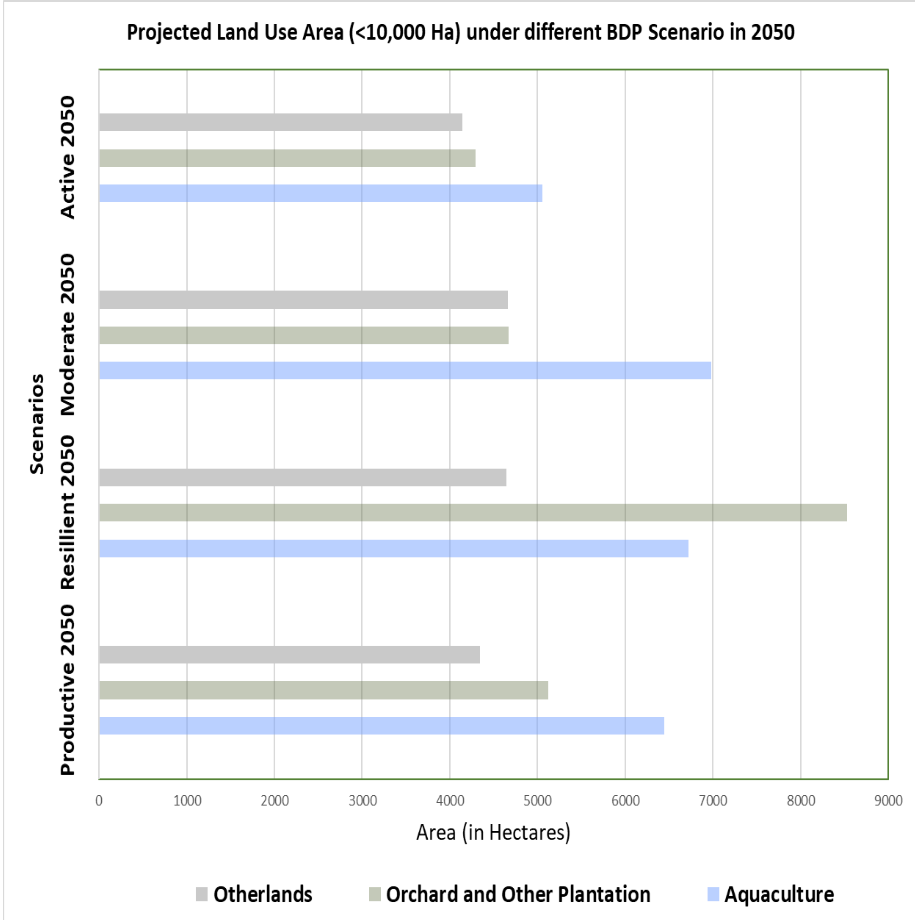
Table 10.8 and Figure 10.11 show projected changes in Land Use in the year 2050 under different scenarios. The projected land use values are shown in Figure 10.11 and Table 10.8. Continuing the trend of change in 2040, orchard and other plantation is subject to most rapid change. Cropland and grassland are likely to be converted into other land use classes to meet the increasing demand. Scenario-wise analyses are presented in the following sections.

Table 10.8: Projected Land Use Change in 2050 with Respect to Baseline (2019) Values

Major Land Use Classes	Base 2019	Productive 2050		Resillient 2050		Moderate 2050		Active 2050	
	Area (in Ha)	Area (in Ha)	Change	Area (in Ha)	Change	Area (in Ha)	Change	Area (in Ha)	Change
Aquaculture	4404	6446	46.37%	6718	52.54%	6978	58.45%	5055	14.78%
CropLand	511970	469974	-8.20%	474352	-7.35%	477449	-6.74%	507037	-0.96%
ForestLand	34027	34517	1.44%	34441	1.22%	34027	0.00%	34421	1.16%
GrassLand	20035	12733	-36.45%	14205	-29.10%	19415	-3.09%	16856	-15.87%
Orchard and Other Plantation	1956	5126	162.07%	8530	336.09%	4667	138.60%	4298	119.73%
Other lands	3733	4348	16.47%	4643	24.38%	4660	24.83%	4141	10.93%
Wetlands	513839	510870	-0.58%	517537	0.72%	518962	1.00%	497669	-3.15%
Rivers and Khals	45967	49668	8.05%	50409	9.66%	46167	0.44%	45011	-2.08%
Built-up Area/Settlements	212657	254906	19.87%	237753	11.80%	236263	11.10%	234100	10.08%



(a)



(b)

(a) LU Classes with Area over 10,000 Hectares (b) LU Classes with Area under 10,000 Ha

Figure 10.11: Projected Land Use Area under Different BDP Scenarios in 2050

Productive 2050

Productive 2050 scenario anticipates accelerated development in the 2041-50 decade, as Bangladesh is predicted to be a high-income country by 2041. More expansion of Aquaculture (>45%), Other lands (16%) and Orchard & Other Plantations (176%) replicate the assumptions. About 8% growth in Rivers and *Khals* depict that the reaping of natural ecosystem benefits of rivers in the *haor* region will be enhanced without illegal encroachment. The wetlands ecosystem is likely to remain unaltered as well. The conversion of croplands (-8.2%) and Grassland (-36.45%) would occur to meet the demand for land for accelerated socio-economic growth.

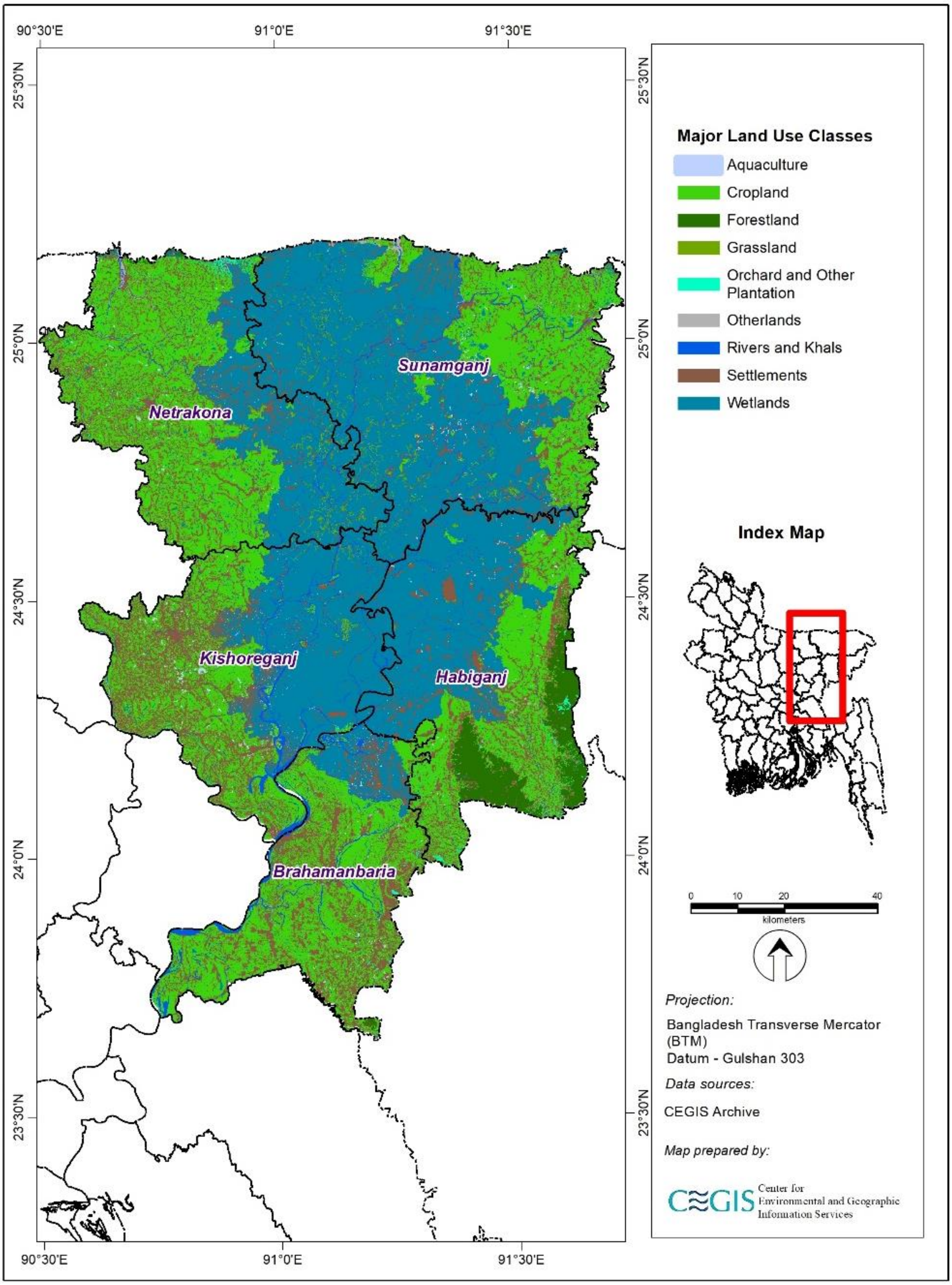


Figure 10.12: Projected Land Use in 2050 for Productive Scenario

Resilient 2050

The scenario assumptions emphasize ecosystem resilience amidst socio-economic growth. The wetlands are anticipated to increase a little bit, resembling maintenance and minimal enhancement of the wetland ecosystem in *haor* region. Orchard and Other Plantation is projected to be almost double (of Baseline values) by 2050. Aquaculture is expected to increase a substantial amount (>50%), which resembles further utilization of natural resources for economic advancement, without debilitating the local ecological balance. Settlement is likely to increase almost 12%. It is projected that cropland and grassland will be converted to meet the land use demand.

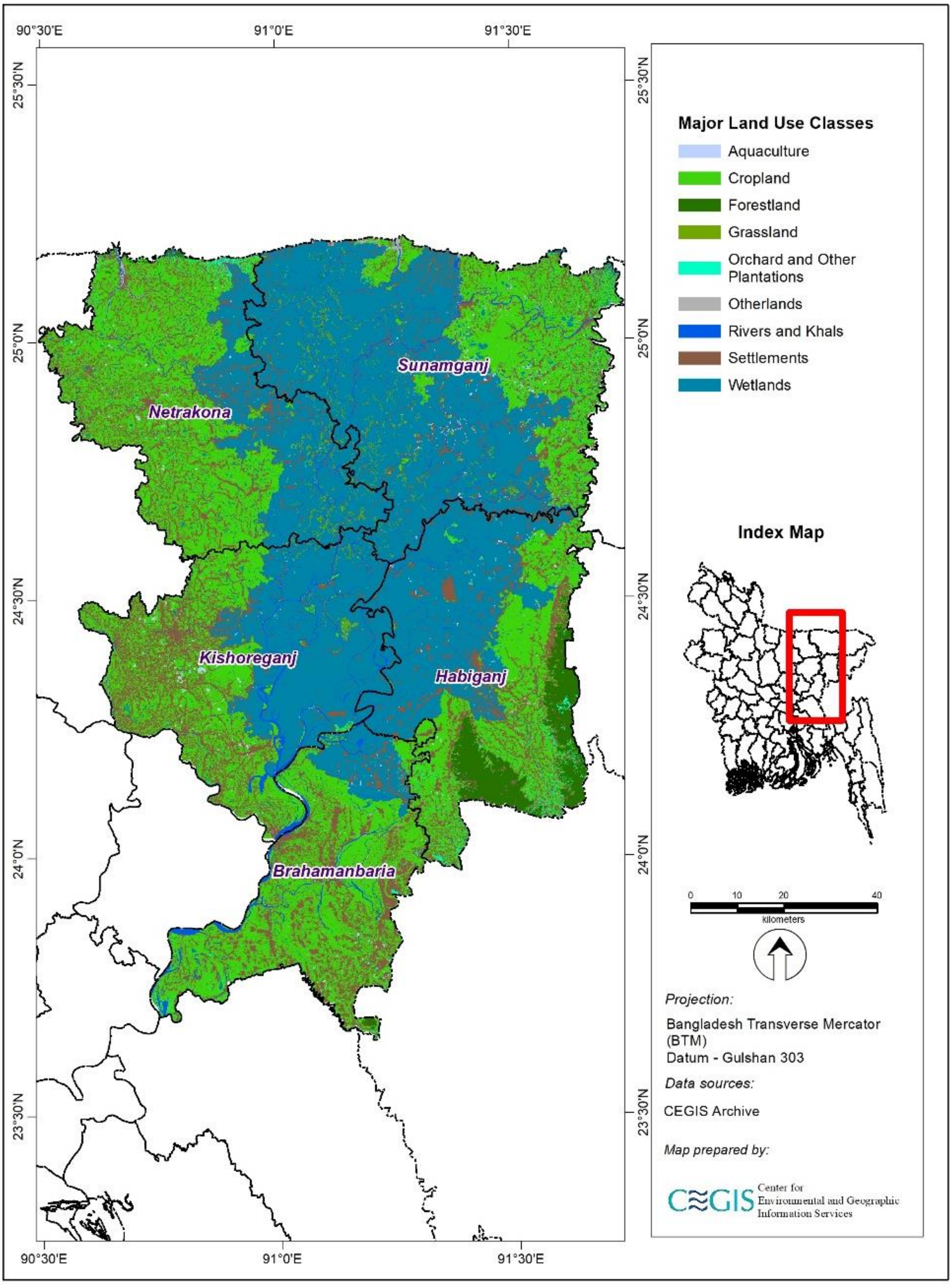


Figure 10.13: Projected Land Use in 2050 for Resilient Scenario

Moderate 2050

This scenario was designed to replicate the current trend of land use change up to 2050. Conversion of cropland and grassland into Built-up Areas and Settlements has been observed from 2010-19, which is likely to continue with 6.7% and 3% reduction in Croplands and Grasslands respectively. The rivers and *khal* area would increase slightly with river restoration and *khal* excavation projects underway. The wetlands ecosystem is likely to be preserved, which is depicted by 1% rise (approximately). The current migration and socio-economic development trends are replicated by 12% and 24% growth in Built-up Areas/Settlements and other areas.

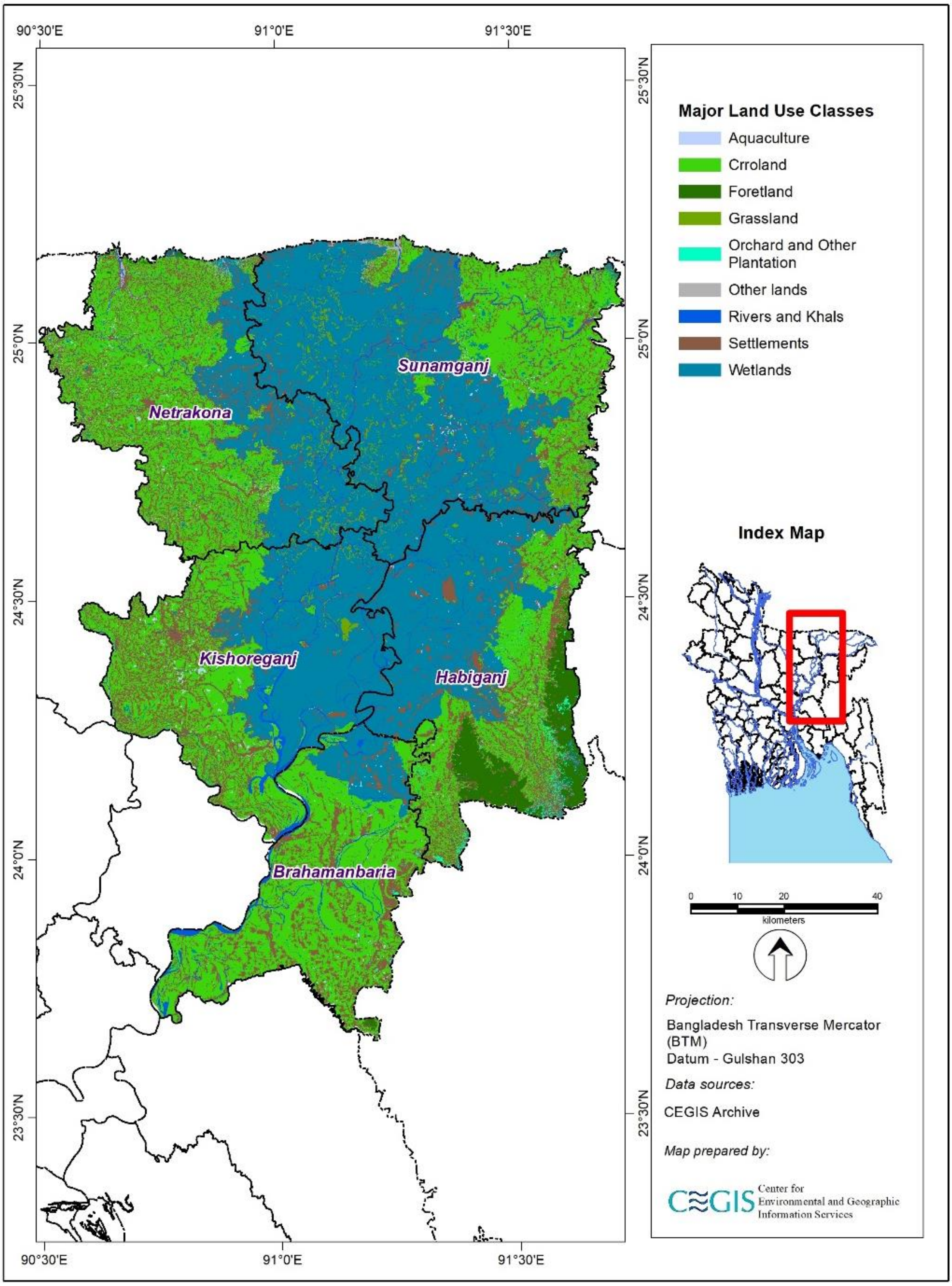


Figure 10.14: Projected Land Use in 2050 for Moderate Scenario

Active 2050

This scenario is designed to replicate the unlikely adverse conditions; in case they prevail. Aquaculture is projected to increase by 15%. Orchard and Other Plantation is also likely to grow to more than double the baseline amount. Rivers and *Khals* would decrease almost 2%, which would indicate encroachment of river bank areas and poor maintenance of river and *khals*. 3% reduction in Wetlands quantifies the debilitating ecosystem conditions in this region. Other lands and Built-up Areas/Settlements are also projected to increase 9% each. Only 1% reduction in cropland would depict the dependence of agricultural practices for economic activities.

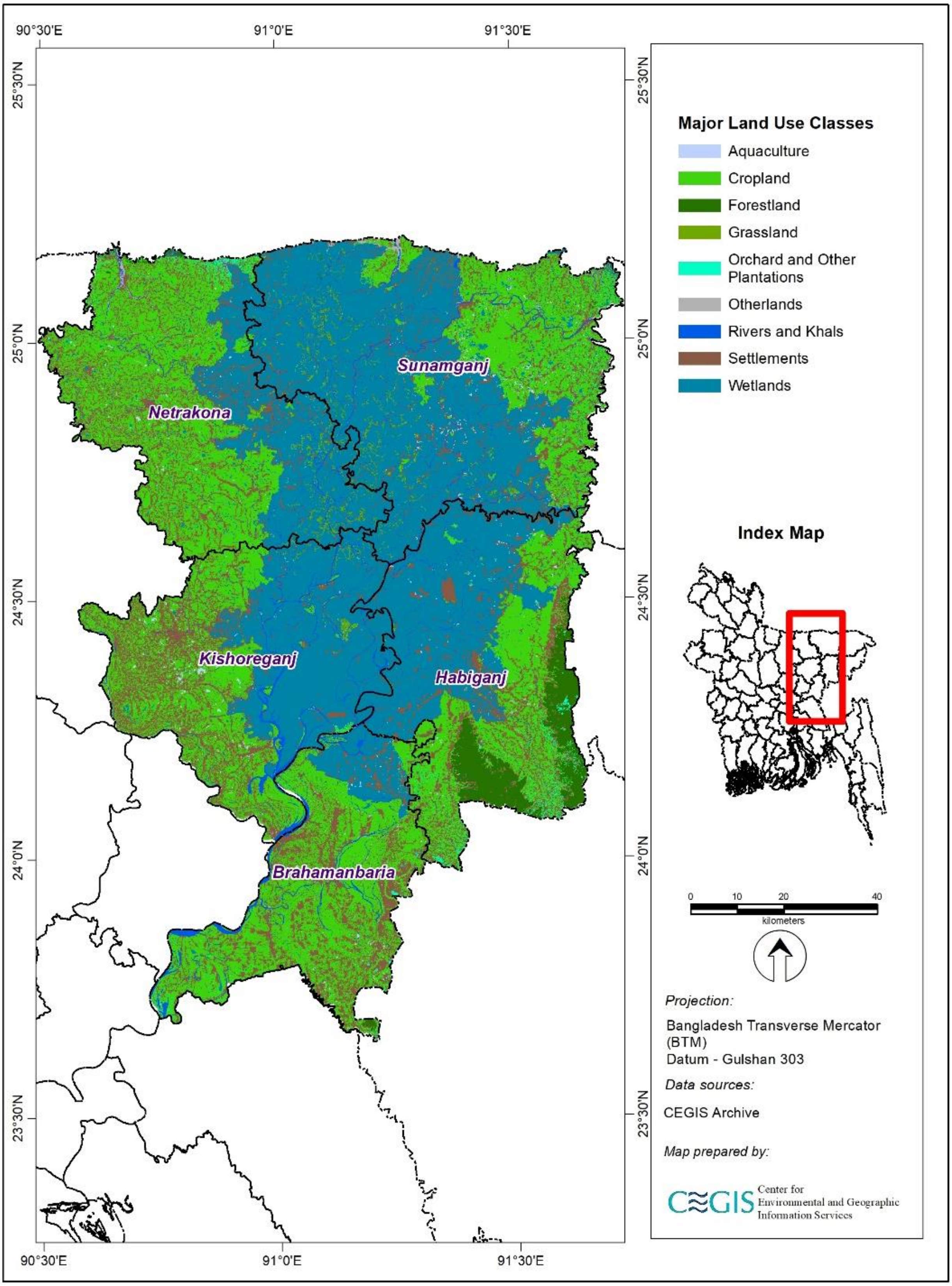


Figure 10.15: Projected Land Use in 2050 for Active Scenario

District-wise Land Use Change Analysis

Brahmanbaria

Projected land use change in the Brahmanbaria district under different scenarios is shown in Table 10.9. Significant increase is observed in Aquaculture, in Productive and Active scenario. Settlements; Orchards and other Plantations are also expected to increase.

Table 10.9: Land Use Change in Brahamanbaria

Land Use Class	Base (Ha)	Active		Moderate		Productive		Resilient	
	2019	2040	2050	2040	2050	2040	2050	2040	2050
Aquaculture	692	3.18%	5.06%	-50.72%	-2.75%	25.29%	27.75%	-0.58%	-0.58%
Cropland	118268	-0.95%	-0.01%	-1.52%	-0.17%	-13.55%	-14.49%	-9.35%	-10.72%
Forest land	572	0.00%	0.70%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Grass Land	8	12.50%	-100.00%	-50.00%	-100.00%	0.00%	-100.00%	12.50%	-100.00%
Orchard and Other Plantations	630	19.84%	113.65%	23.17%	4.76%	41.59%	61.11%	37.62%	186.03%
Other Lands	674	1.93%	2.52%	3.56%	0.00%	49.11%	49.41%	55.79%	56.82%
Wetlands	19298	-2.23%	-40.38%	-2.71%	0.00%	-17.42%	-19.63%	-0.37%	-3.58%
Rivers and Khals	9095	-1.81%	-0.29%	-3.77%	1.09%	4.08%	13.41%	0.37%	6.33%
Settlement	40313	3.68%	17.52%	7.00%	0.24%	45.17%	46.65%	25.93%	27.91%

Kishoreganj

Variation in Land use classes in different scenarios is shown in the following table for Kishoreganj district. In the Productive scenario, the increase in ecosystem-based services like Aquaculture, Orchard and Other Plantations is expected to be lesser than in Active and Resilient scenarios. Increase in Aquaculture; Orchard and other plantations from 2040 to 2050 depict focus on conservation of nature-based development initiatives when the country is likely to be endowed with high economic growth and activities.

Table 10.10: Land Use Change in Kishoreganj

Land Use Class	Base (Ha)	Active		Moderate		Productive		Resilient	
	2019	2040	2050	2040	2050	2040	2050	2040	2050
Aquaculture	1436	7.03%	9.89%	-24.03%	6.75%	31.20%	47.35%	0.00%	0.35%
Cropland	87890	-0.95%	-0.04%	-1.09%	-1.62%	-12.46%	-14.14%	-7.78%	-9.78%
Forest land	0	0%	0%	0%	0%	0%	0%	0%	0%
Grass Land	2539	-1.89%	-8.74%	-7.25%	-0.91%	-4.49%	-46.00%	-1.06%	-32.81%
Orchard and Other Plantations	168	216.07%	256.55%	81.55%	-52.38%	82.74%	136.31%	13.10%	200.00%
Other Lands	559	11.45%	0.18%	6.98%	0.00%	18.25%	18.07%	8.05%	13.60%
Wetlands	104145	-2.15%	-2.07%	-0.80%	0.17%	-5.18%	-4.59%	-0.11%	0.20%
Rivers and *Khals*	12559	-1.50%	-0.47%	-7.12%	0.41%	1.19%	7.88%	0.17%	4.39%
Settlement	45557	5.95%	4.17%	6.66%	2.66%	34.27%	35.94%	15.11%	18.11%

Netrokona

In Netrokona district, the Orchards and Other Plantations are expected to increase in Active scenario more than in Resilient and Productive scenario.

Table 10.11: Land Use Change in Netrokona

Land Use Class	Base (Ha)	Active		Moderate		Productive		Resilient	
	2019	2040	2050	2040	2050	2040	2050	2040	2050
Aquaculture	751	8.39%	40.21%	-4.79%	211.19%	7.99%	20.51%	1.20%	2.80%
Cropland	138170	-0.99%	-0.03%	-0.02%	-9.50%	-1.81%	-3.70%	-0.75%	-3.94%
Forest land	767	-1.83%	0.00%	-1.83%	0.00%	-1.83%	0.13%	-1.83%	2.87%
Grass Land	4163	-1.83%	-7.25%	-3.65%	-0.72%	-3.63%	-22.00%	-1.13%	-15.97%
Orchard and Other Plantations	173	181.50%	-22.54%	28.90%	0.00%	84.97%	587.86%	20.81%	969.94%
Other Lands	891	4.71%	0.22%	0.11%	49.05%	0.00%	0.11%	0.00%	9.99%
Wetlands	75466	-2.11%	-2.53%	0.00%	1.05%	-0.39%	1.57%	0.02%	1.05%
Rivers and *Khals*	7444	-1.64%	-7.91%	-1.59%	0.82%	0.35%	2.70%	-0.04%	2.67%
Settlement	50990	5.35%	5.04%	0.58%	20.15%	5.35%	6.81%	2.05%	6.49%

<u>Habiganj</u>

Orchard & other Plantations in Habiganj and Aquaculture is expected to increase in the Resilient and Moderate scenario. Decrease in Crop Land is anticipated to accommodate for the increase in these land use classes as well as in Settlements.

Table 10.12: Land Use Change in Habiganj

Land Use Class	Base (Ha)	Active		Moderate		Productive		Resilient	
	2019	2040	2050	2040	2050	2040	2050	2040	2050
Aquaculture	718	12.67%	7.24%	-8.08%	52.23%	4.74%	12.67%	0.14%	2.51%
Cropland	75198	-0.98%	-4.05%	-0.08%	-16.09%	-4.00%	-5.21%	-2.54%	-6.24%
Forest land	32505	-0.05%	1.20%	-0.05%	0.00%	-0.05%	1.50%	-0.05%	1.20%
Grass Land	670	-1.34%	-77.46%	-7.91%	-43.43%	-4.33%	-82.84%	-3.28%	-85.82%
Orchard and Other Plantations	882	38.32%	147.73%	6.92%	323.70%	75.96%	126.08%	73.58%	345.69%
Other Lands	441	16.78%	2.95%	0.23%	0.23%	1.81%	3.85%	2.49%	5.67%
Wetlands	104169	-2.14%	-3.61%	-0.07%	1.26%	-0.52%	-0.40%	-0.03%	-0.11%
Rivers and *Khals*	4732	-1.82%	-2.51%	-0.61%	0.00%	0.34%	0.91%	2.20%	2.73%
Settlement	38710	6.40%	14.69%	0.38%	20.28%	7.21%	8.11%	2.94%	4.58%

<u>Sunamganj</u>

In Sunamganj, Aquaculture is expected to increase very sharply between 2040 and 2050. This might be credited to change in climatic conditions driving this economic practice. Orchard and Other Plantations are also likely to increase in Resilient scenario from 2040 to 2050.

Table 10.13: Land Use Change in Sunamganj

Land Use Class	Base (Ha)	Active		Moderate		Productive		Resilient	
	2019	2040	2050	2040	2050	2040	2050	2040	2050
Aquaculture	807	24.41%	14.87%	133.46%	66.29%	15.99%	114.62%	105.08%	281.78%
Cropland	92444	-0.93%	-1.95%	0.00%	-8.31%	-0.83%	-3.67%	-3.24%	-6.71%
Forest land	183	-0.55%	0.00%	-0.55%	0.00%	-0.55%	0.00%	-0.55%	0.55%
Grass Land	12655	-1.75%	-16.82%	-1.11%	-2.12%	-6.84%	-36.78%	-6.50%	-29.62%
Orchard and Other Plantations	103	733.01%	-66.99%	1172.82%	-83.50%	402.91%	414.56%	104.85%	329.13%
Other Lands	1168	11.99%	32.11%	-1.37%	41.87%	0.00%	13.96%	0.00%	28.85%
Wetlands	210761	-2.16%	-0.26%	0.03%	1.35%	0.01%	2.29%	0.14%	1.66%
Rivers and *Khals*	12137	-1.49%	-1.34%	0.15%	-0.09%	9.42%	10.27%	21.84%	24.61%
Settlement	37087	12.82%	11.38%	-5.71%	11.26%	0.02%	1.23%	-0.03%	1.37%

11. Nursery Development Protocol for Swamp Afforestation

11.1 Guide to Quality Seedling Production

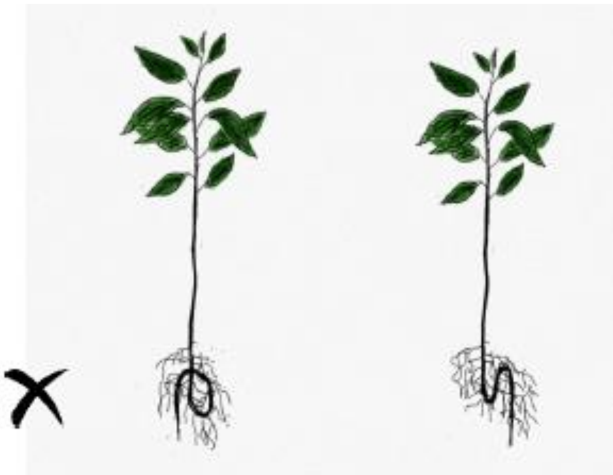
11.1.1 Germplasm

To get high-quality seedlings, it is important to consider planting materials from mother trees. It was evident from this study that the majority of seedlings' morphological (root and stem structure) structures were not satisfactory for successful reforestation outcomes. Germplasm taken from healthy, mature, and straight-stemmed trees would likely exhibit superior growth compared to that taken from defective trees (Mulawarman et al. 2003). It was also observed that the nursery operators mostly collected germplasm only from a few trees, and the distance between the mother trees is not considered. This practice is likely to result in the collection of seed lots with a narrow genetic base. Dawson and Were (1997) and Koffa and Rosethco (1997) pointed out that seeds should be collected from a broader genetic base with a minimum of 30 trees that are at least 50 m apart.

11.1.2 Characteristics of Healthy Seedlings

According to Gregorio et al. (2020) a high-quality seedling has the following characteristics (Figure 11.1):

- Superior mother trees or trees from seed production areas or seed orchards. Hence, it is urgent to protect the remaining patches of swamp vegetation in *haor* areas of Bangladesh to stop genetic erosion.
- The seedling should be healthy, vigorously growing, free from diseases, and with dark green leaves.
- The seedling should have a strong stem and a relatively large root collar diameter.
- A root system that is free from deformities, dense with many fine fibrous hairs should be considered for plantation.
- Balanced root and shoot mass. With regards to the root-shoot ratio, it is argued that a seedling with balanced root and shoot biomass should have a root-shoot ratio between one and two (Jaenicke, 1999).
- The ratio of the seedling height to the root collar diameter that expresses the vigor and robustness of the seedling should be less than six (Jaenicke, 1999).
- Before planting in the field, seedlings should be fully hardened, adapted to full sunlight, and reduced soil moisture.

<table>
<tr><th colspan="2">Absence of pest and diseases</th></tr>
<tr><td>
Healthy seedling</td><td>
Poor health</td></tr>
<tr><th colspan="2">Straightness of the stem</th></tr>
<tr><td>
Straight stem</td><td>
Bent stem</td></tr>
<tr><th colspan="2">Root Form</th></tr>
<tr><td>
Straight taproot</td><td>
Curled taproot</td></tr>
</table>

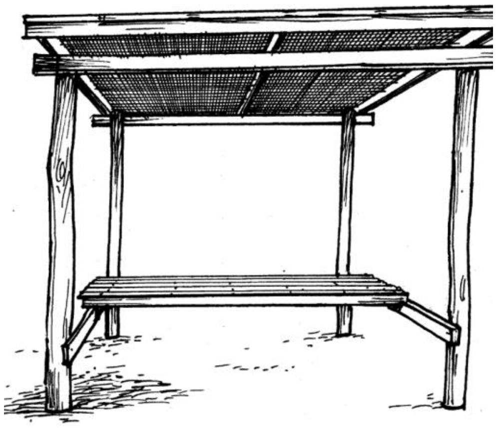
<table>
<tr><th colspan="2">Sturdiness [SQ=Height (cm)/base diameter (cm)]. Good seedling has values less than 6</th></tr>
<tr><td>
Sturdy seedling</td><td>
Lanky seedling</td></tr>
<tr><th colspan="2">Shoot-Root ratio [dry weight of Shoot (g)/dry weight of roots (g)]. Appropriate value is not more than 2.</th></tr>
<tr><td>
Low shoot-root ratio</td><td>
High shoot-root ratio</td></tr>
</table>

Source: Gregorio et al. 2020 and 2021

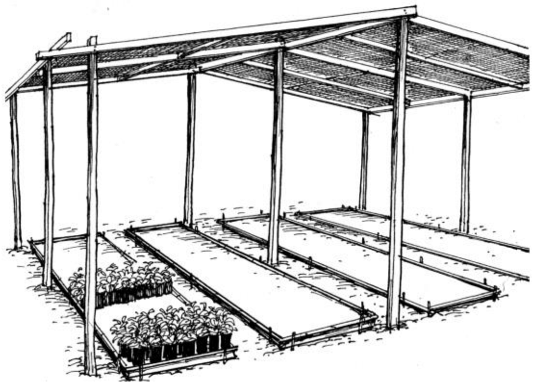
Figure 11.1: Pectoral Representation of Characteristics of Healthy Seedlings

11.1.3 Nursery Facilities

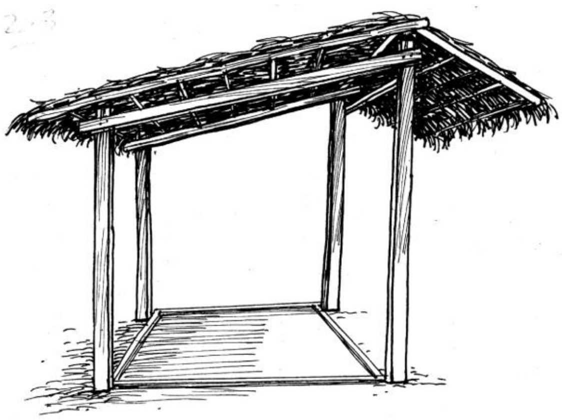
All the nurseries should have basic nursery structures for quality seedling production. From the field observation, it was found that most of the nurseries don't have necessary structures such as a germination shed, transplanted shed, potting shed, and Hardening bed before planting in the field (Figure 11.2).



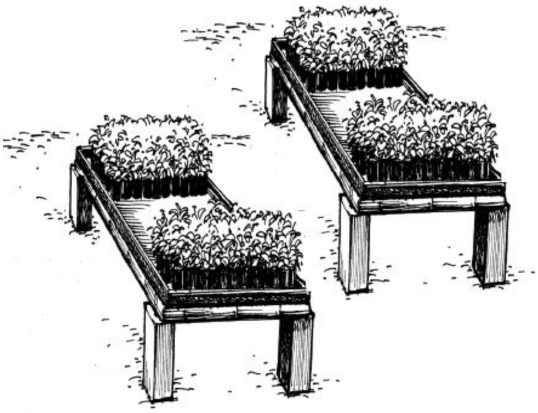
(a) Germination shed



(c) Transplanted shed



(b) Potting shed



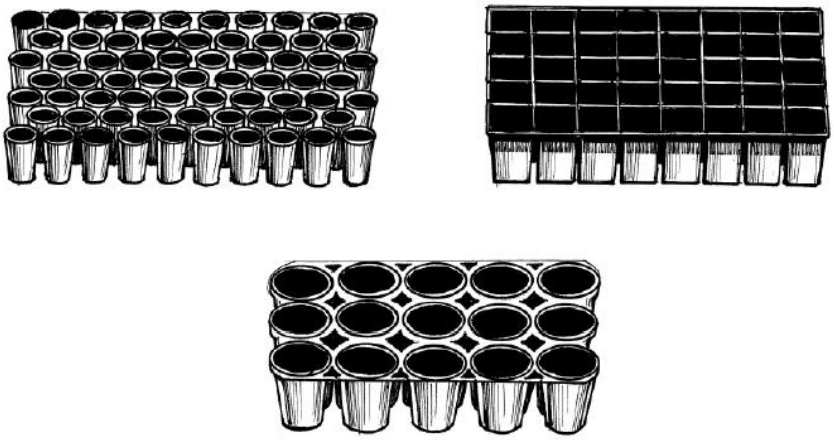
(d) Hardening bed

Source: Portrait of necessary structure were obtained from Gregorio et al. (2020)

Figure 11.2: Essential Nursery Structures to Grow Quality Seedlings

11.1.4 Plant Potting Facilities

Most swamp nurseries either produce bare-rooted seedlings or use polybags which often restrict the root growth resulting in weak plants. Nurseries should use containers with root trainers. A root trainer, root-training pot, or root pruning container is an aid to the cultivation of young plants and trees in nurseries. There are many different designs of pots that will train the roots (Figure 11.3).



Source: Gregorio et al. 2020 and 2021

Figure 11.3: Root-Training Pot Potting Mix

Root trainer potting mix should have topsoil plus drainage enhancers (e.g. sand, rice hulls) plus fertilizer.

12. Brief Summary Status of the Findings and Way Forward Recommendation

12.1 Nursery Specific Recommendation

The nursery sector has great significance for providing livelihood and reforestation success by providing access to high-quality planting stock of a wide variety of species and information on proper Site and species combination. However, with limited inputs both on financial and technical aspects, a package of support systems, as discussed above, is needed for the sustainability of these nurseries and to harness their potential for promoting the success of swamp nurseries in the *Haor* ecosystem of Bangladesh. With improved technical skills, nursery operators will eventually become valuable extension agents to disseminate knowledge on effective nursery management and match the species to the planting Site. Further, improving access to high-quality germplasm and the income derived from seedling production will help sustain smallholder nurseries' operations and continuously provide support services to a broader small-scale tree farmer community. This support includes seedling production and tree planting advice and a timely and sufficient quantity of high-quality planting stock of various species.

12.2 Cropping Pattern Specific Recommendation

Flash floods and heavy waves are major constrain for cultivation during monsoon in the *haor* homestead level areas. To reduce wave actions reforestation is a major need. The construction of a small dam and the use of proper fertilizer and insecticides are also recommended by the local stakeholder to improve crop production at the homestead level.

12.3 Swamp Plantation Design to Reduce Wave Action Impact

This study explores the effects of dominant swamp vegetation resistance capacity against flow velocity. To estimate plantation resistance against high flood flow "manning roughness coefficient (n)" was used. To calculate this, necessary field data was collected on various parameters such as roots, trunk systems, and spacing between trees. Manning's number calculation shows that there are no significant differences in resistance among Hijol (*B. acutangula*), Koroch (*P. pinnata*), and Pitali (*T. nudiflora*) regardless of vegetation density and water depth. In addition, Vetiver Grass (*V. nemoralis*) shows high resistance against water flow compared to other species observed in this study. This study suggests that the combination of Vetiver Grass with Hijol (*B. acutangula*), Koroch (*P. pinnata*), Pitali, or Borun will significantly reduce severe flow velocity. However, to make these preliminary findings more acceptable, it is recommended to develop a water-flow model or a water hydrodynamic model for proper planning and plantation design in terms of the reduction of flash flood vulnerabilities.

12.4 Suitable Site Selection for Plantation

Freshwater ecosystems support approximately 6 % of the estimated 1.8 million described species worldwide (Heino et al., 2009). However, the decline of swamp species is rapid and even exceeding that of tropical rainforests (Xenopoulos et al., 2005). This scenario is also true for the swamp ecosystem of Bangladesh. Especially, *Haor* ecosystem swamp vegetation is declining day by day. A recent Bangladesh Forest Inventory report shows that the total area of tree-dominated natural swamp forest is only 140 ha and the swamp planted area is only 628 ha which is significantly low (GoB, 2019). If this scenario continues, swamp forests and its related vegetation will be extinct in northwest Bangladesh soon. Therefore, it is urgent to document swamp vegetation adaptive capacity-related information such as where the species can grow in the landscape and their water tolerance characteristics. This will aid a better understanding of future reforestation programs. The present study findings show that 35 native swamp plant species are available in the study area, which is frequently available. These species were grouped into high, medium, and low water tolerance categories based on water stagnant duration and inundation depth. It is important to note that low water tolerance doesn't mean they are not suitable for plantations. Those species are, of course, suitable where water doesn't stay longer. The study also found that Hijol (*Barringtonia acutangula*), Koroch (*Pongamia pinnata*), Borun (*Crataeva magna*), Pitali (*Trewia nudiflora*) is widely used for ongoing reforestation programs though this is not sufficient. The habitat suitability model shows that more majority of the study area is highly suitable for Hijol, Koroch, Pitali, and Borun species. Based on the findings, the following recommendations are being proposed.

- Immediate reforestation/afforestation program using dominant swamp trees such as Hijol (*Barringtonia acutangula*), Koroch (*Pongamia pinnata*), and Pitali (*Trewia nudiflora*). The potential Sites that may be planted with these species are the kanda areas, submergible embankment edges in the floodplains, edges of the khas, roadsides, surrounding the homestead/settlement areas, settlement excavated canals and their banks. This will undoubtedly increase vegetation cover, which in turn will reduce wave action force.
- To reduce exploitation pressure on dominant swamp tree species (Hijol, Kororch, and Pitali) plantations, short rotation and economically important non-timber species such as Rattan (*Calamus tenuis*) and Murta (*Schumannianthus dichotoma*) should be encouraged for plantation program. Both species have huge demand in local cottage industries. It is important to note that Murta is high water-tolerant species, whereas Rattan is medium water tolerant. This indicates they have high water tolerance ability and can be planted in *Kanda*, shallow Sites and surrounding settlement areas.
- To reduce erosion and wave force in *haor* areas, mixed plantation using suggested tree species in section 1 together with Vetiver grass (*Vetiveria zizanioides*) can increase resilience against climate extremes. Vetiver is moderate water-tolerant species, so this species can be planted in shallow waterlogged areas, roadside and surrounding settlement/areas.

The sustainable management of the swamp flora demands a detailed understanding of species composition and spatial distribution patterns. Utilizing swamp vegetation resources while retaining the eco-hydrological characteristics of swamp flora mandates the preservation of the entire wetland ecosystem. Urgent action must be taken to develop a network of protected areas or reserve areas of representative wetlands to preserve the threatened swamp ecosystem. A management mechanism that ensures the participation of the local people to meet the needs of the local communities and broaden the resource base is essential for a successful reforestation program. Here, LGED should work closely with Bangladesh Forest Department.

12.5 Indicators and Contribution of Swamp Tree in Climate Resilience

In this Anthropocene, understanding the dynamics of ecosystems such as freshwater swamp forest is crucial for restoring a degraded ecosystem. In our rapidly changing world, “resilience” has gained wide popularity in forest management, but the implementation of the concept still lags because of a lack of ecosystem and Site-specific information. In this review, we reviewed one resilience attribute of the freshwater ecosystem. Improving our understanding of how certain swamp forest ecological attributes confer resilience will help practitioners develop best practices for successful restoration. By monitoring the response and recovery of such attributes, we can better understand which attributes contribute to ecological resilience to climate change.

Freshwater swamp forests are a key carbon sink and contribute to mitigating climate change worldwide. However, the conditions of the swamp forest, the present extent, and the degree of disturbance in forests are the factors on which their carbon storage potential depends. In this sense, freshwater swamp forest areas of Bangladesh have high potential carbon stock. However, if not designed and managed properly, it could become a source of greenhouse gases such as carbon dioxide because of its rapid degradation. At present, the total area of swamp forest is only 14,205 ha of the total country's forest area and the average tree density is 92 stem/ha (GoB, 2020). In the present study, the average tree density was 87.13 stem/ha, close to the national forest inventory. According to the national forest inventory, the average carbon stock in swamp forests is 122.2 t/ha which includes soil (GoB, 2020). In the present study, total carbon in trees was estimated at approximately 151 t/ha without soil which is comparatively higher. It is important to note that carbon storage in trees varies because of species diversity, stand age, size, and density (Wei et al., 2013; Mensah et al., 2016). This study also found that carbon storage varies with tree density and species-specific variation is prominent (Chapter 5: Table 5.2).

This study examined the swamp trees' carbon stock dynamics relationship and revealed that swamp tree density has a significant effect on carbon storage. The study further identified Koroch (*P. pinnata*), Hijol (*B. acutangular*) and Borun (*C. nurvala*) has a high potential for carbon storage in the freshwater swamp. Therefore, to increase resilience against climate change, these species can be selected for future large-scale plantations.

12.6 Ecosystem Functions and Resilience's Assessment Tool

RAWES approach of ecosystem service assessment is a qualitative approach that uses a set of questions against ES indicators. Even though this approach is not able to capture quantitative information; it is widely used for its rapid nature where resources are limited for quantitative assessment of ES. The ability of the field assessors in this study to conduct RAWES assessments indicates that the indicators and simple narratives provided had utility. The RAWES ecosystem service rapid assessment approach as indicators of swamp restoration outcome turned out to be an effective way to assess whether restoration is on the right track or not. This assessment technique found that most of the reforested Sites show good restoration outcomes except for a few Sites in terms of ecosystem services. Therefore, swamp forest restoration managers can take necessary steps to improve restoration outcomes from the remaining Sites. However, if funding and manpower are not an issue, the results should be checked with quantitative data which would make this rapid assessment tool more acceptable to the wider community.

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Appendix 1: Site wise Species Diversity Indices

Site	Shannon	Simpson
Site1	0.00	0.00
Site2	0.00	0.00
Site3	0.00	0.00
Site4	0.00	0.00
Site5	0.00	0.00
Site6	0.00	0.00
Site7	0.00	0.00
Site8	0.00	0.00
Site9	0.24	0.12
Site10	1.34	0.73
Site11	1.29	0.71
Site12	0.37	0.17
Site13	0.00	0.00
Site14	1.38	0.74
Site15	0.56	0.38
Site16	0.00	0.00
Site17	0.00	0.00
Site18	0.00	0.00
Site19	1.48	0.75
Site20	0.38	0.22
Site21	0.27	0.12
Site22	1.38	0.74
Site23	0.92	0.57
Site24	1.48	0.75
Site25	0.82	0.47
Site26	0.54	0.27
Site27	1.46	0.74
Site28	0.69	0.50

Appendix 2: Nursery Condition in Different Location of *Haor* Areas

Nursery Seedling on polybag at Habiganj

Nursery Seedling on polybag at one of the nursery at Brahmanbaria

Nursery condition in Brahmanbaria

Forest nursery condition in Brahmanbaria

Nursery condition in Sunamganj

Nursery condition in Sunamganj

Appendix 3: Homestead Level Crop Suitability Survey Locations Site Details

Location	Latitude	Longitude
Baskar Beel	24.95784	91.19958
Talka Beel (Joysree)	24.92392	91.06052
Nainda Beel, Sunamganj Sadar	24.97367	91.38392
Noyahalt, Jamalganj	24.99257	91.21614
Sultanpur, Shantigonj, South Sunamganj	24.94471	91.41193
Sorail, Baliazuria khal, B. Baria	24.04458	91.15277
Ghotghotia Nadi, Bishwomvarpur	25.09965	91.29588
Bogadubu Khal	24.55293	91.03177
Boiragimara, Sunamganj Sadar	25.00968	91.40218
Borokhal Beel, Sullah	24.715	91.2757
Chatol udaytara Beel, Shimulbak	24.94688	91.28679
Katiar khal, Habiganj	24.28848	91.24948
Jatichar Beel	24.82294	91.32656
Kasipur Liradigha Beel, Sullah	24.76611	91.18639
Khagail, Sunamganj Sadar	25.03872	91.42873
Lawranjani	24.87383	91.30806
Martain haor	24.01422	91.14528
Nali khal, Alinagar, Austagram	24.28278	91.06937
Chatirchar, Nikli haor, Kishoreganj	24.32413	90.93334
Kuri Beel, Itna	24.50647	91.12218
Bhati dhal, Dirai, Sunamganj	24.73220	91.38342
Gumai nadi	24.94393	90.75168
Kejaura village, Dirai, Sunamganj	24.84041	91.32877

Appendix 4: Homestead Crop Suitability FGDs

FGD at Jatichar Beel, Sunamganj

Homestaed at Jatichar Beel, Sunamganj

Chatol udaytara Beel

Kasipur Liradigha Beel, Sullah

Habiganj

Chatirchar, Nikli Haor, Kishoreganj

Appendix 5: KII with Officials

LGED office, Brahmanbaria

Forest official at Brahmanbaria

LGED office, Habiganj

Upazila Agriculture Department office, Kishoreganj

Department of Fisheries, Netrokona

Upazila LGED officer, Netrokona

LGED office at Sunamganj

Agriculture office at Sunamganj

At Jamalganj

Appendix 6. Swamp Trees Plantation Forest Situation

Road side plantation at Titas khal, B.Baria

Scattered Swamp plantation at Itna, Kishoreganj

A patch showing Swamp plantation at Chatir Char, Nikli, Kishoreganj

Scattered Swamp plantation at Chatir Char, Nikli, Kishoreganj

Scattered Swamp trees at Khadiar Beel, Itna, Kishoreganj

Road side plantation at Netrokona

Scattered Swamp trees at Lauran Jheel, Batipara, Sunamganj

Scattered Swamp trees at Matian Haor, Sunamganj

Scattered Swamp trees at Matian Haor, Sunamganj

Scattered Swamp trees at Chatol Udaytara Beel, Sunamganj

Liradigha, Sullah, Sunamganj

Bhadikara Khal, Habiganj

Appendix 7: HILIP Officials KII Status

Respondents	Subject/Matters	Responds/Suggestion
Mr. Gopal Chandra Sarker *Project Director,* *Haor* Infrastructure & Livelihood Improvement Project (HILIP), Local Government Engineering Department (LGED)	1. Swamp Vegetation (SV) influence on *haor* ecosystem resilience 2. Swamp vegetation influence on wave action reduction	○ Swamp forest basically means Hijol and Koroch. Other includes Kadamba and Borun and others; ○ Hijol and Koroch naturally flourish in the *Haor* area; ○ Hijol tree buckle provides food for the fish in the *haor* area and also make habitat for the fish; ○ Community based social forestry and swamp vegetation scheme is very rare in the *haor* area; ○ Homestead vegetation increased too much in the *haor* area compared the past time which indicates the interest of the *haor* community for the plantation to get services and reduce vulnerability like cyclone and house protection; ○ People also use Hijol for shelter during any natural calamity especially farmers and fishermen; ○ Mainly Hijol and Koroch reduce some sort of wave actions as there are no other tall plant vegetation in the *haor* areas;
	3. Swamp vegetation influence on fish abundance in the reforested site	○ Swamp vegetation provides habitat for fish resources; ○ Support partial food sources; ○ Last season (2020-2021), there was not too much fish production in the *haor* areas. Due to embankment and less freshwater inflow during May to July, the rate of breeding and spawning was very low. ○ Height of submersible embankment has been raised compare to past times therefore the *haors* become segmented soon enough meaning the open water is found only for 2-3 months now a day;
	4. Swamp vegetation influence on infrastructural damage reduction	○ Swamp forest barricade should be a continued one, otherwise it cannot protect the embankments and other infrastructures; ○ The swamp vegetation plantation should be along the stream particularly in the deep *haor*; ○ Plantation can be made on the bank side which can help to reduce the damage; ○ Deforestation at the upstream areas might be another reason for carrying huge sediments in the downstream and sediment the *Haor* areas;
	5. Short rotation crops can be introduced in homestead areas	○ Short rotation crops can be very helpful for the *haor* communities. But the homestead space is very rare in the wet season. Some villages can be supported where protection is ensured by the LGED; ○ Crop diversification is the only option for improve the vegetation production in the *haor* areas; For instance, some villagers grow cauliflower, beans, green vegetables, tomatoes, and other winter vegetables; ○ Recently, people are interested in wheat production in *haor* areas as this crop has high survival capacity; ○ Short rotation crops with the crop diversification scheme could be a great option in the *haor* areas;

Respondents	Subject/Matters	Responds/Suggestion
	6. Recommended Swamp vegetation for plantation in roadside, kanda, perennial water bodies, homestead and other places	○ Koroch, Hijol, Kadamba, Borun etc.; ○ Need research findings;
	7. Nursery situation in terms of financial return and creation of employment opportunities	○ Generally, nursery can be a profitable business; ○ Species composition in the nursery should be considered respecting demands by the *haor* community. Otherwise, nursery development will not be sustainable in the *haor* areas; In addition, selected swamp vegetation and its importance and uses should be shared with the local community to increase the interest in plantation those;
	8. Seedling performance (species specific growth and mortality rate) in the nursery and plantation sites of LGED	Seedling performance must be increased.
	9. Initiative taken to improve source of Germplasm by LGED	○ Assessment of swamp forests and its vegetation composition in the *haor* areas; ○ Preservation and protection of the existing swamp vegetation along with the findings of responsible line agencies or stakeholders/NGOs/communities
	Recommendation	○ Social forestry like strip plantation could be a good option for the *haor* areas (terrestrial part); ○ Evaluation of species wise economic benefit of swamp vegetation; ○ Introduction of crop diversification is a must; ○ Enhancing resources specific awareness to the *haor* communities; ○ *Haor* and Wetland Development Board should work on the policy development and coordination of the *haor* management line agencies and stakeholders;

Respondent Name & Designation	Subjects/matters	Response/Suggestion
Mr. Md. Zakir Hossain *Mid-Level Livelihood Specialist,* *Haor* Infrastructure & Livelihood Improvement Project (HILIP), Local Government Engineering Department (LGED)	1. Swamp vegetation influence on *haor* ecosystem resilience	o Mainly Hizol, Koroch, Pitali, Dholkolmi can increase resilience as well as the fish habitat especially in deep *haor*; o Bird rusting and roasting places; o Leaves for fish ingredients;
	2. Swamp vegetation influence on wave action reduction	Koroch, Dholkolmi, Binnah Ghash is reducing wave action;
	3. Short rotation crops can be introduced in homestead areas	o Wet season vegetation: Pumpkin (Misty-Kumra); o Dry season vegetation: Bottle gourd (Lau), Tomato, Brinjal (Begun), Cauliflower (Fulcopy), Cabbage (Badha copy), Cucumber (Shosha), Balsam (Corolla), Sponge gourd (Jhinge), Snake-gourd (Chichinga), Arum-lobe (Latiraj Konchu);
	4. Recommended swamp vegetation for plantation in roadside, kanda, perennial water bodies, homestead and other places	o **Roadside/Kanda:** Hizol, Konchu, Kodom, Boroi, Pitali; o **Perennial water body:** Floating vegetables like Lal-Kolmi;
	5. Nursery situation in terms of financial return and creation of employment opportunities	**1. Recommendation for increase financial return:** o Proper training on swamp/*haor* vegetation species; o Species wise manual development and provide to the nursery owners; o Quality seed collection and increase availability; o Social networking and linkage; **2. Recommendation for employment opportunities:** o Awareness for benefits; o Increasing employment opportunities; o Creation of demand for plantation that will assist to increase the employment opportunities;
	6. Seeding performance (species specific growth and mortality rate) in the nursery and plantation sites of LGED	o **Success rate:** Around 80% of success rate; o **Mortality rate:** Well nursed site: 15-20%, Lack of proper nursing: 40-50%;
	7. Initiatives taken to improve sources of Germplasm by LGED	Must need germplasm and swamp vegetation improvement;

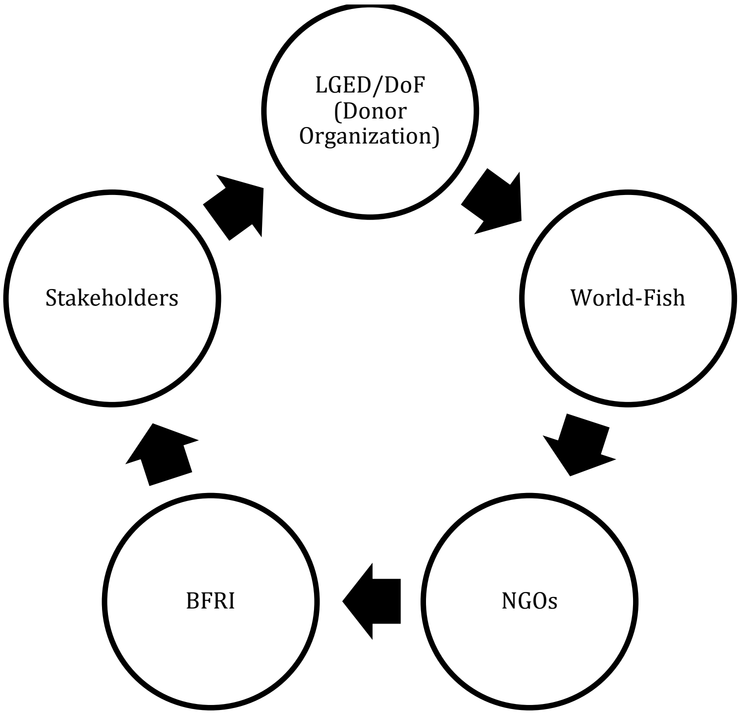


Figure 1: Recommended Fish Germplasm Improvement Framework

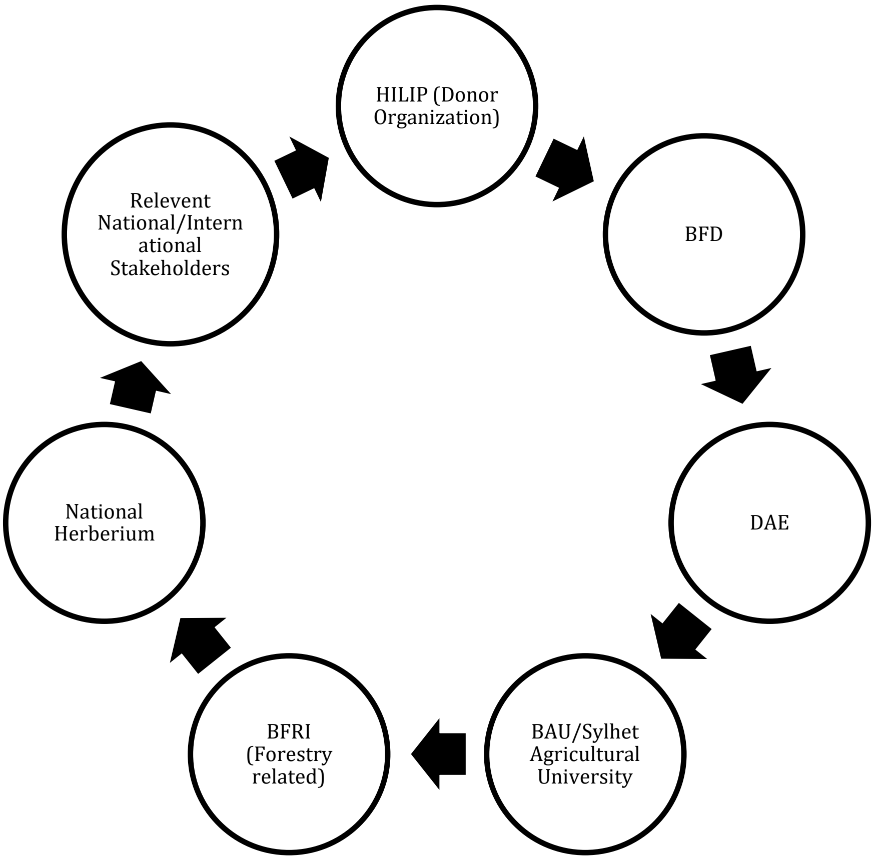


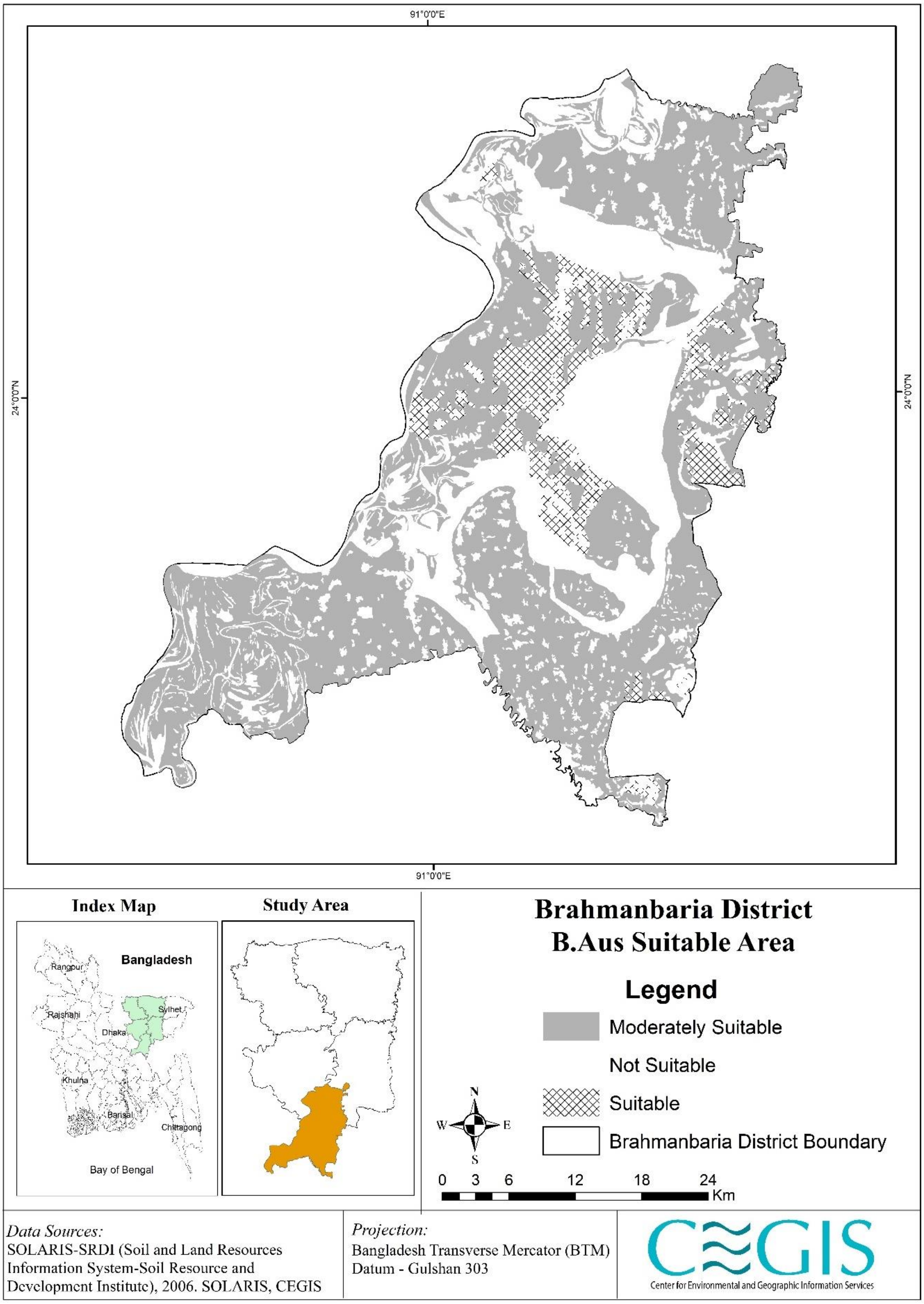
Figure 2: Recommended Swamp Vegetation Improvement Framework

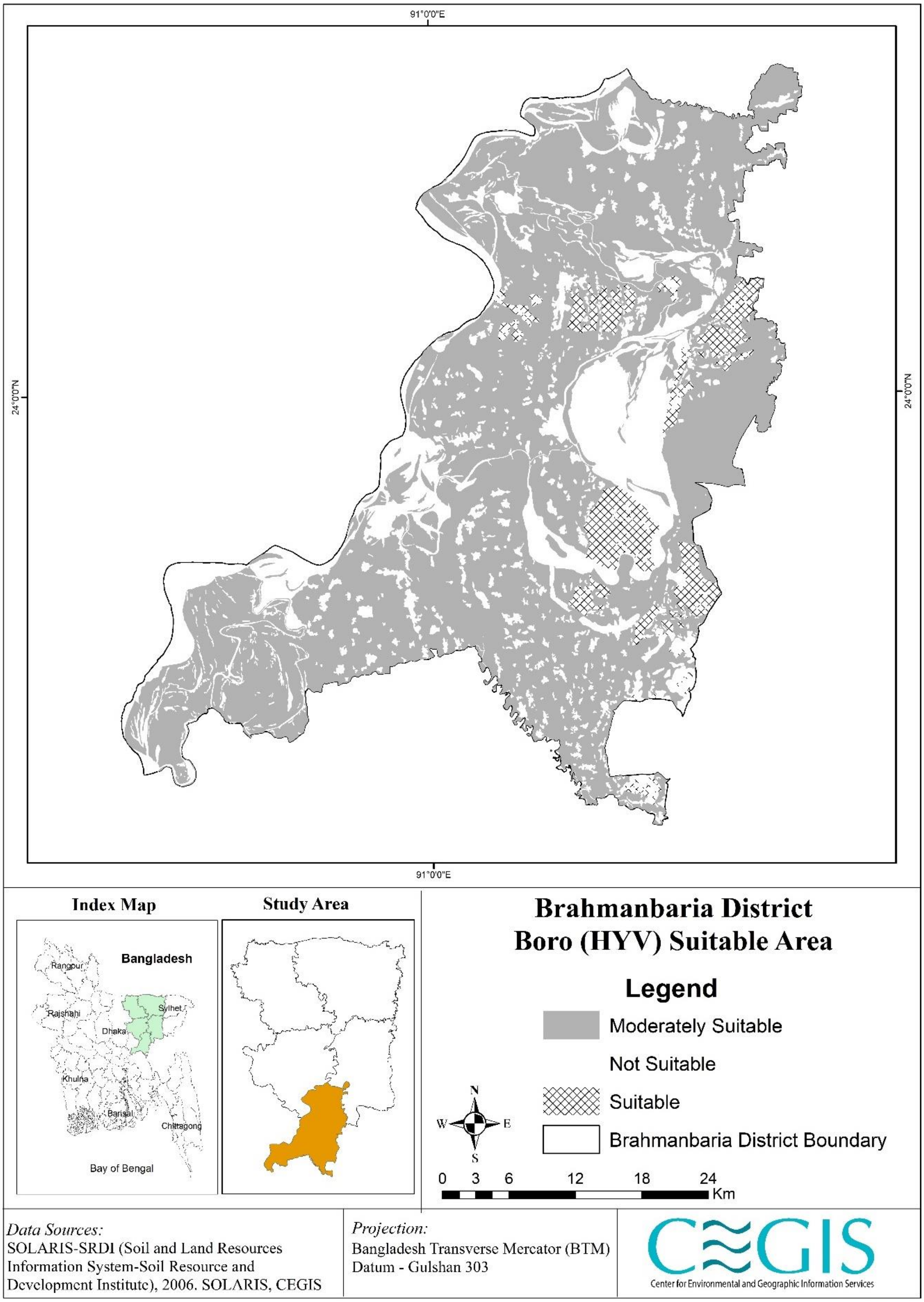
Respondents	Subject/Matters	Responds/Suggestion
Mr. A.K.M. Salah Uddin *Livelihood and Training Specialist* *Haor* Infrastructure & Livelihood Improvement Project. Local Government Engineering Department (LGED)	1. Swamp Vegetation (SV) influence on *haor* ecosystem resilience 2. Swamp vegetation influence on wave action reduction	○ Swamp tree is very much important in respect to the protection of land, embankment, from flood, and soil; ○ Carry nutrients i.e., micro nutrients particularly; ○ Kanda protection;
	3. Swamp vegetation influence on fish abundance in the reforested site	○ Help in habitat formation; ○ Create safe zone for fish where they can breed;
	4. Swamp vegetation influence on infrastructural damage reduction	○ Protect land and therefore its infrastructures; ○ Reduce repairing cost;
	5. Short rotation crops can be introduced in homestead areas	○ It is very important issue and has a great importance; ○ **Short rotation vegetation:** Lal shak, Pui shak and others; ○ **Short rotation crop:** Lentil type, floating crops (e.g., Kochu, Kolmi shak, Helancha) for wet season, floating gardening; ○ Dry season cropping intensity increases in the *haor* areas;
	6. Recommended swamp vegetation for plantation in roadside, kanda, perennial water bodies, homestead and other places	○ **Road side**: Binna, Vetiver; ○ **Perennial Water Body:** Hijal, Koromcha; ○ **Homestead:** Vegetables, fruits especially short duration crops/vegetable;
	7. Nursery situation in terms of financial return and creation of employment opportunities	○ Financial Return: One lack benefits (monthly 10, 000) from 1-acre nursery; ○ Employment opportunity: Number of people engaged per nursery; ○ Demand should be “Add in the report”: Marketing source of swamp vegetation; ○ Vegetation from the nursery;
	8. Seedling performance (species specific growth and mortality rate) in the nursery and plantation sites of LGED	○ *Haor*/Roadside plantation – mortality rate in the plantation site is high due to lack of management. 10-20% in general but for swamp tree it is more due to lack of management. ○ Livestock grassing; ○ Illegal harvesting at the plantation site;
	9. Initiative taken to improve source of Germplasm by LGED	It would be a great idea: The following organization can be involved- ○ FoD ○ DAE ○ BAU ○ Sylhet Agricultural University
	Recommendation	○ Ecosystem resilience-based ecosystem support for *haor* ecosystems and the community; ○ Swamp vegetation improvement;

Respondents	Subject/Matters	Responds/Suggestion
		○ Need to reduce livelihood dependency on *Haor* resources; ○ Need a *haor* monitoring of all the developed plan for *haor*; ○ People awareness on *haor* ecosystem services; ○ Harvest best practices and inform policy makers; ○ Involve community during development of *haor* livelihood of ecosystem; ○ Sanctuaries/ protected zones for fisheries resources conservation;

Appendix 8: District Wise Crop Suitability

Brahmanbaria

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Boro (HYV) Suitable Area
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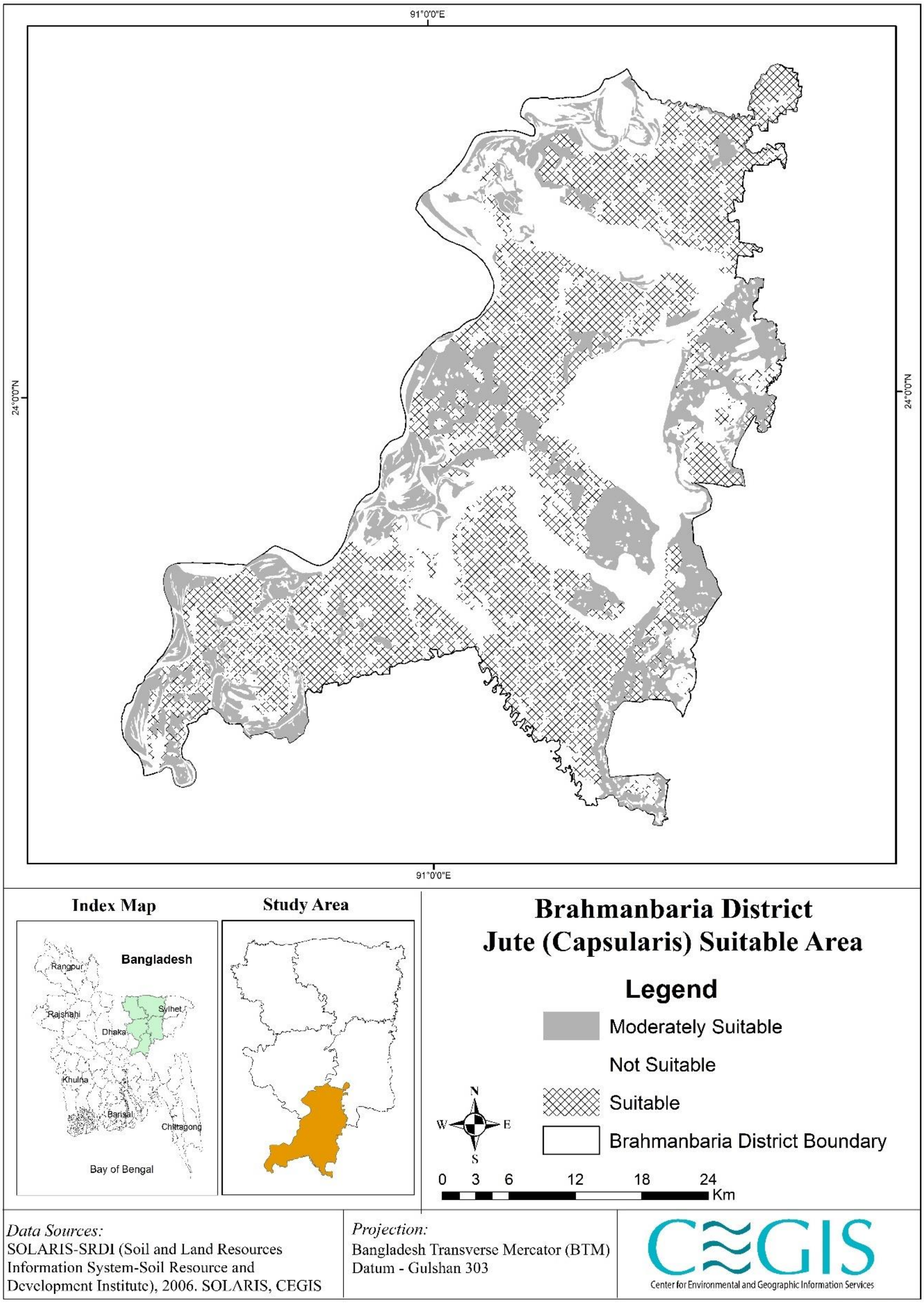
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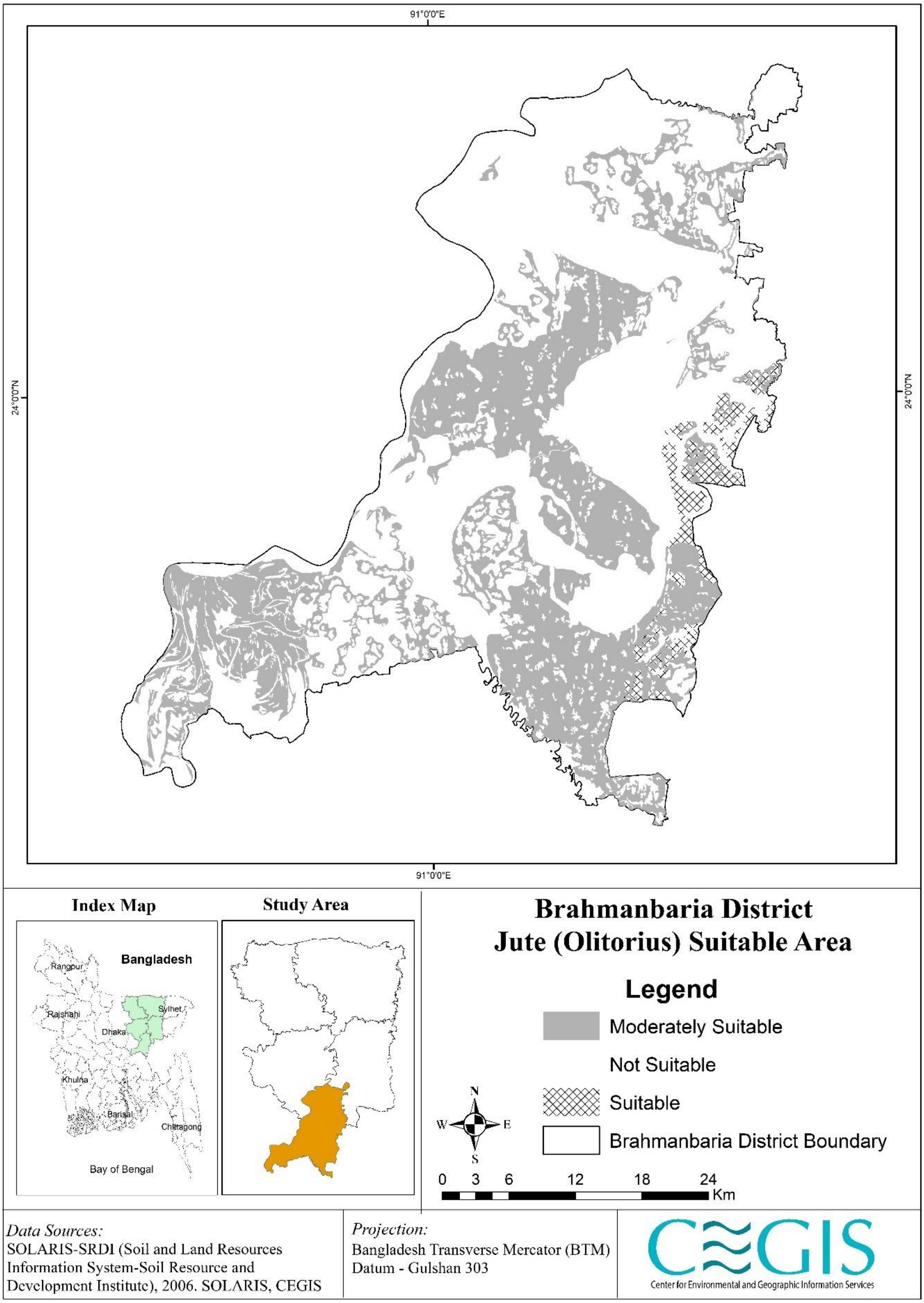
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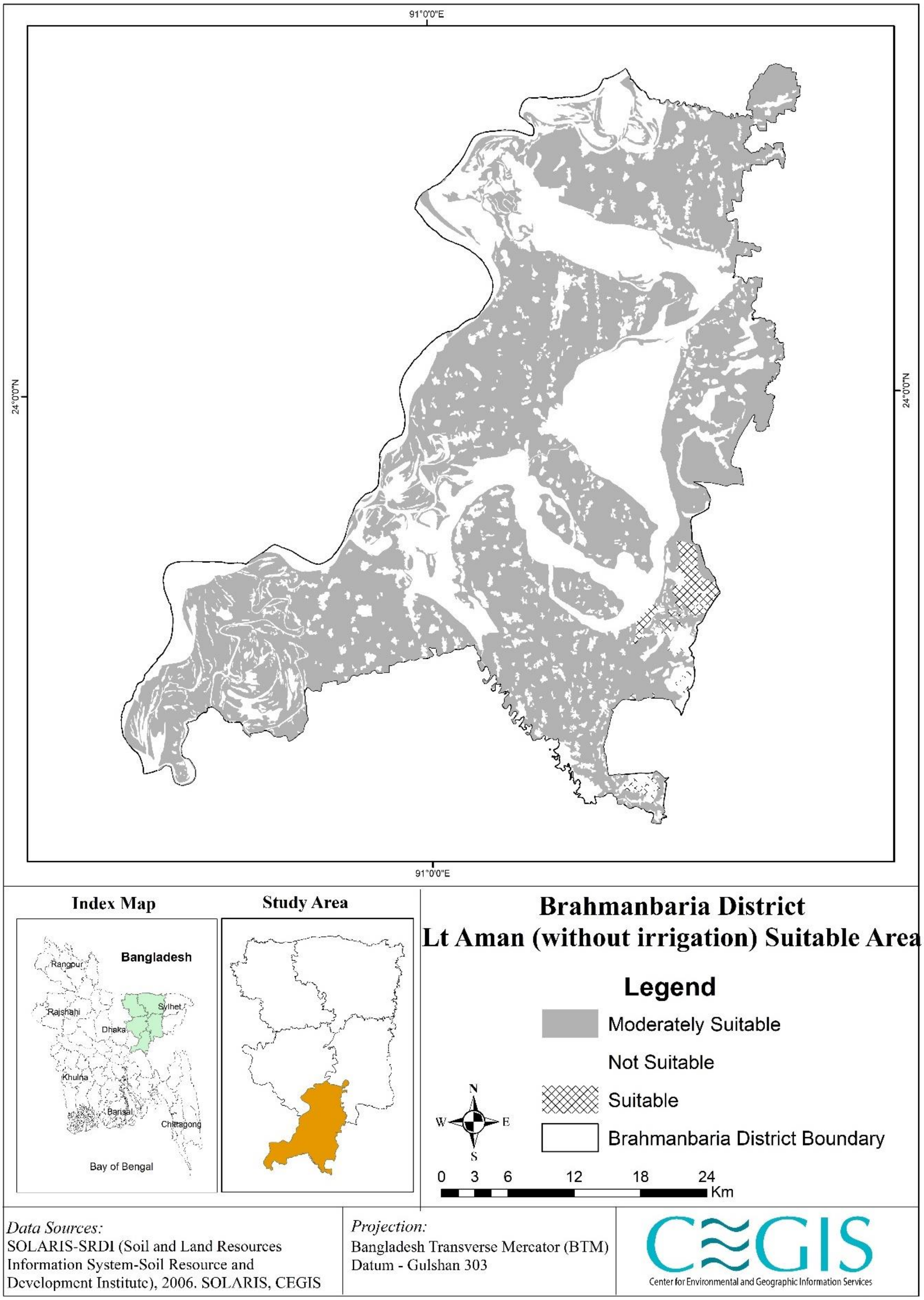
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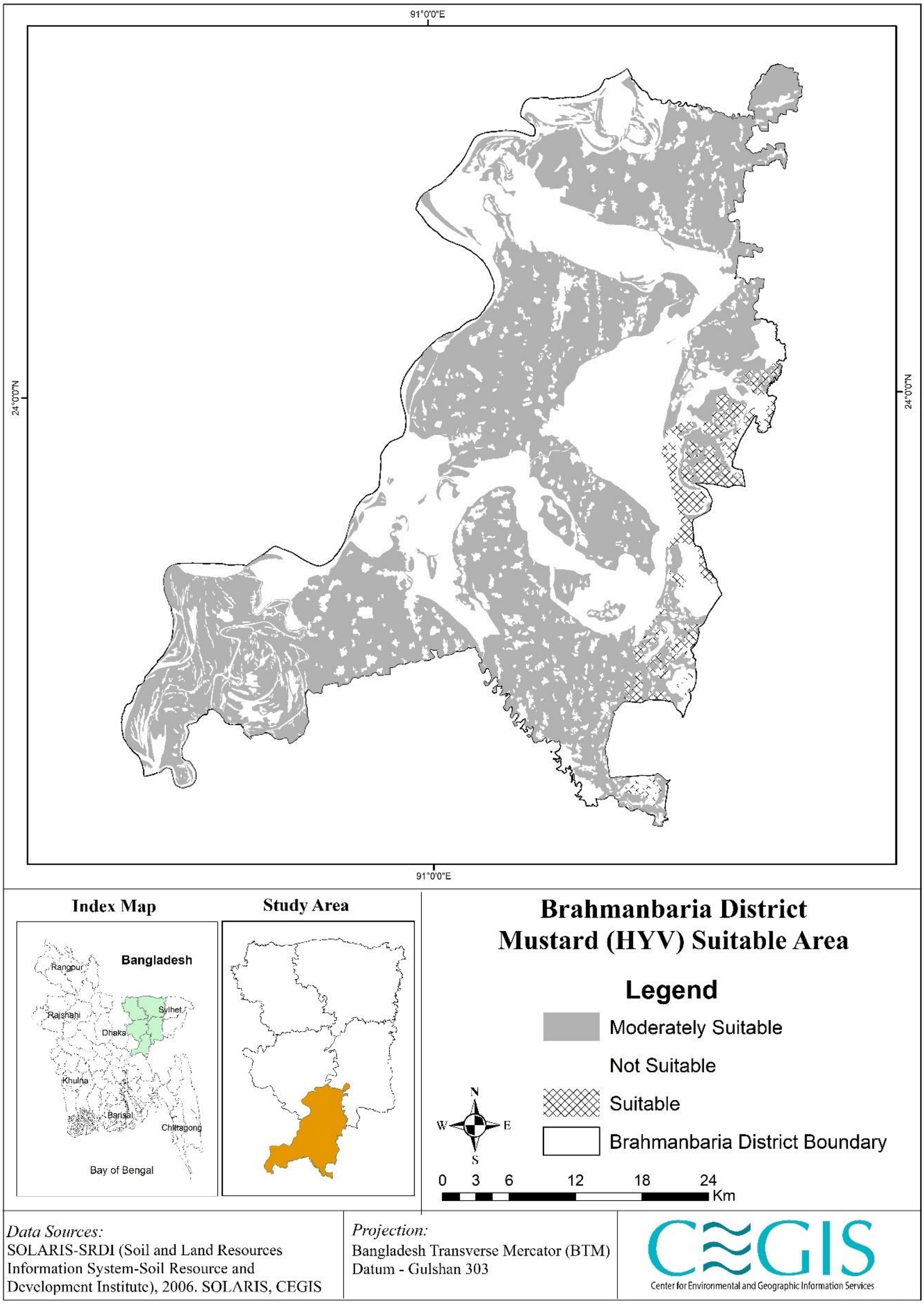
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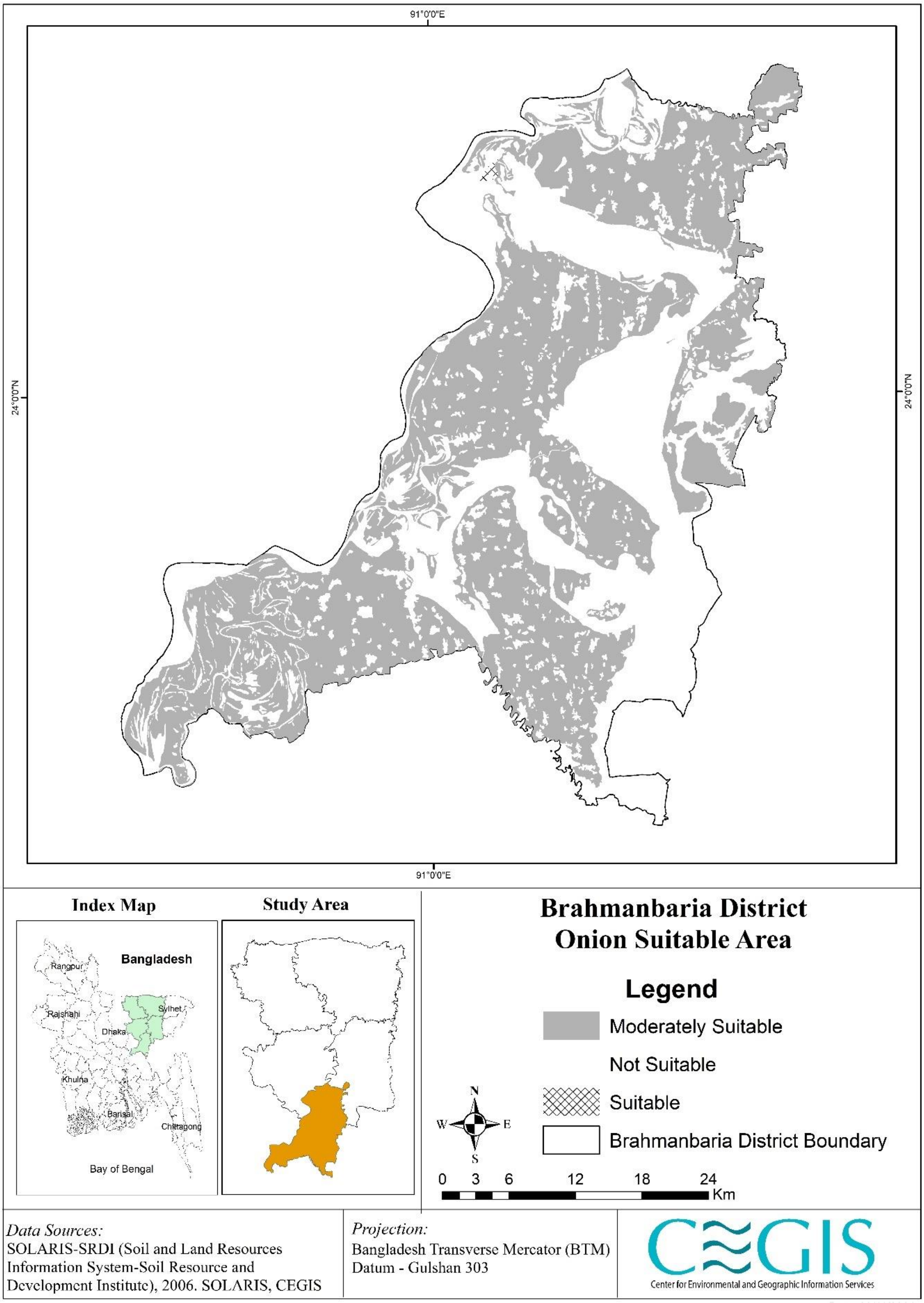
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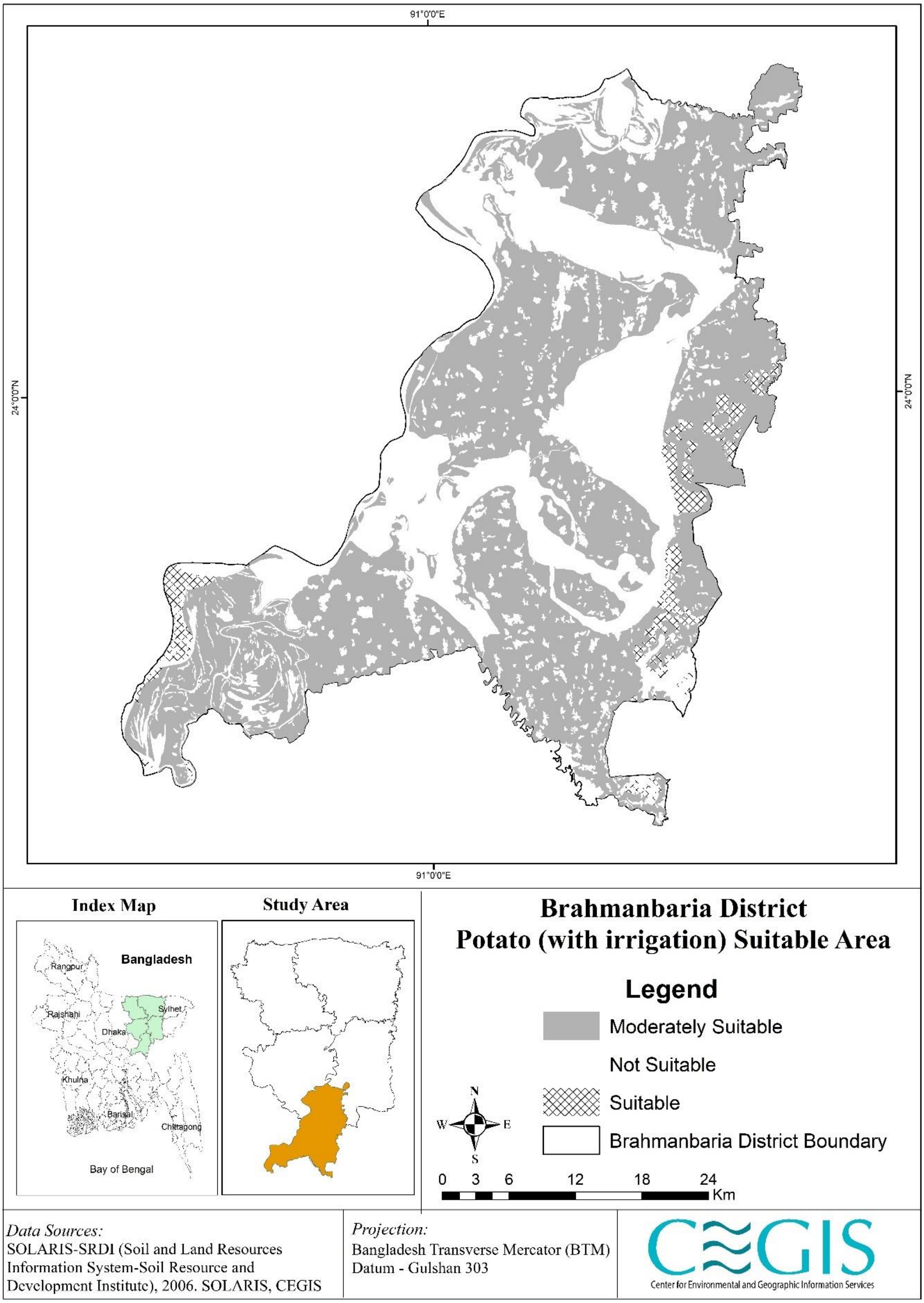
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Bay of Bengal
Brahmanbaria District
Potato (with irrigation) Suitable Area
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Data Sources:
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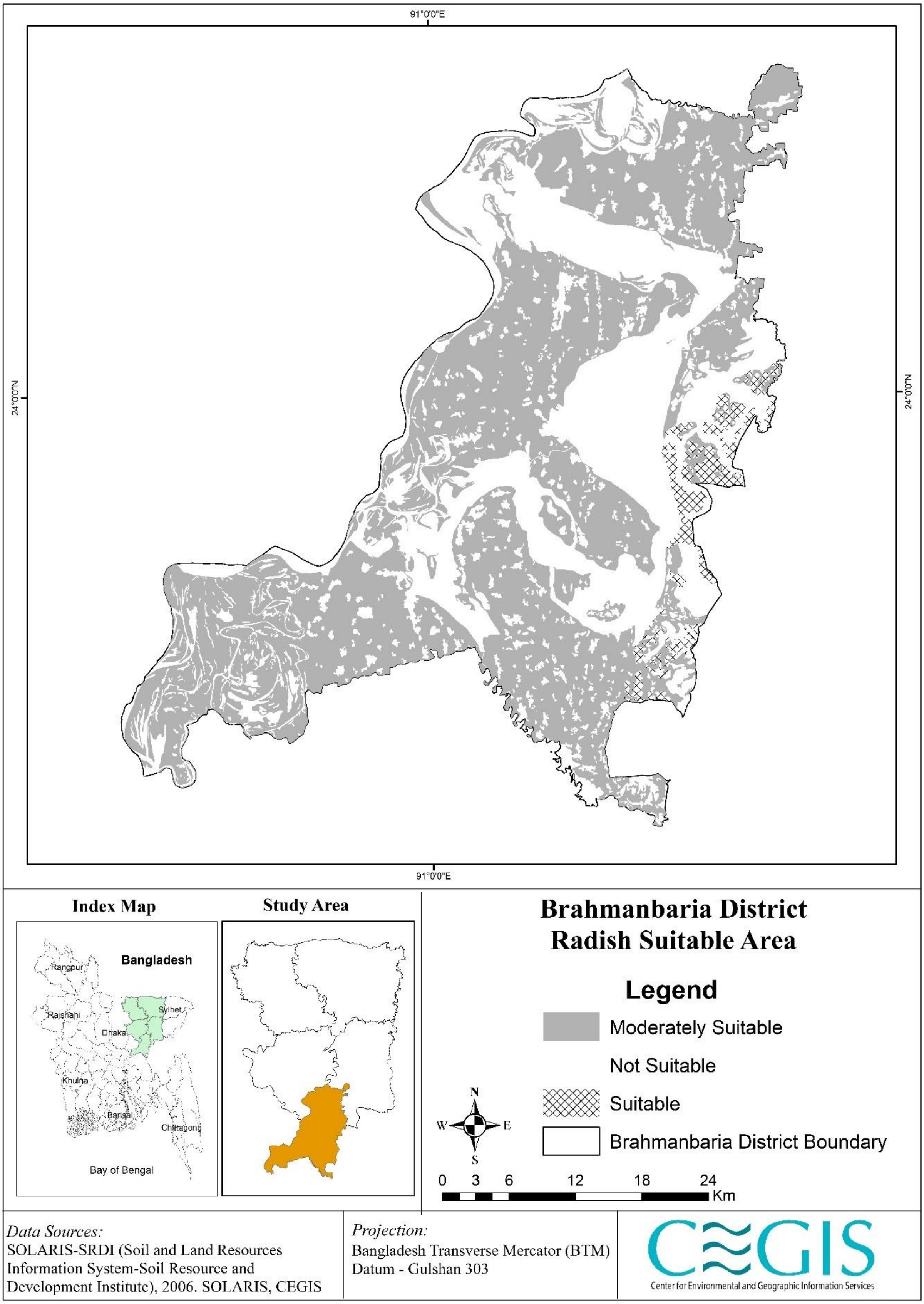
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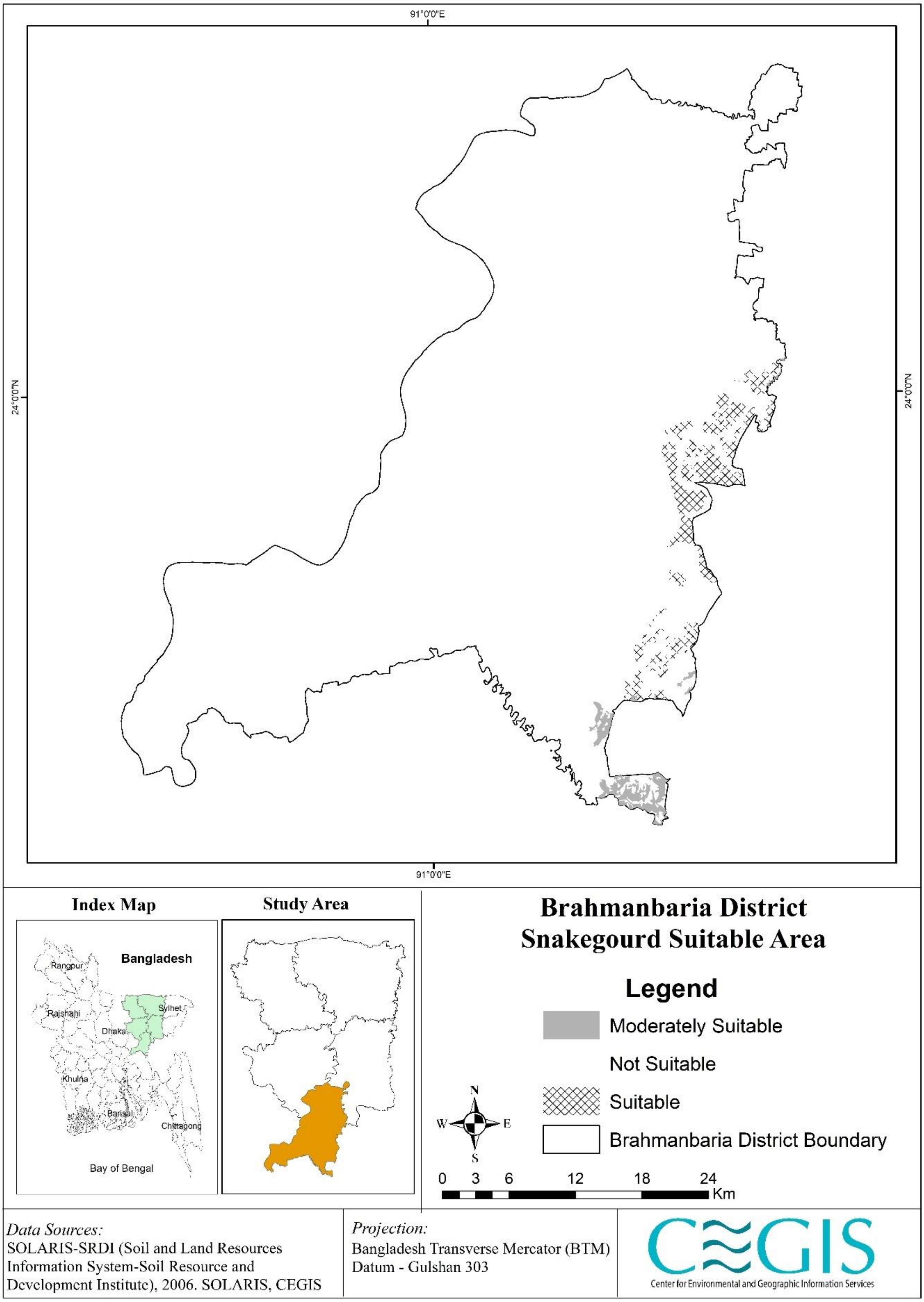

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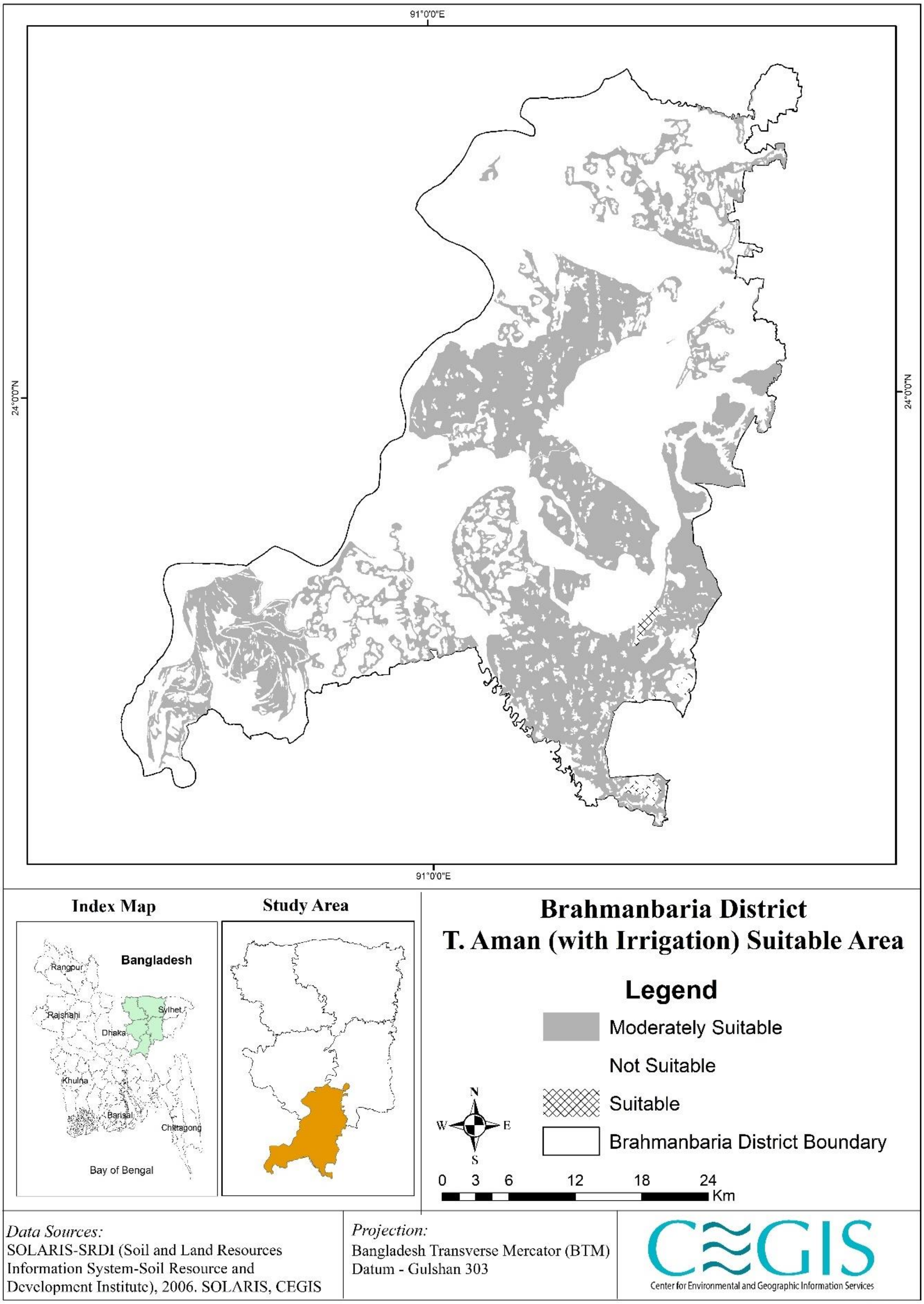

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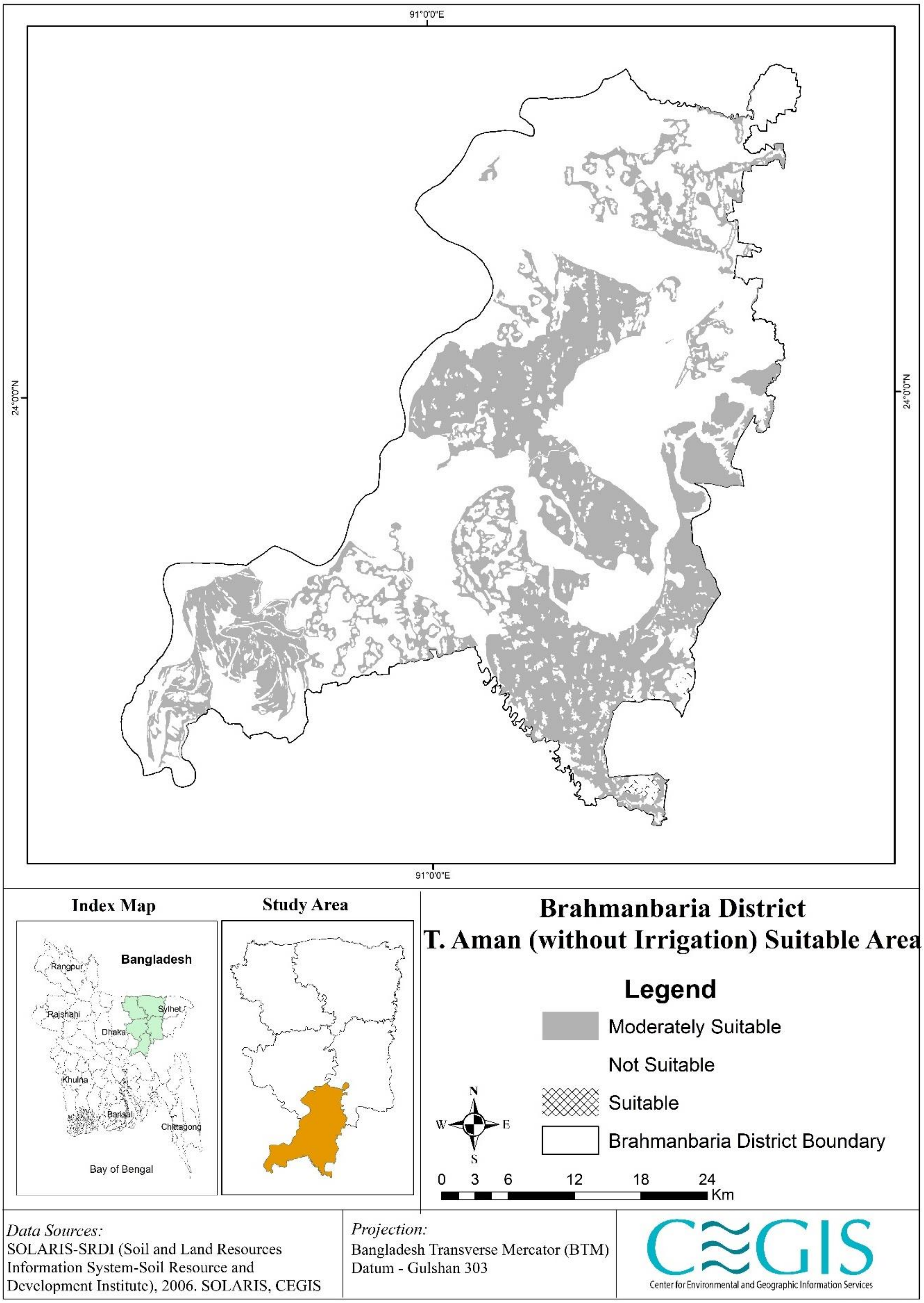
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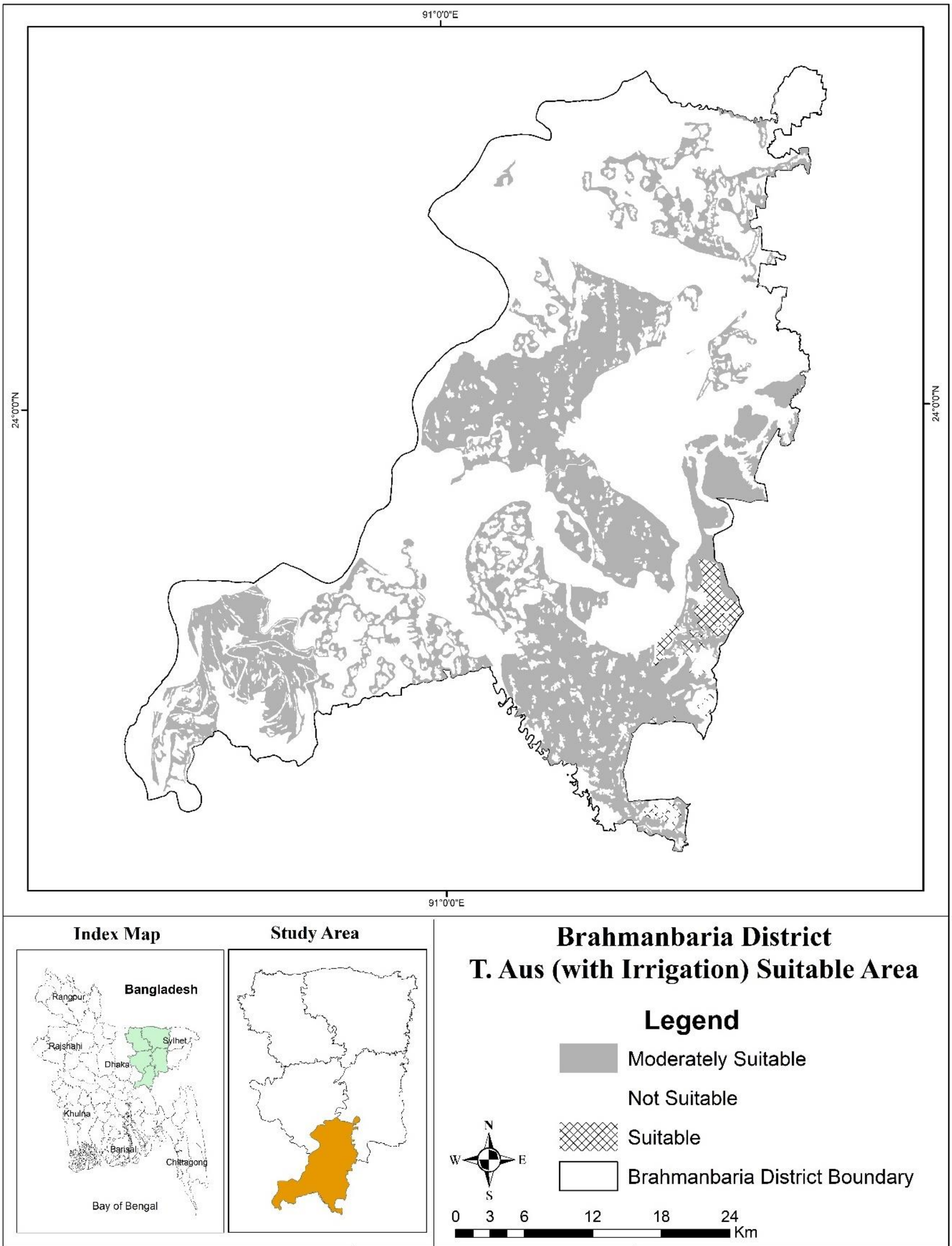

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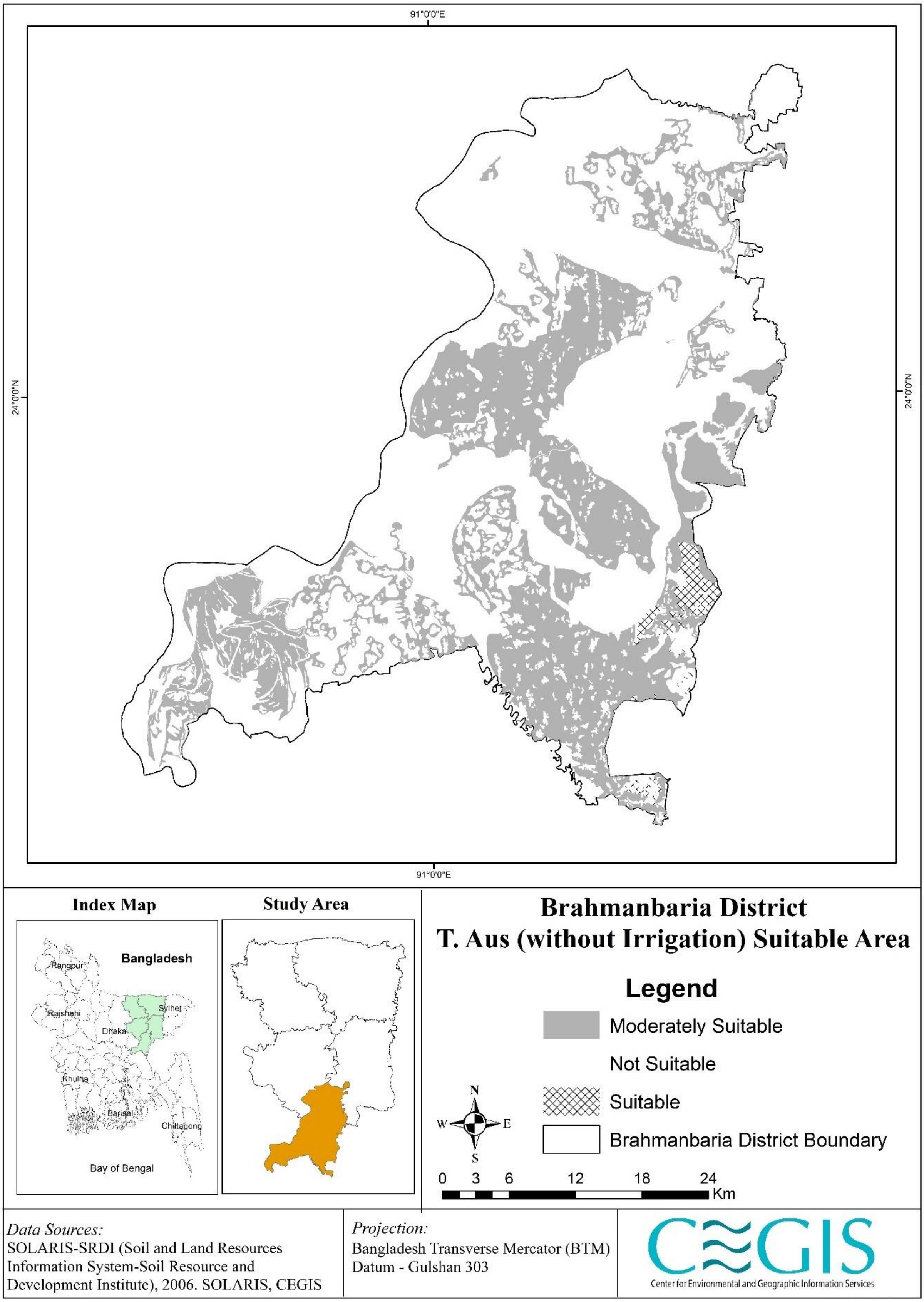
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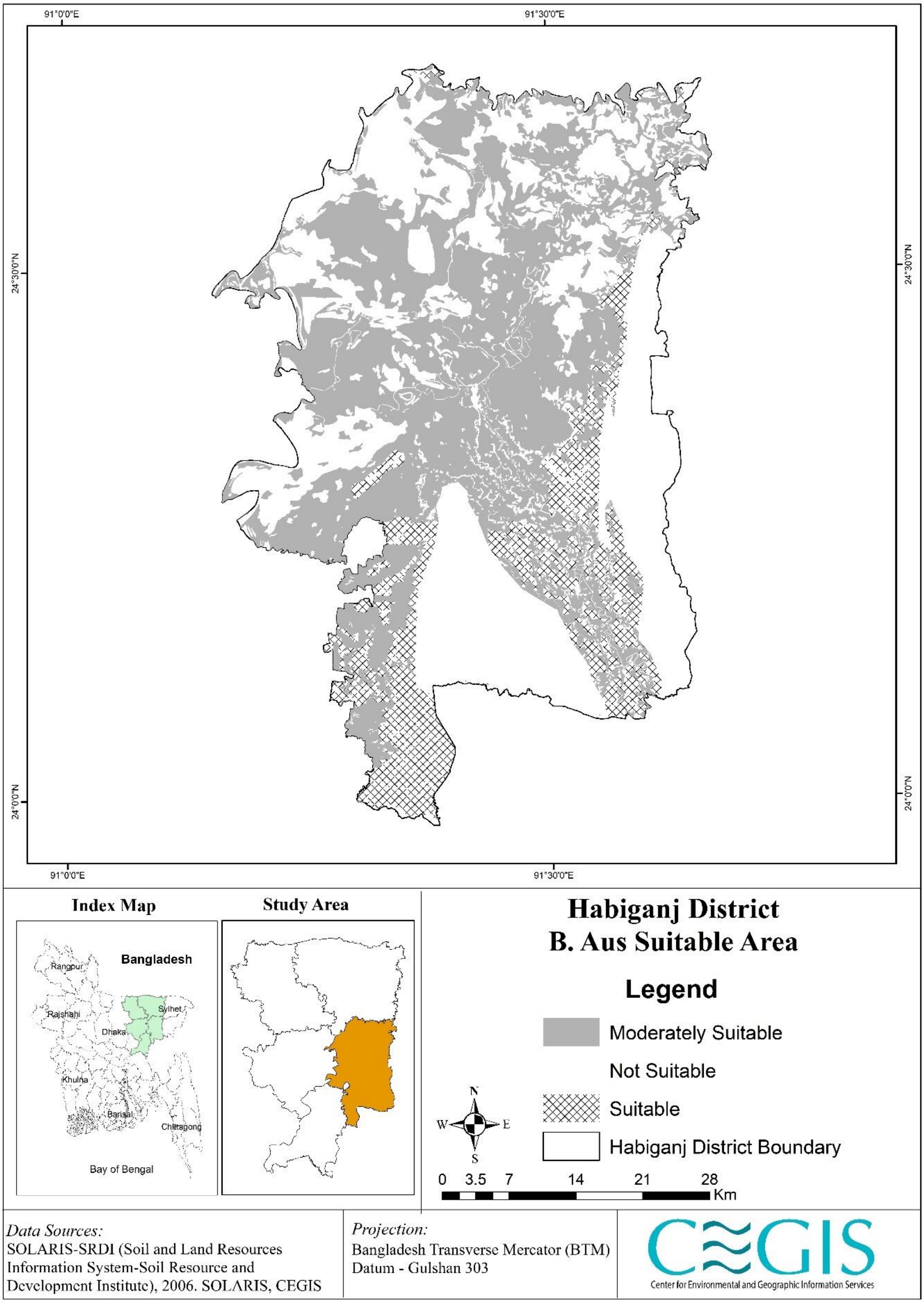
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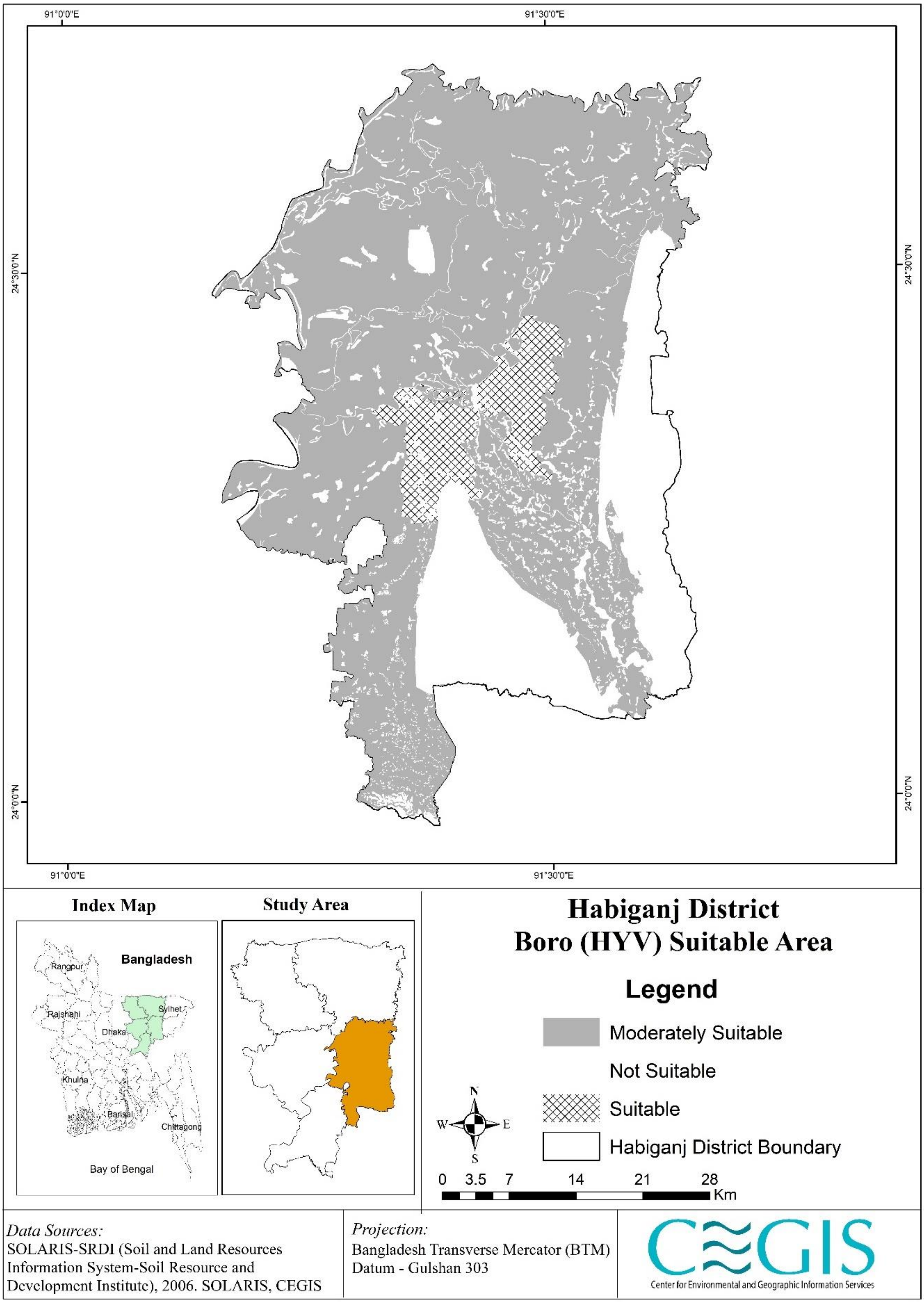
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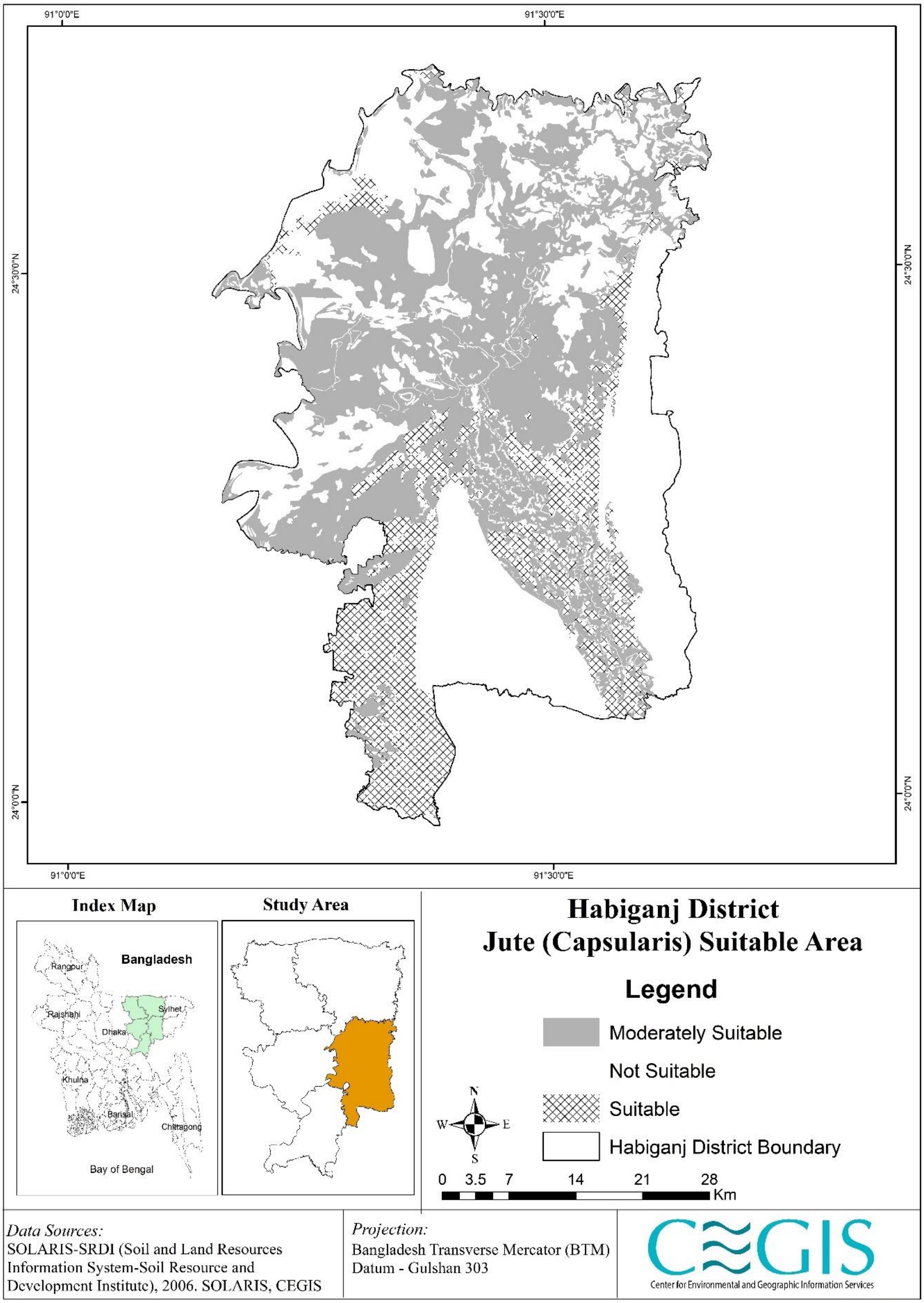
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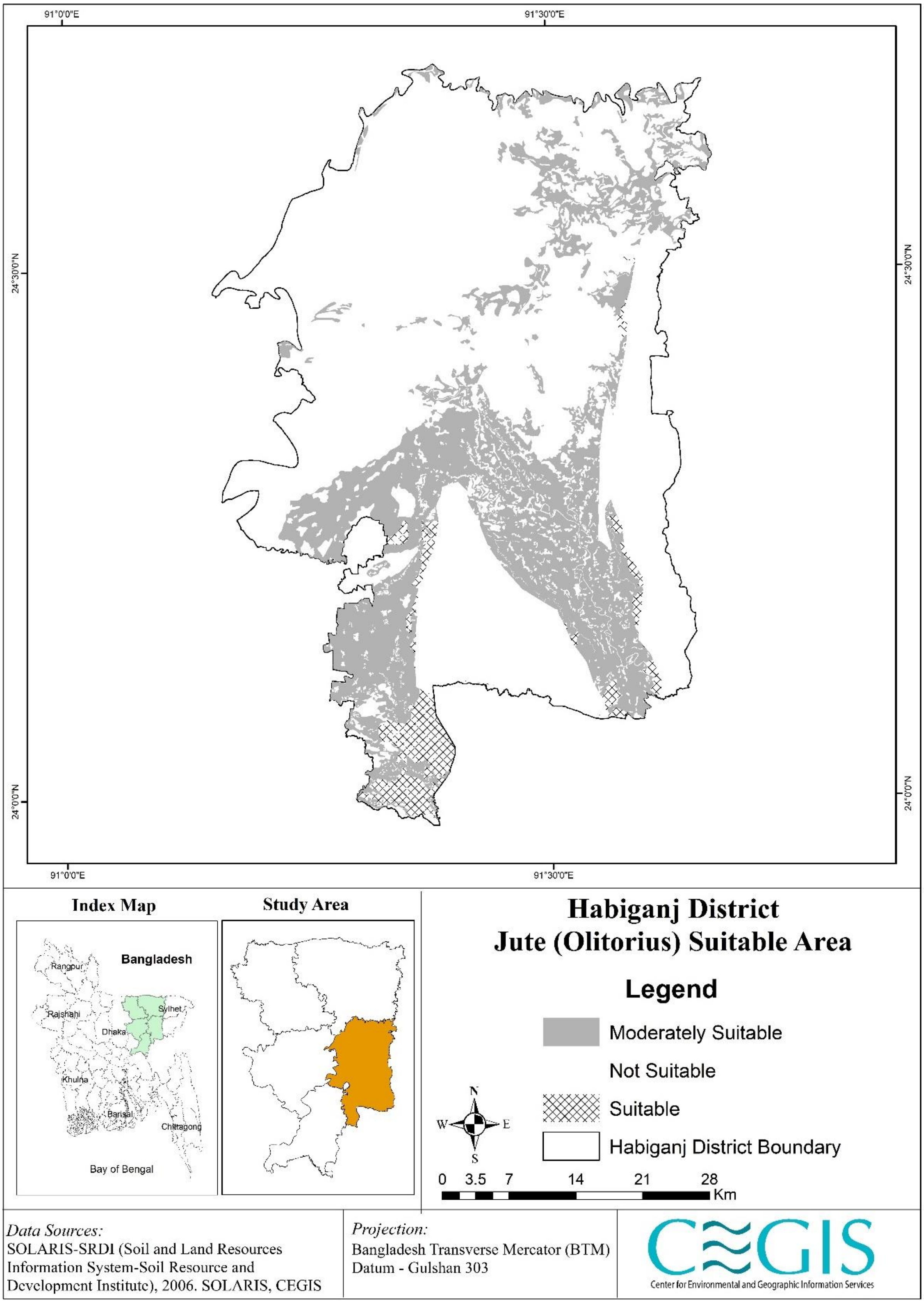
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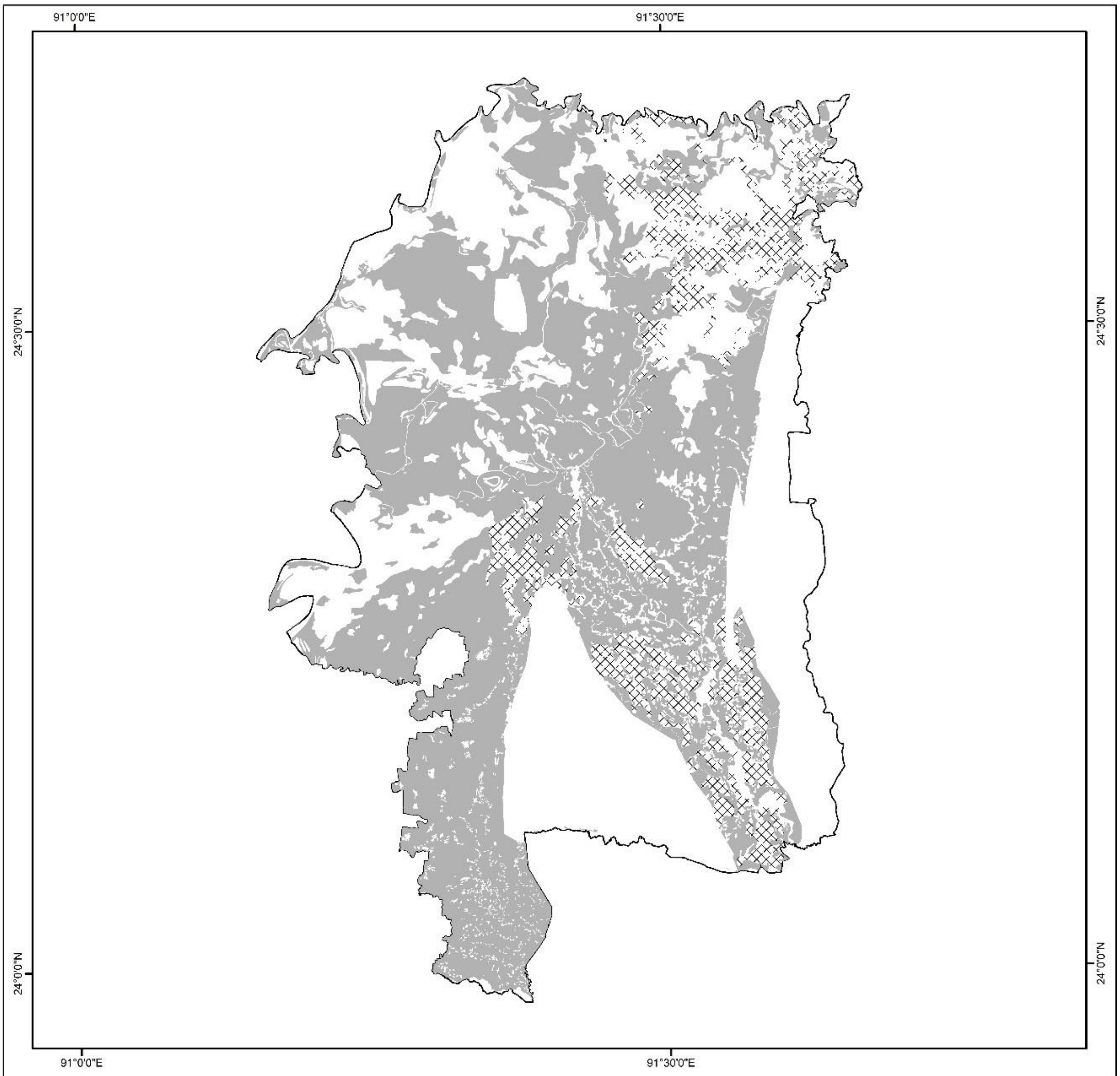

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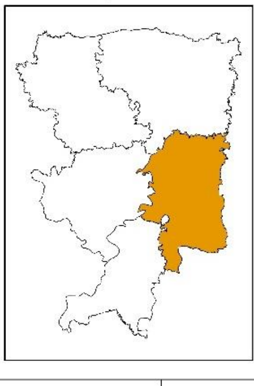

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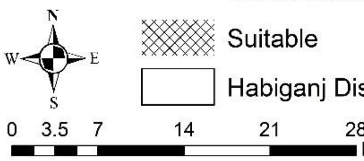

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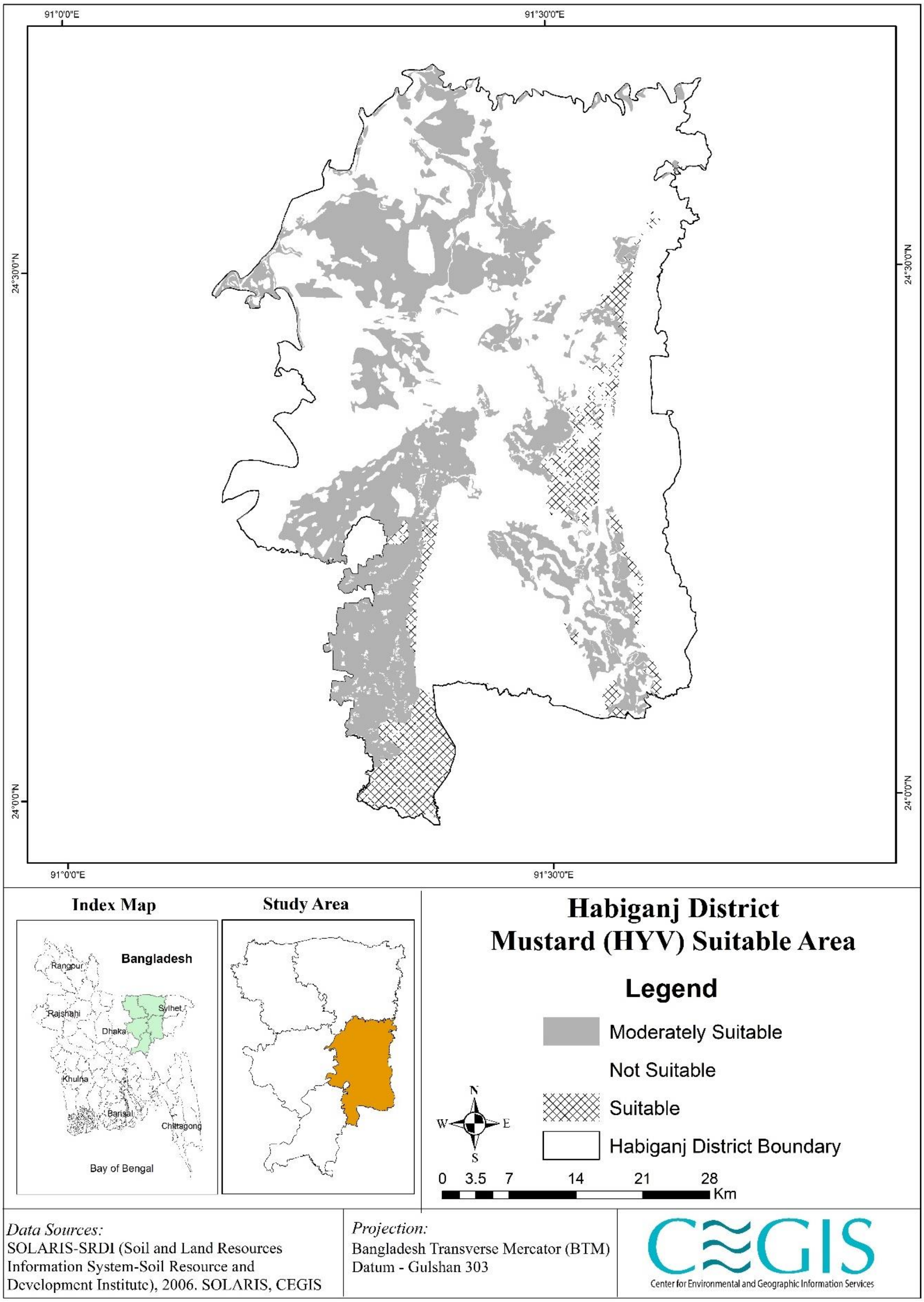
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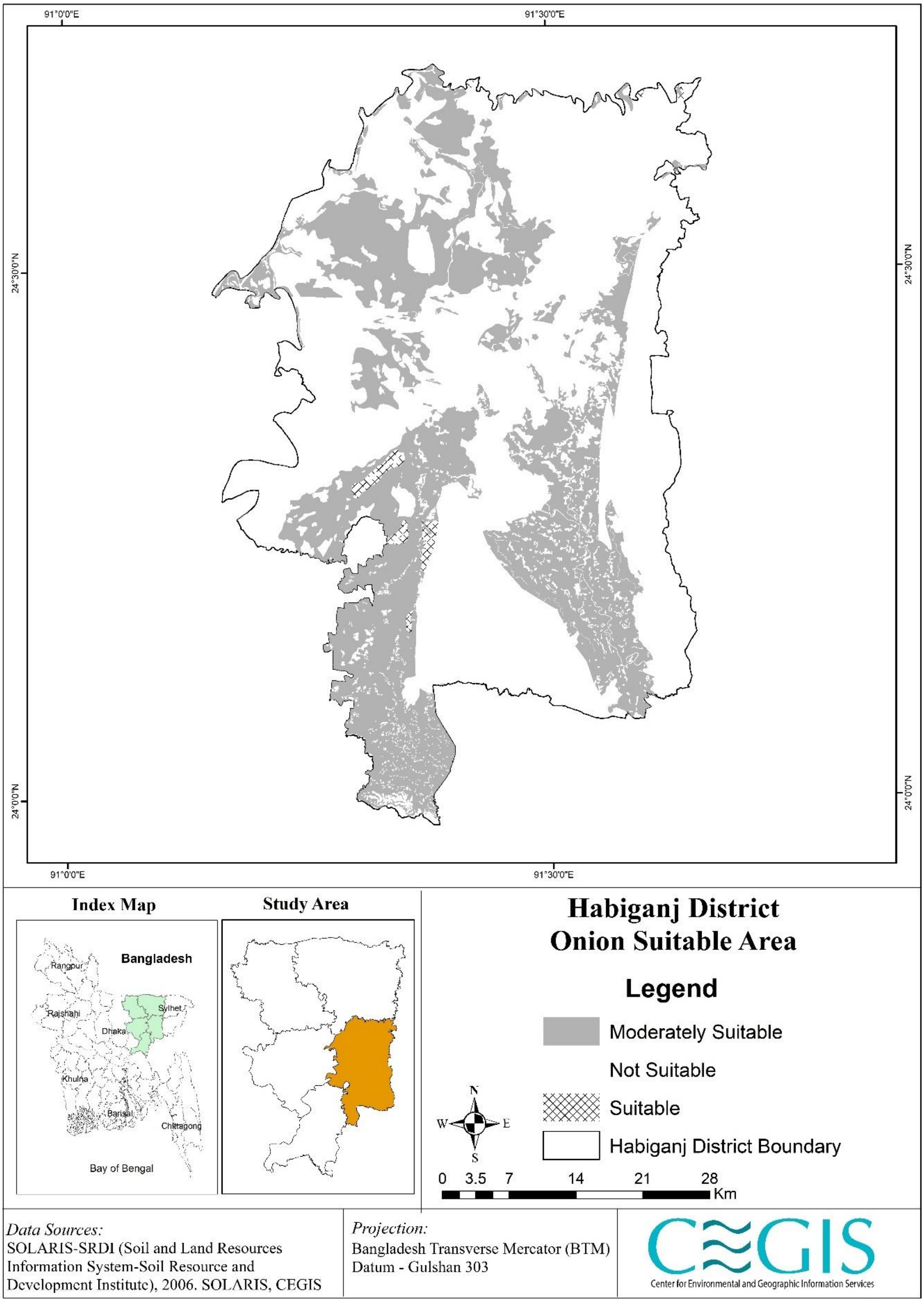
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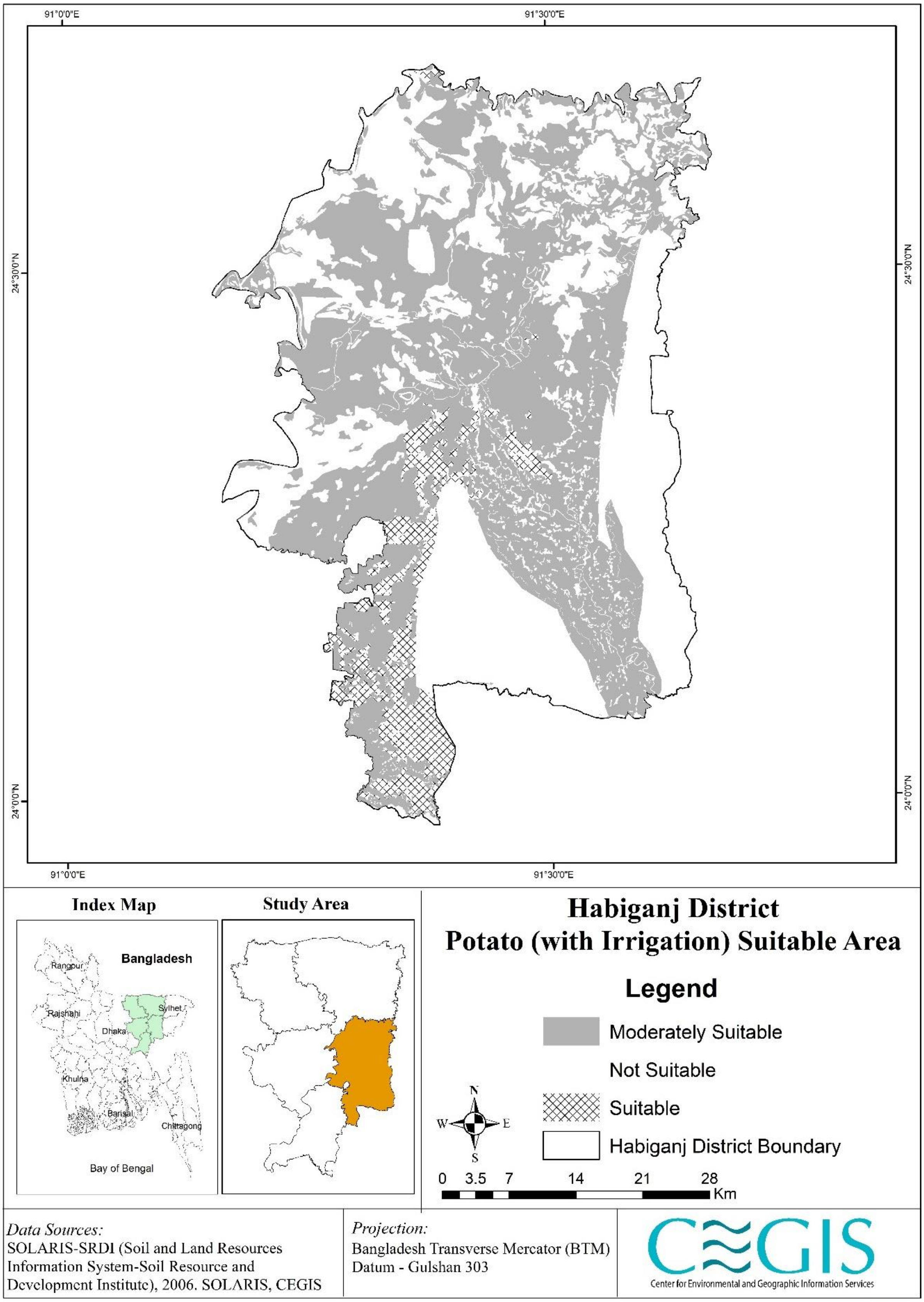
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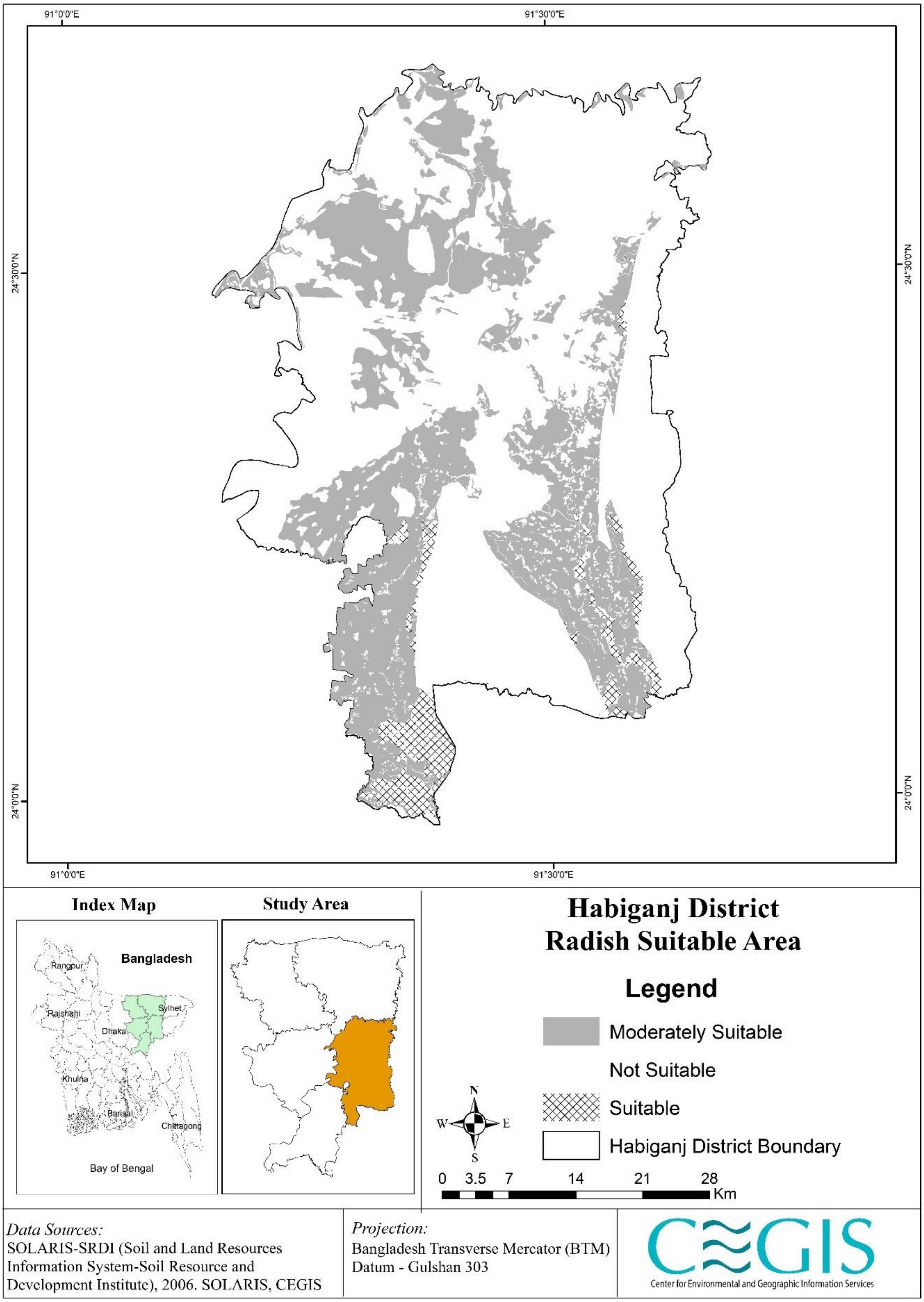
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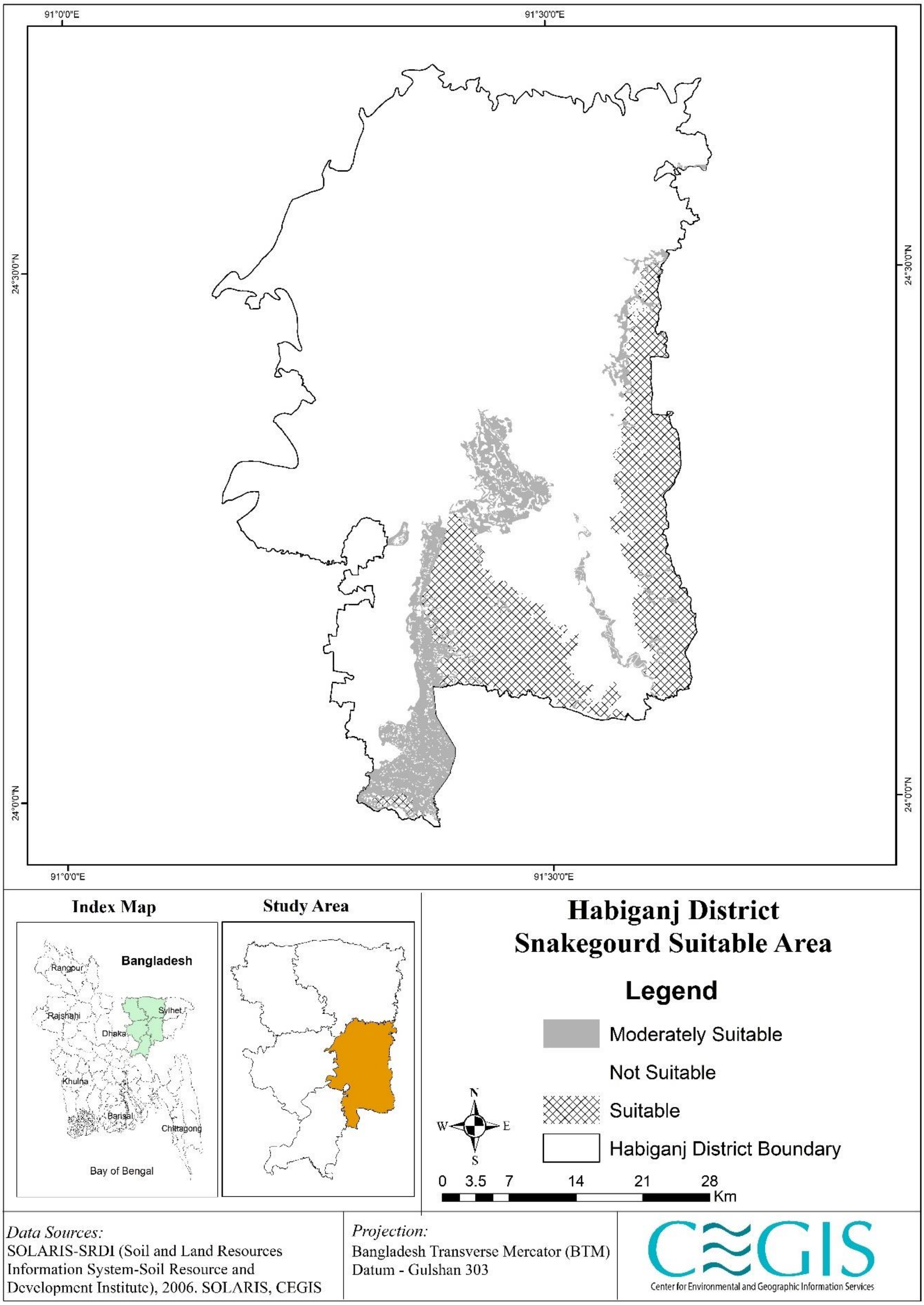
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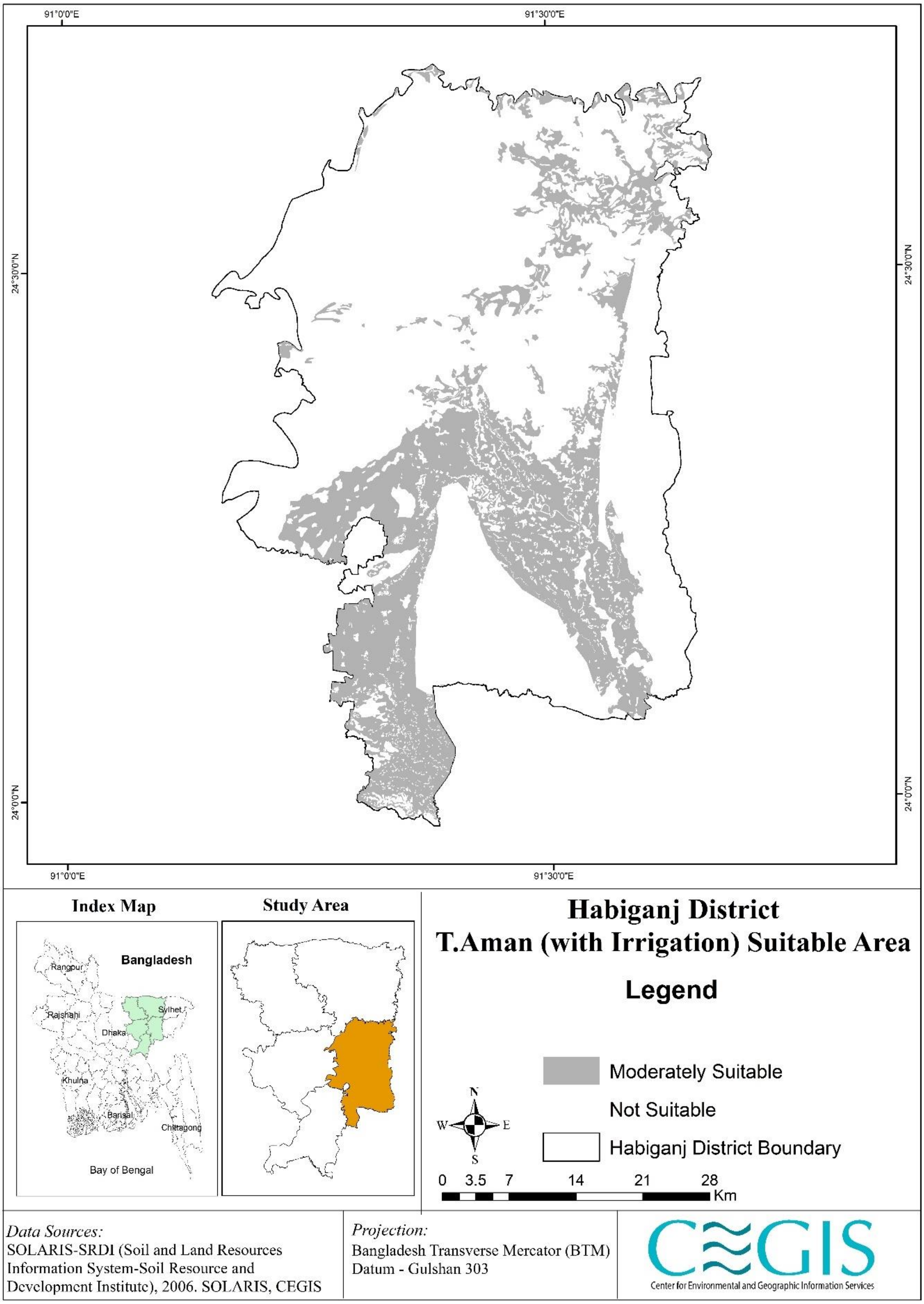
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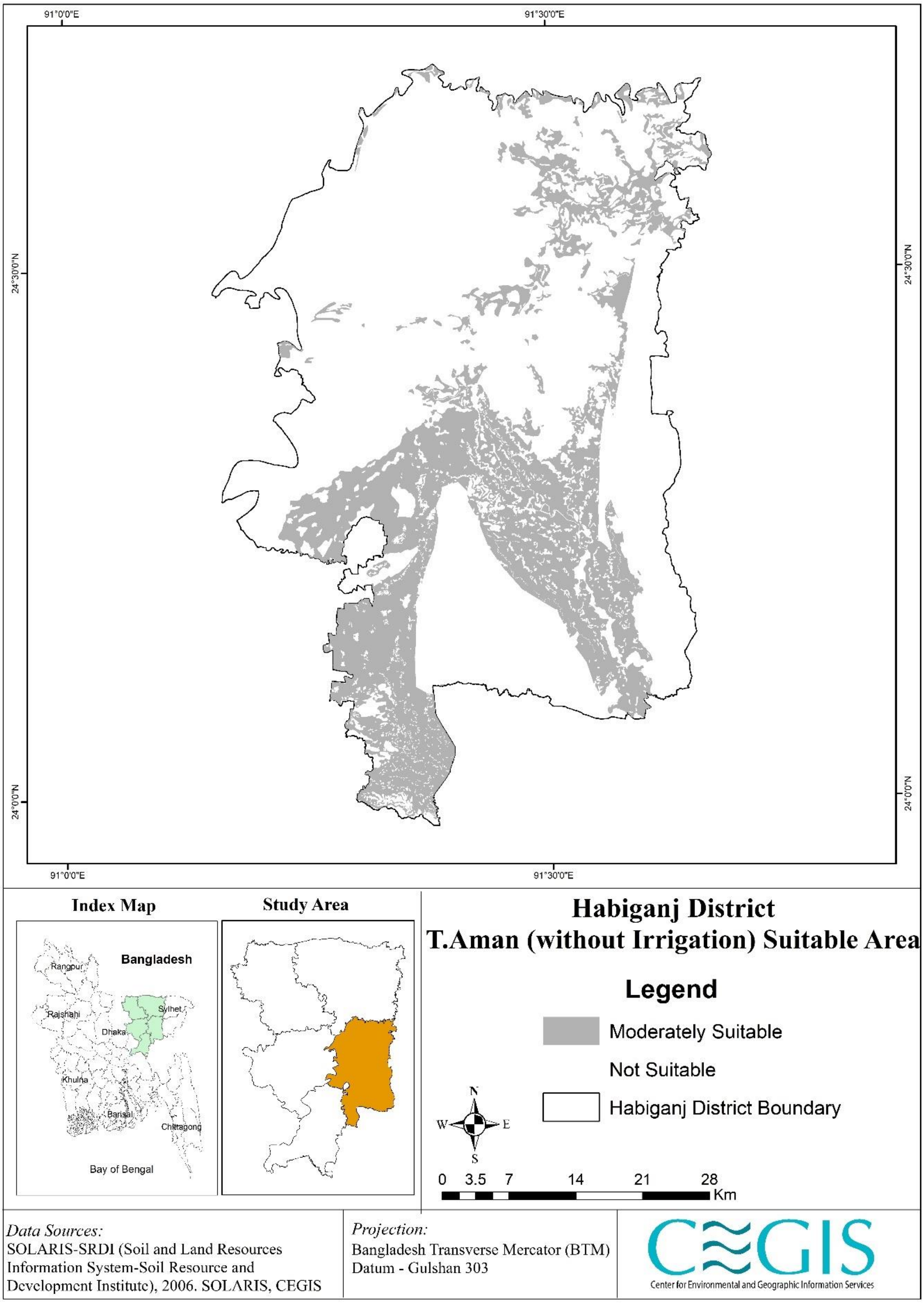

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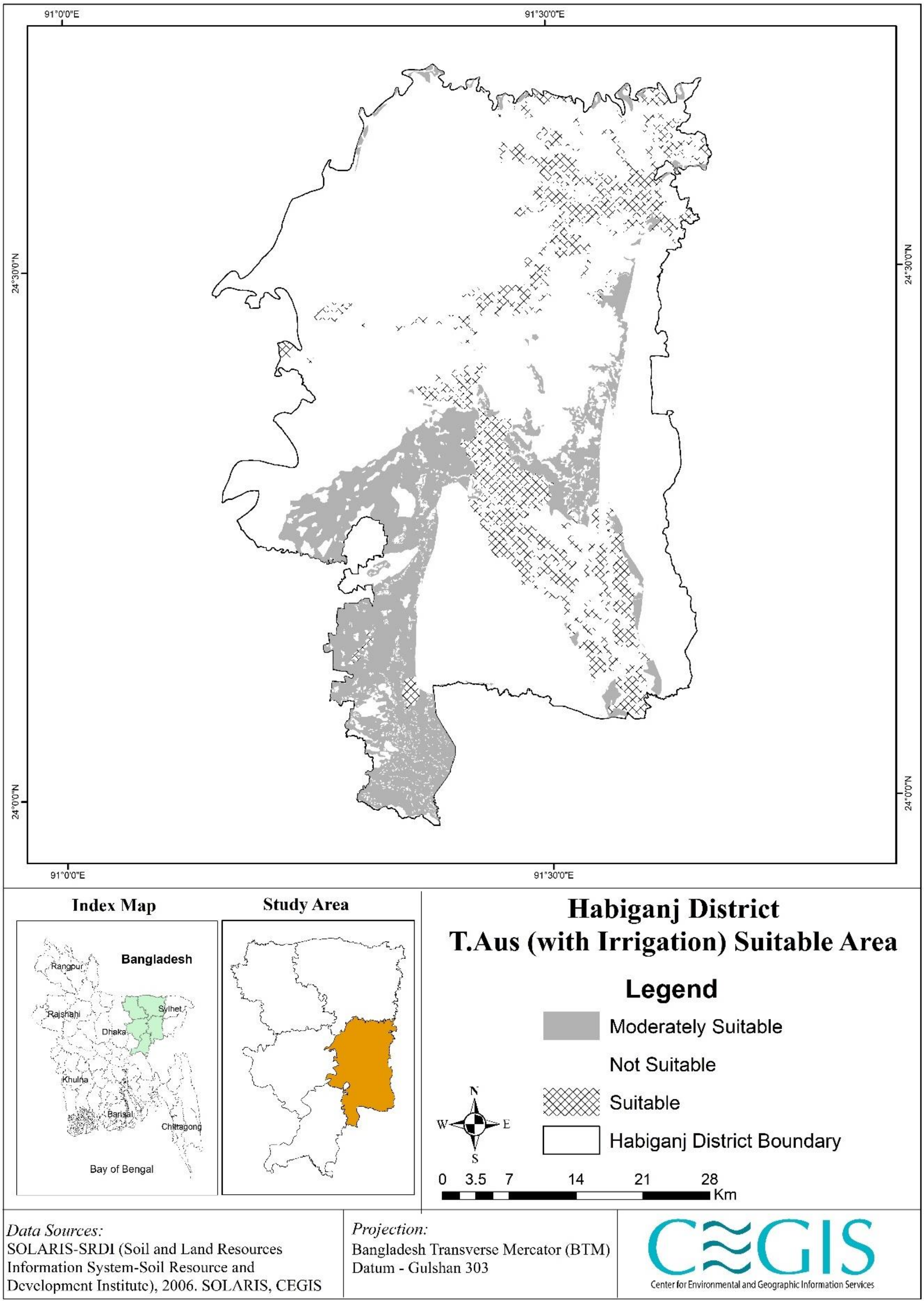
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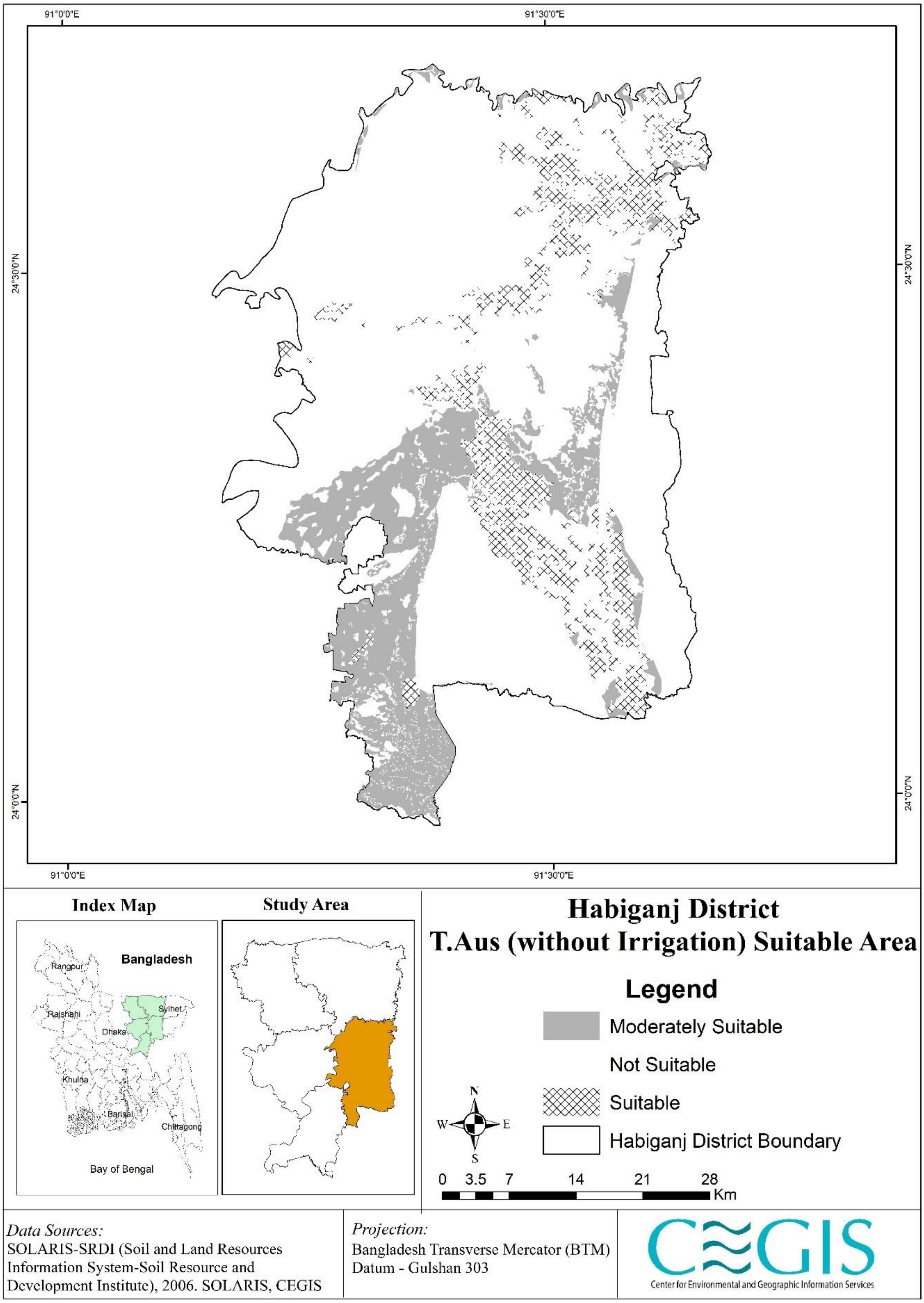
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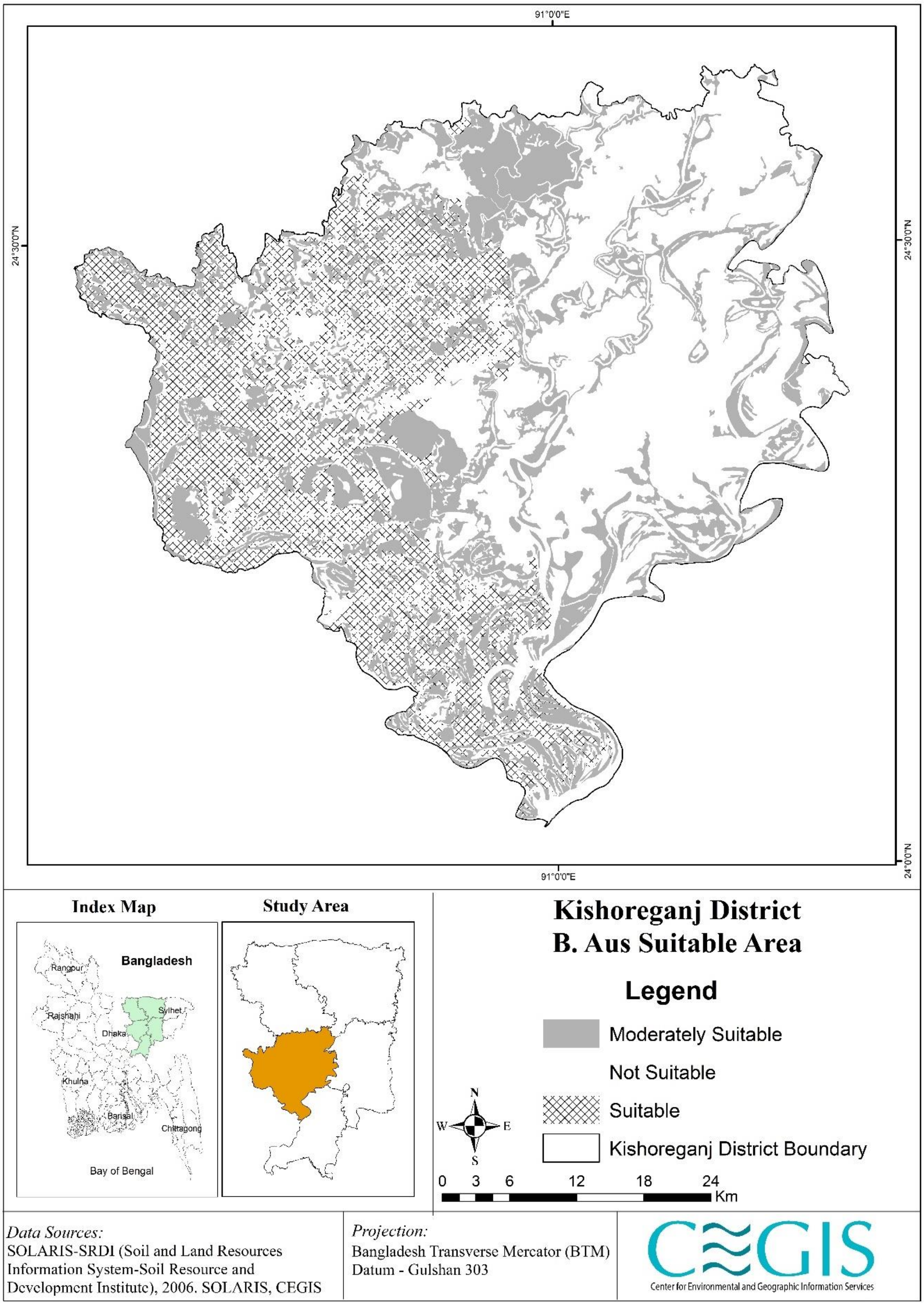

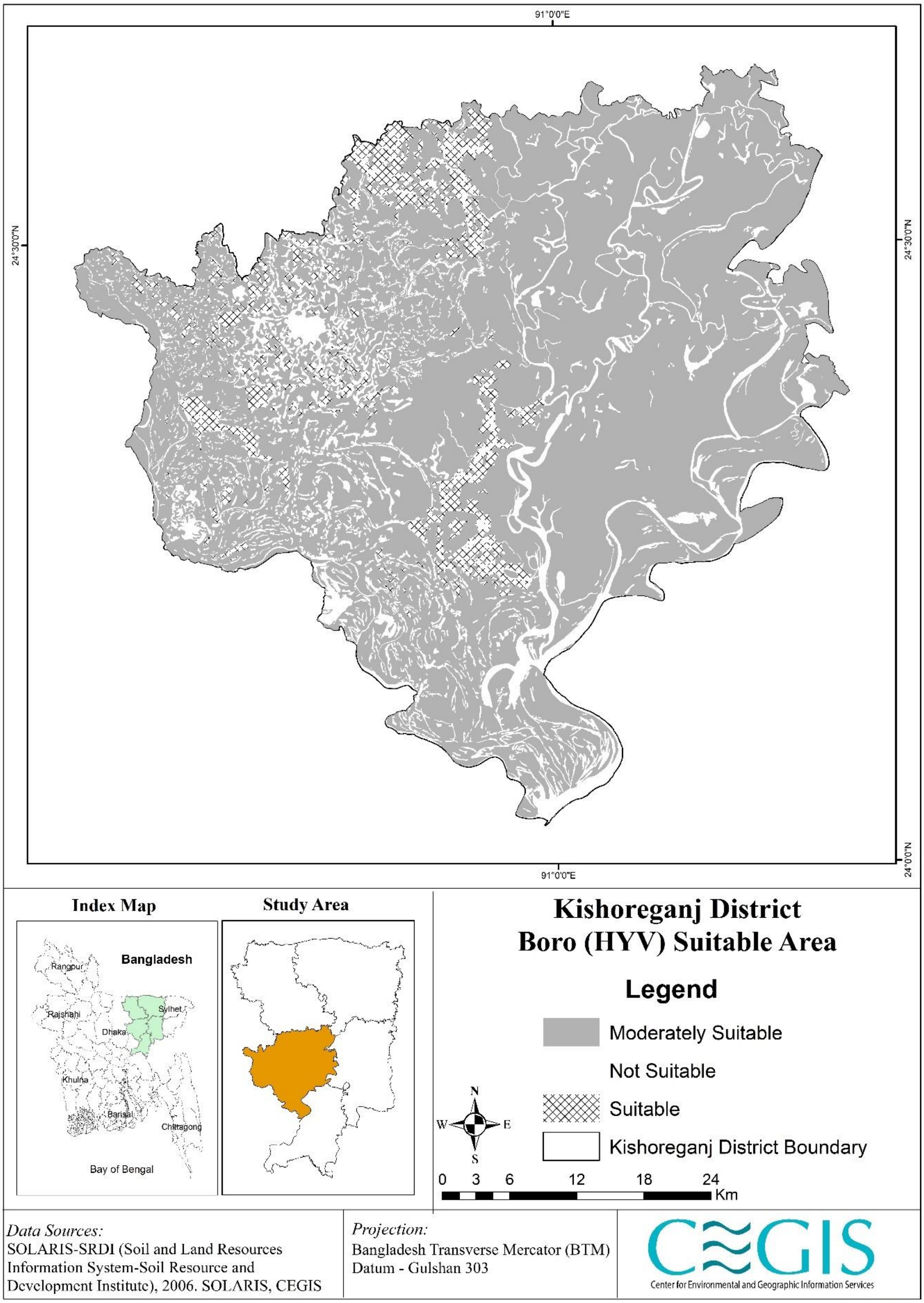
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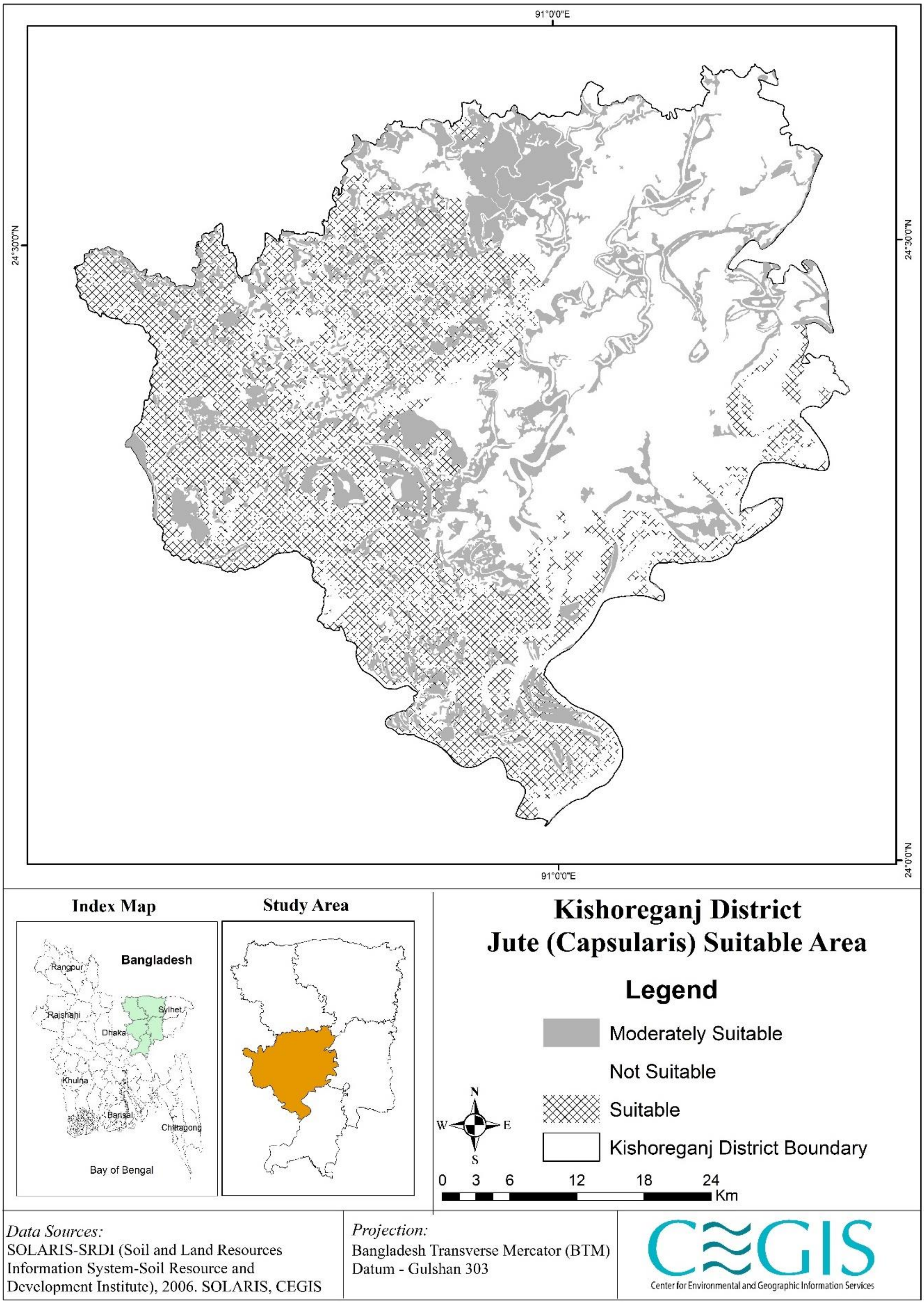
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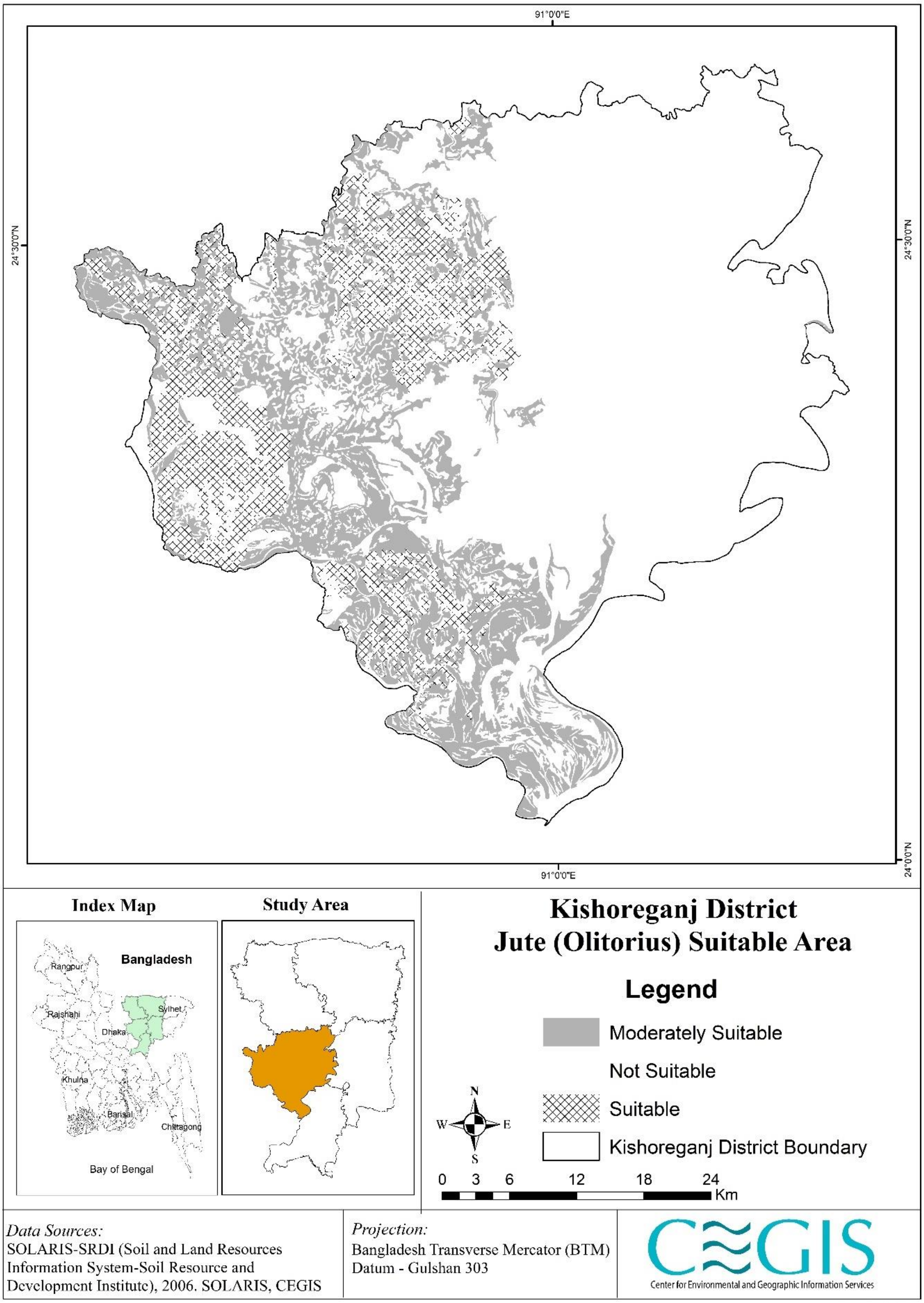
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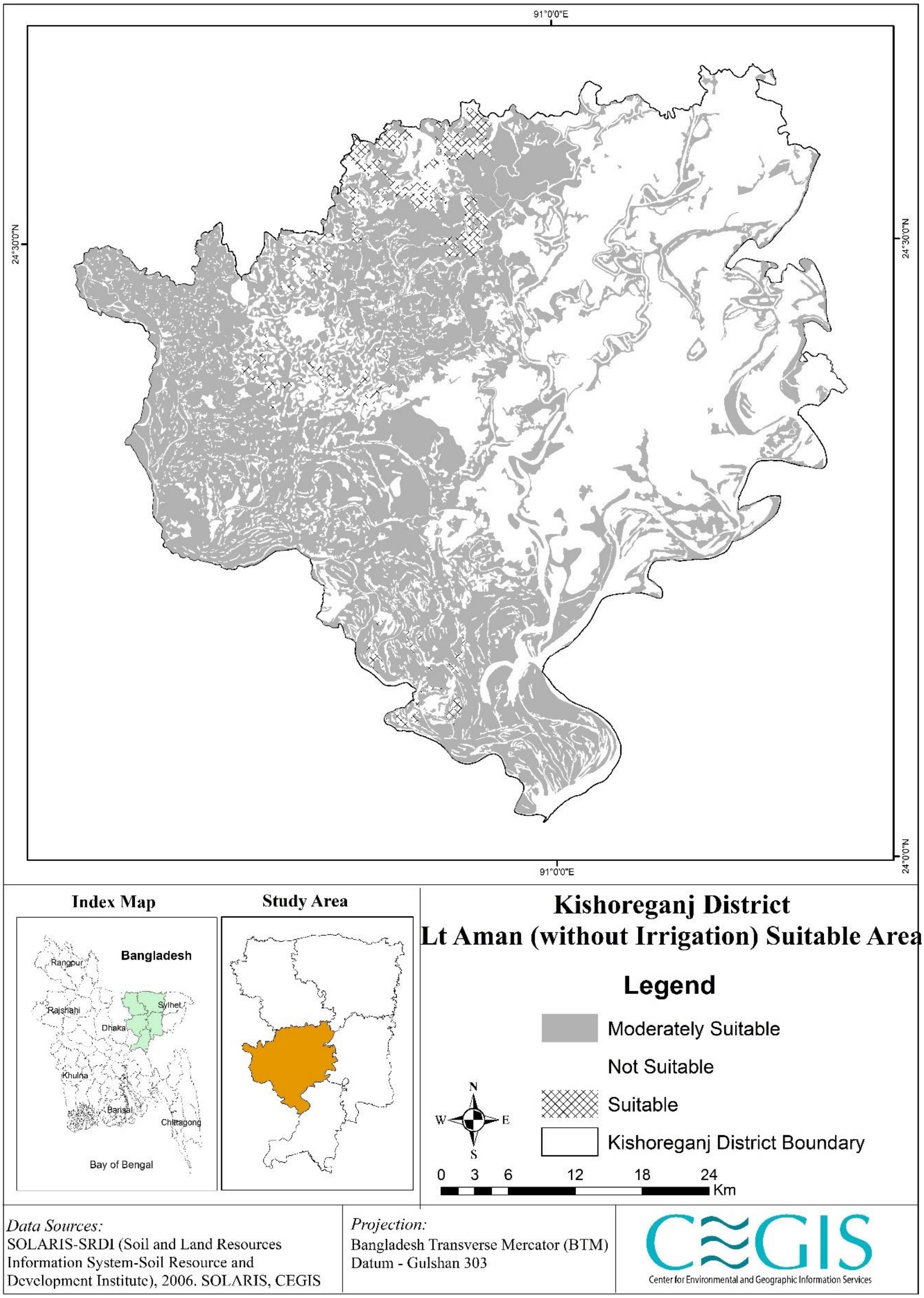
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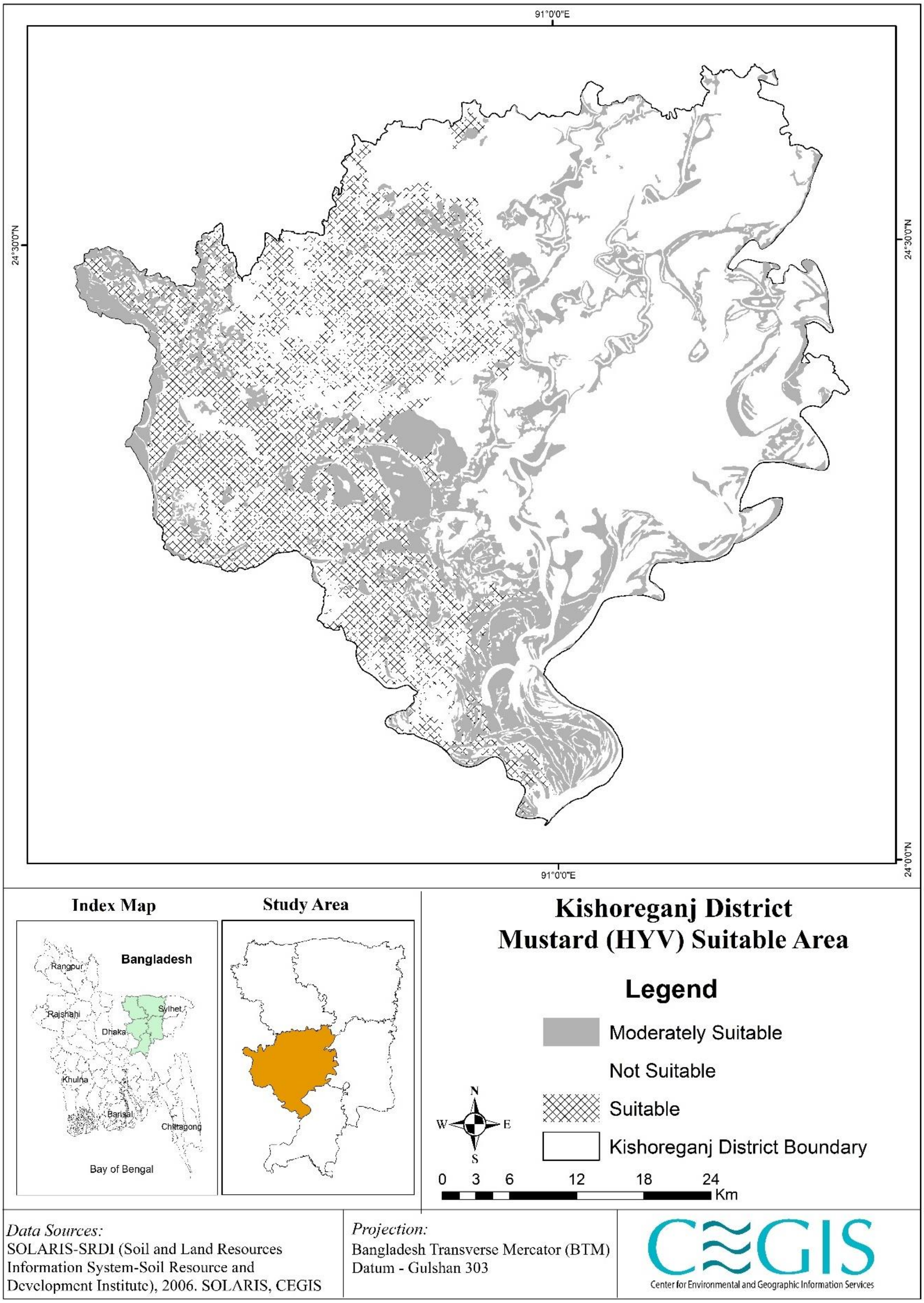
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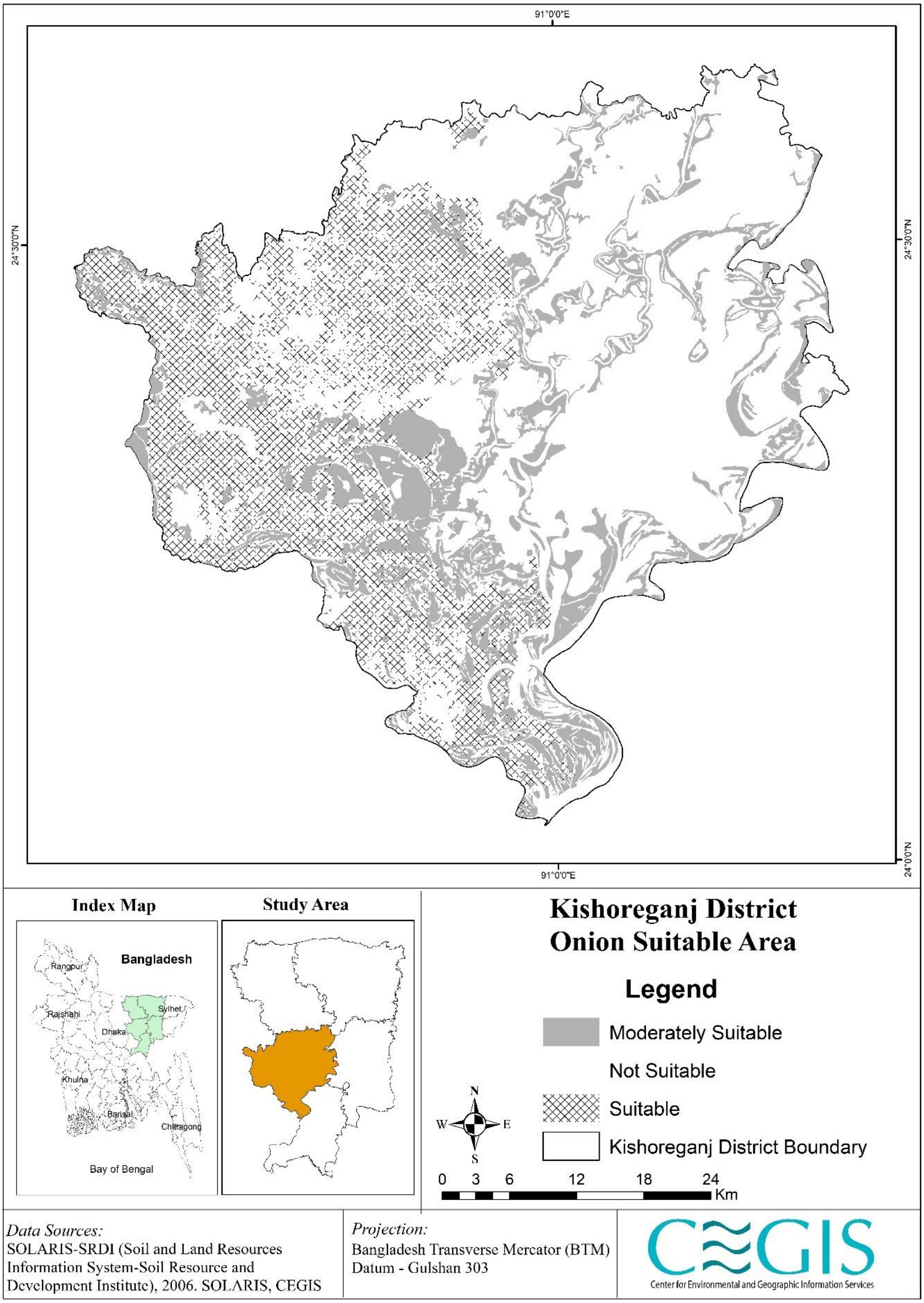
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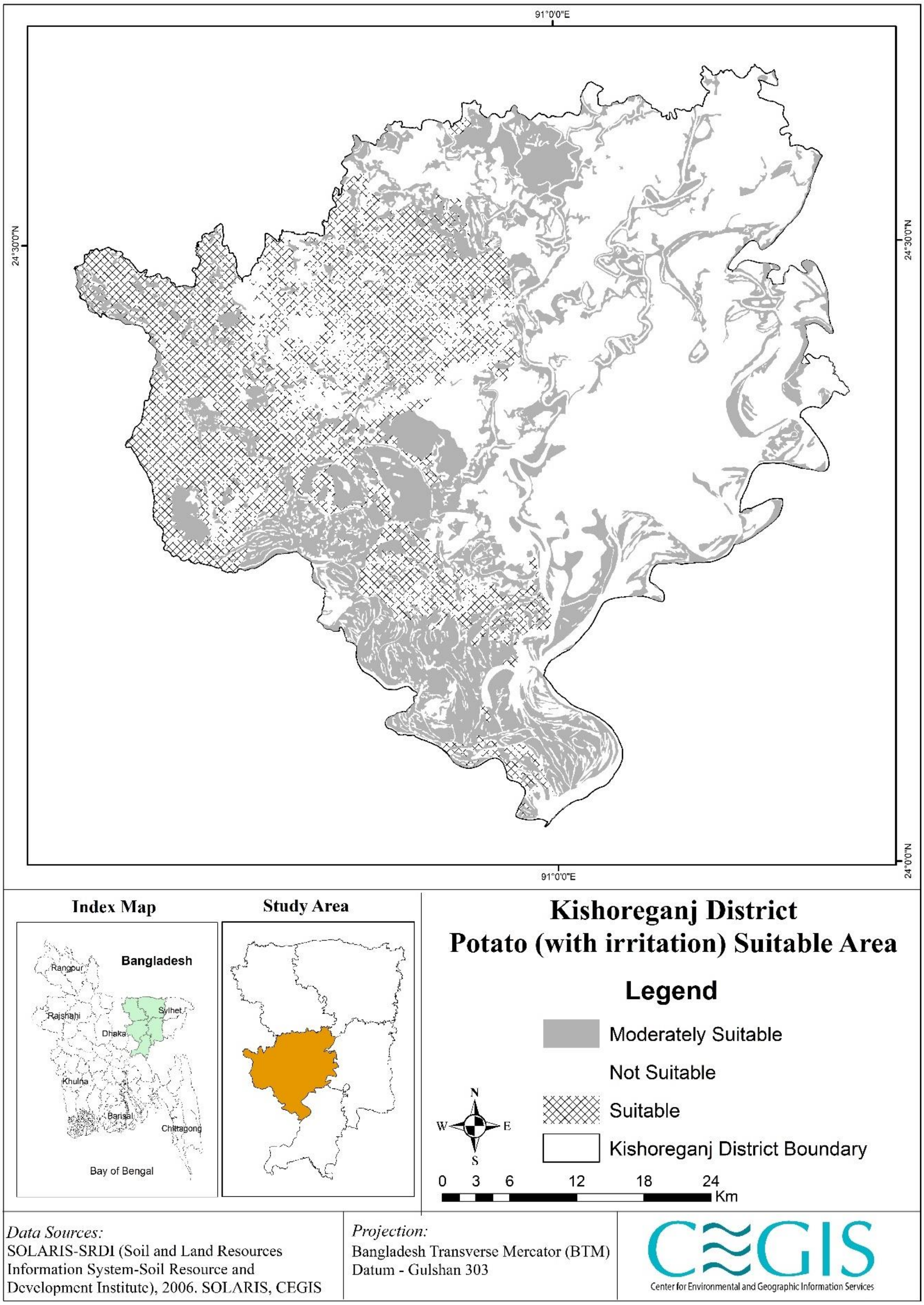
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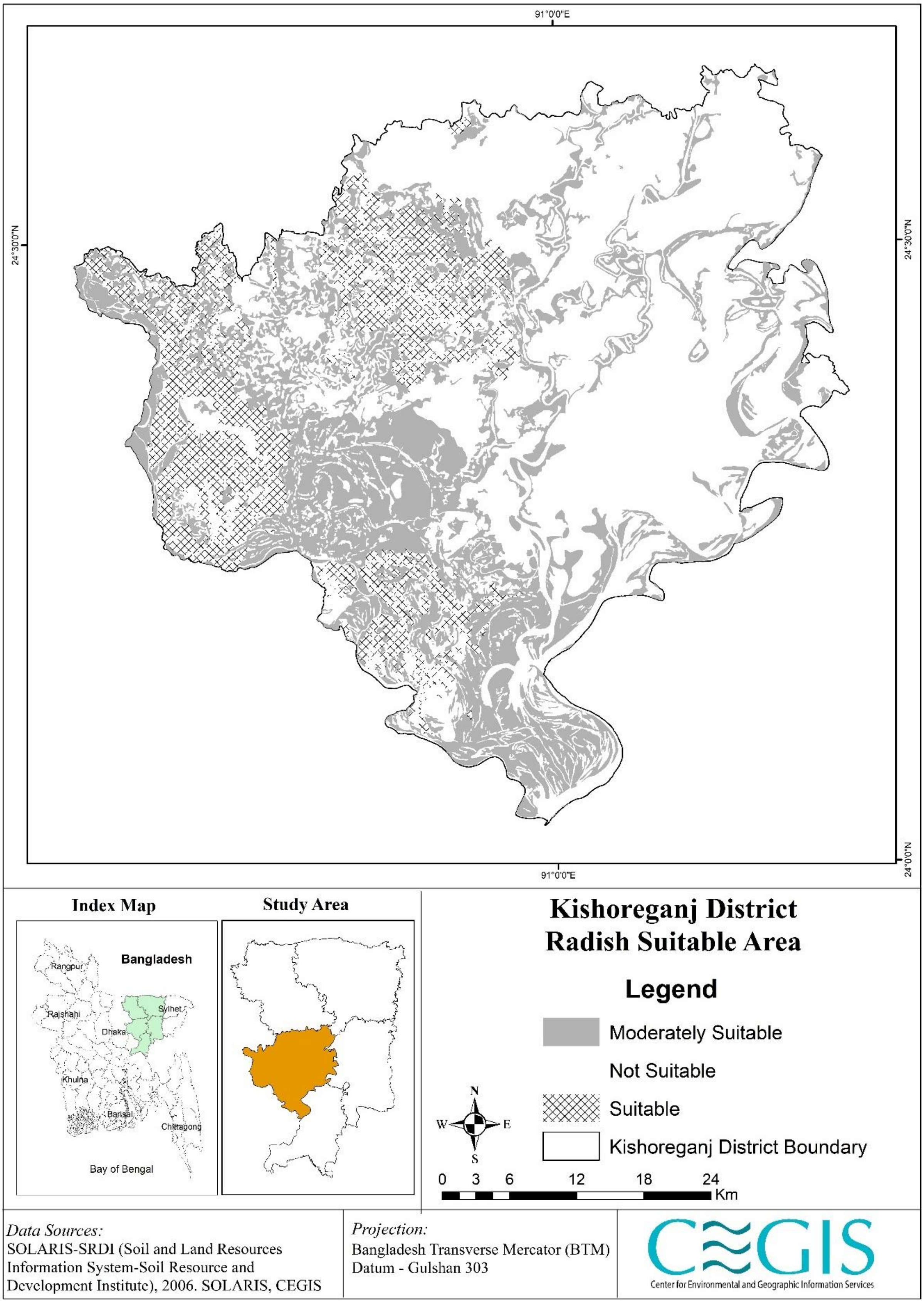
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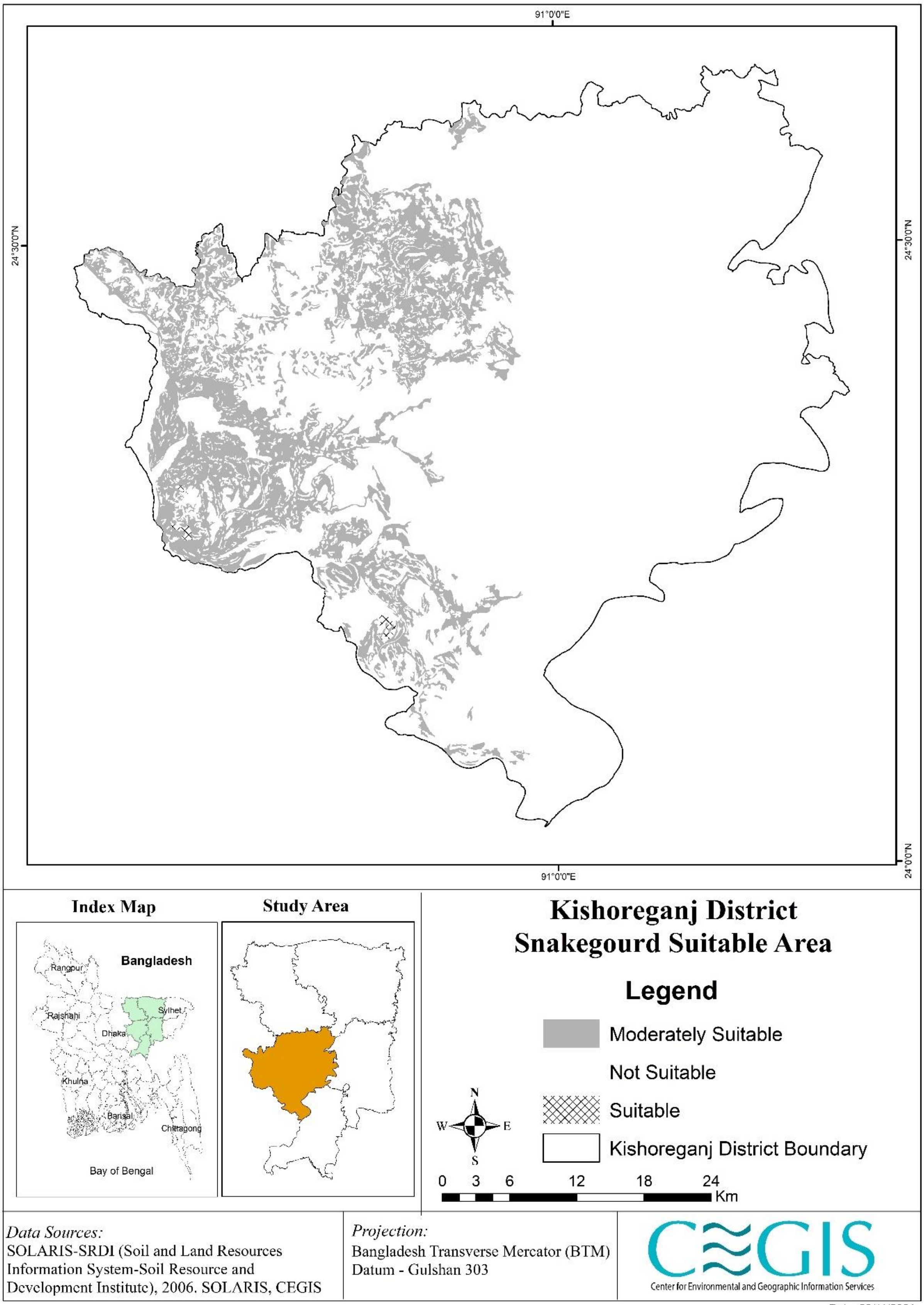
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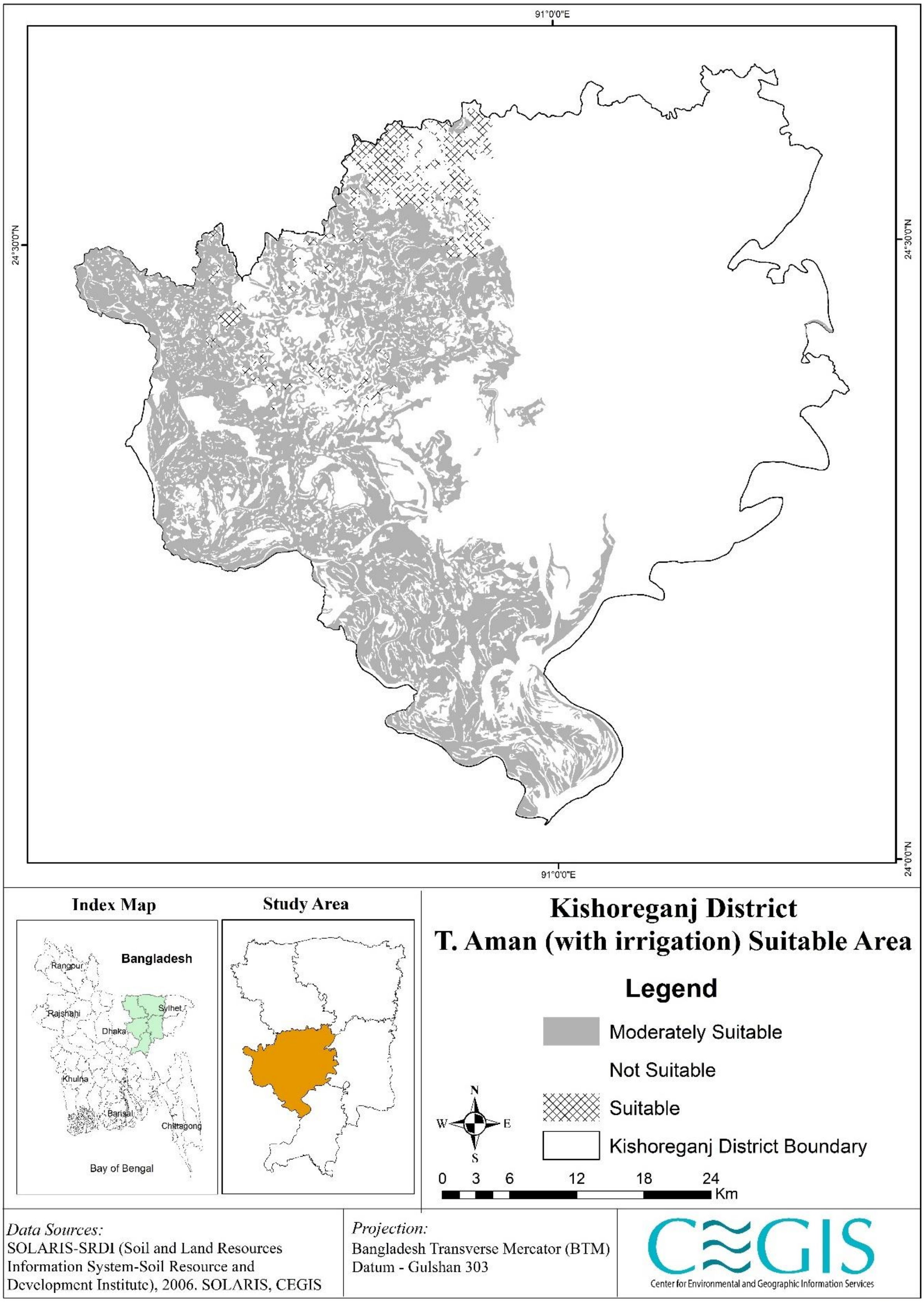
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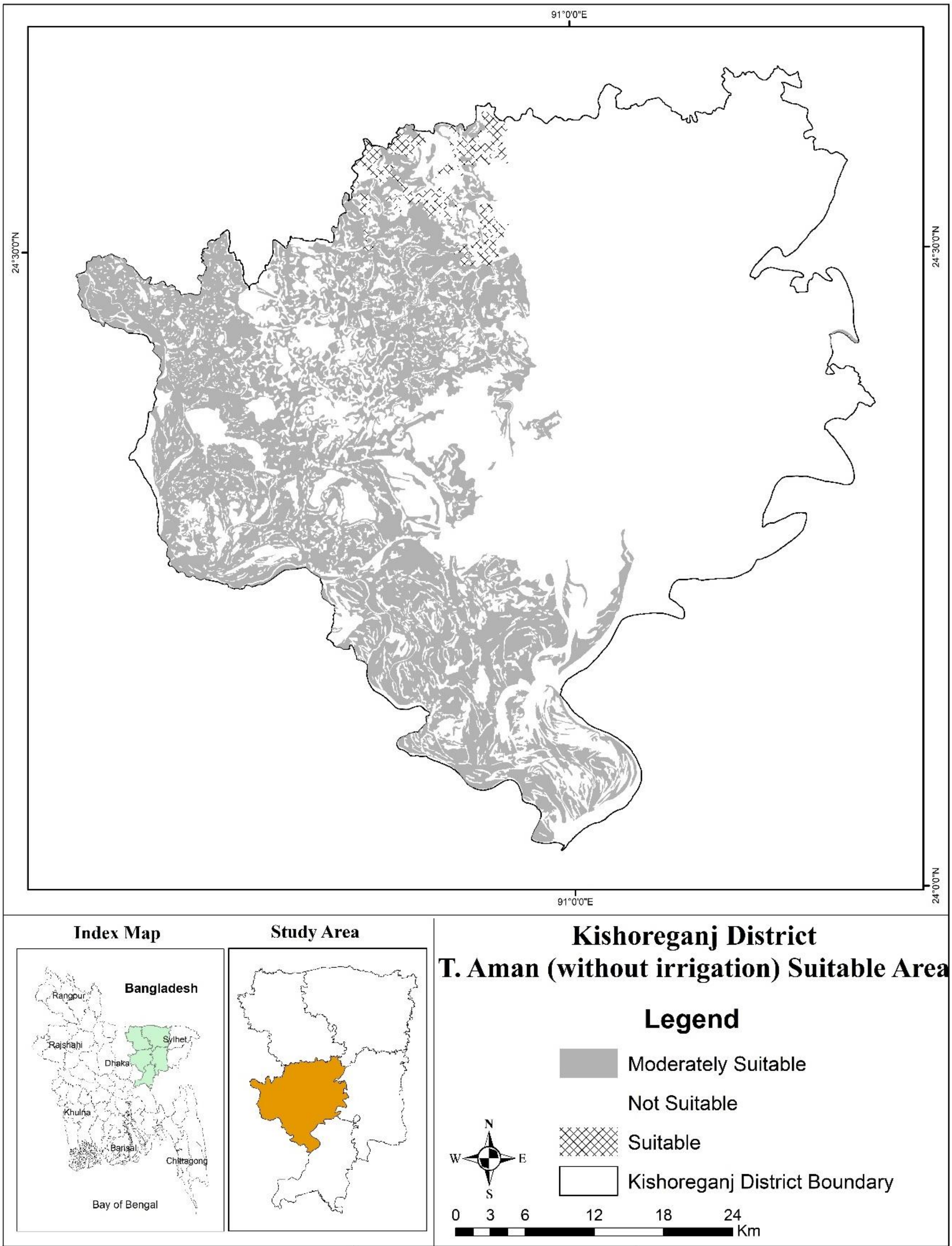

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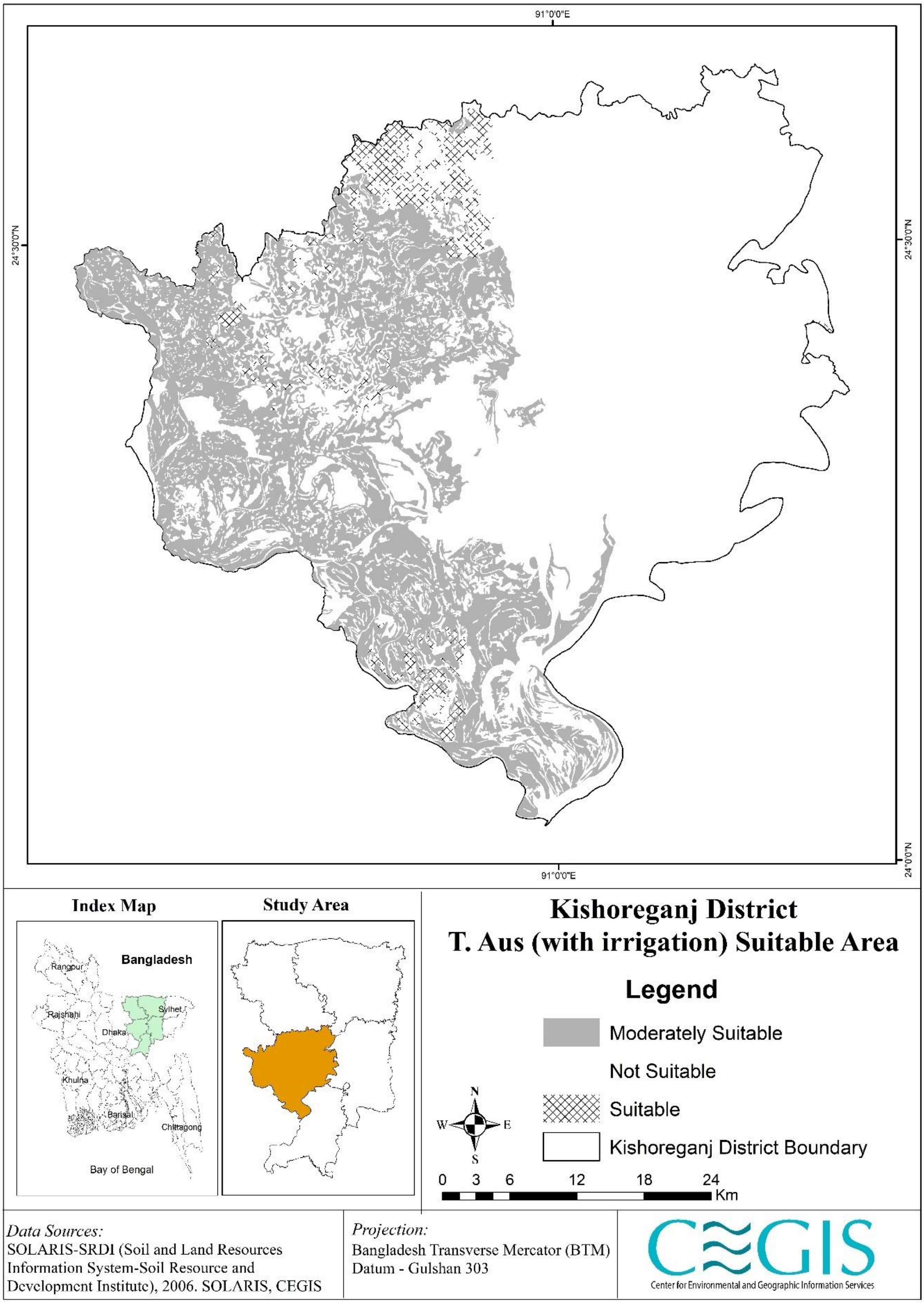
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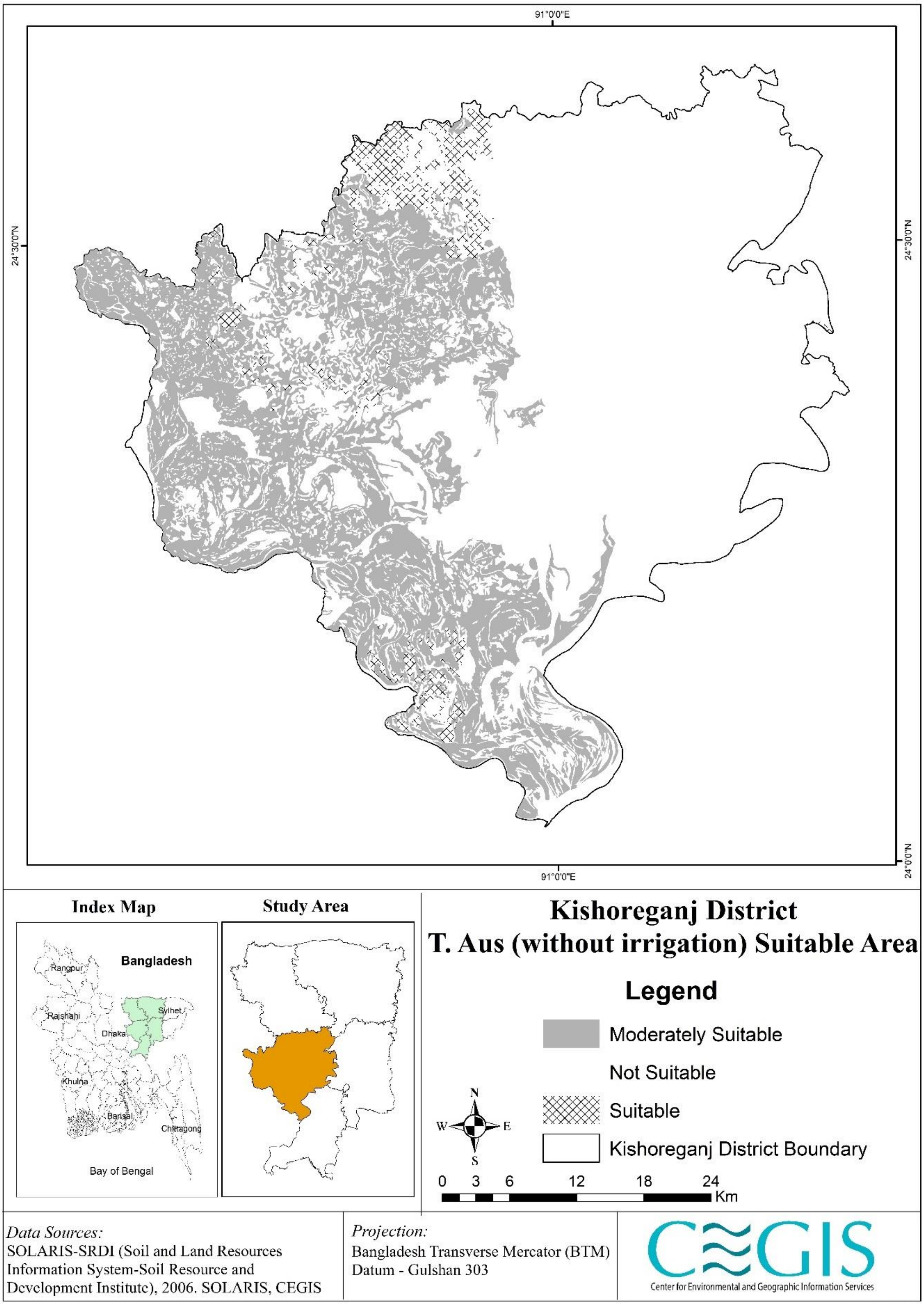
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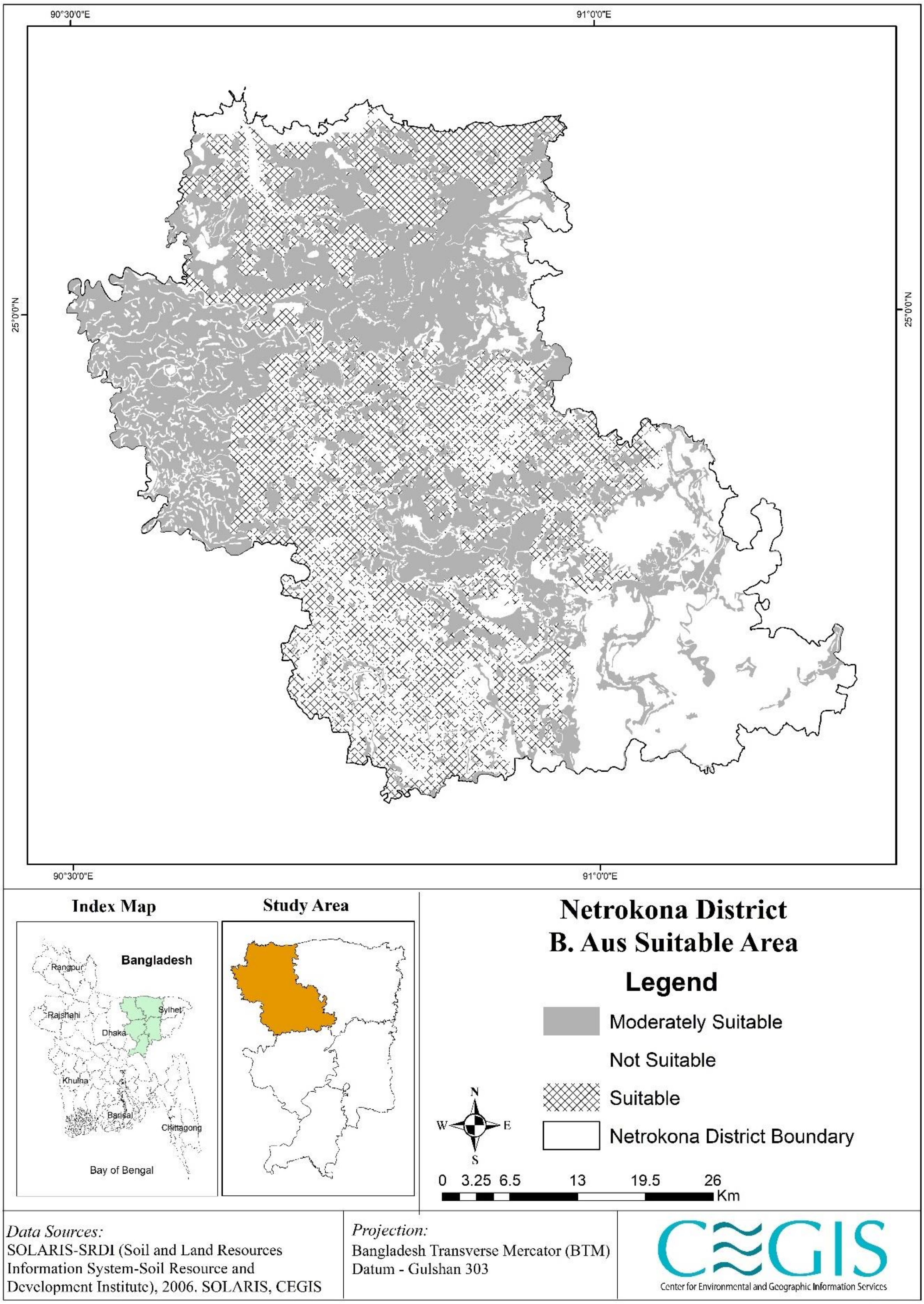
Netrokona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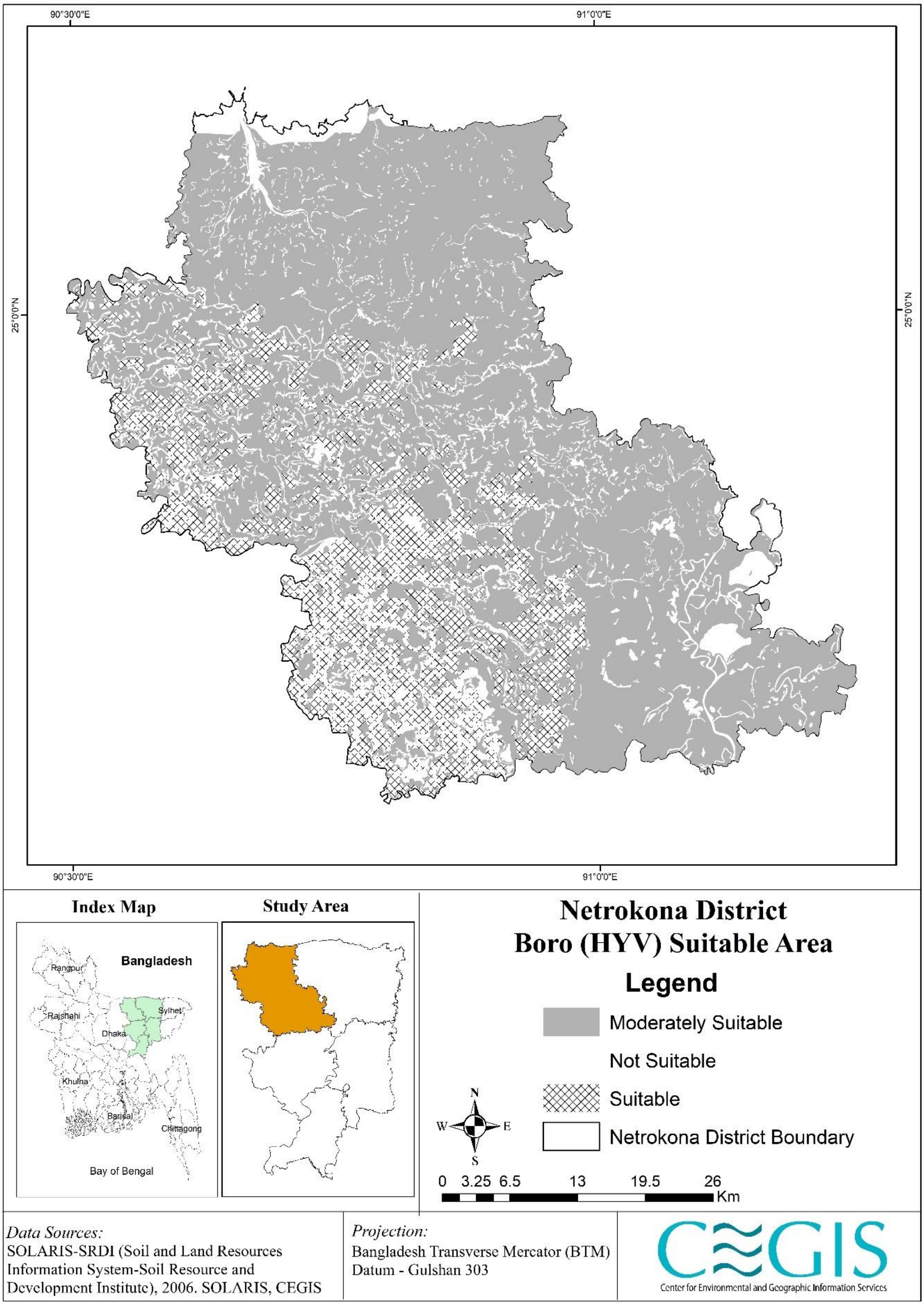
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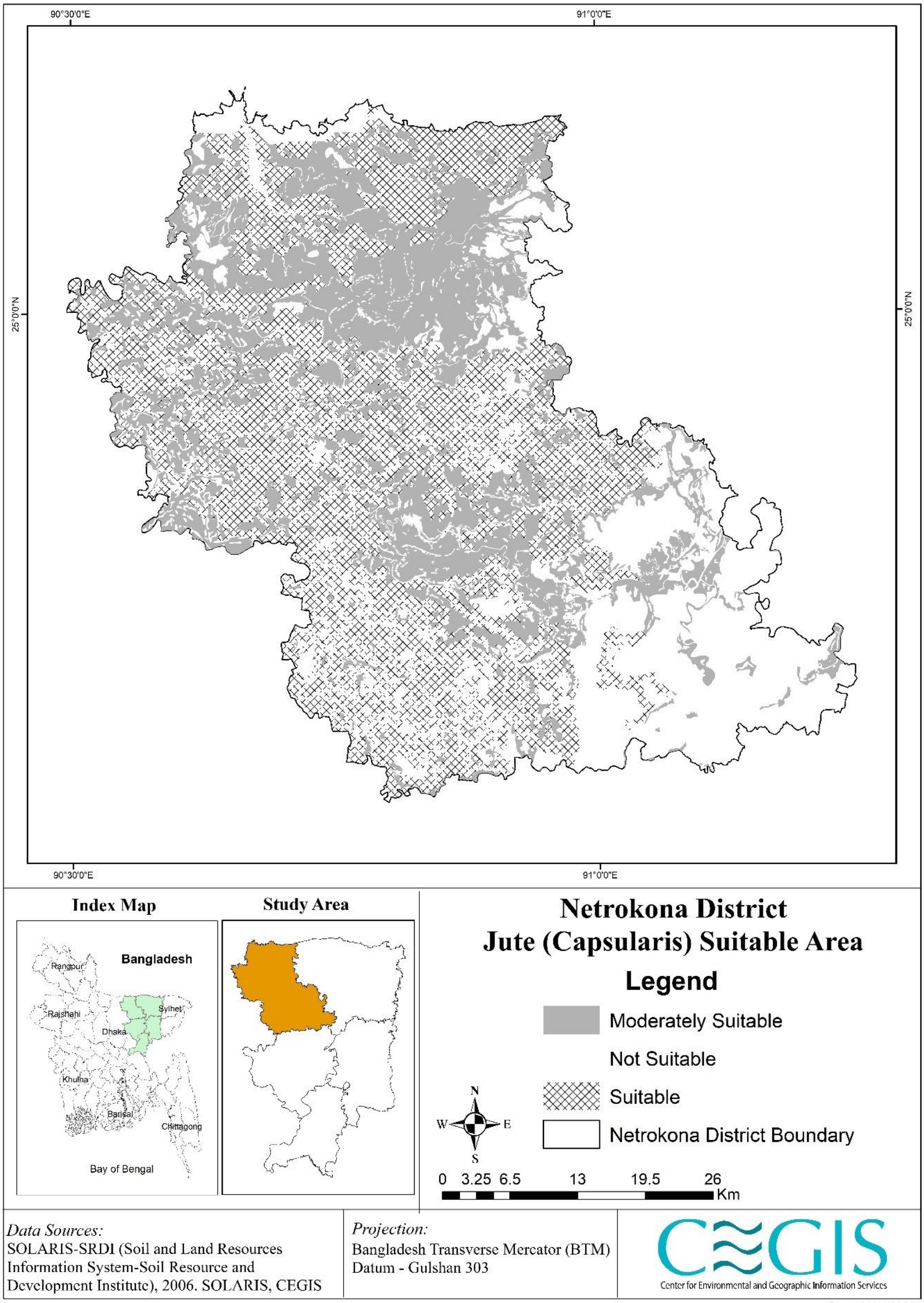
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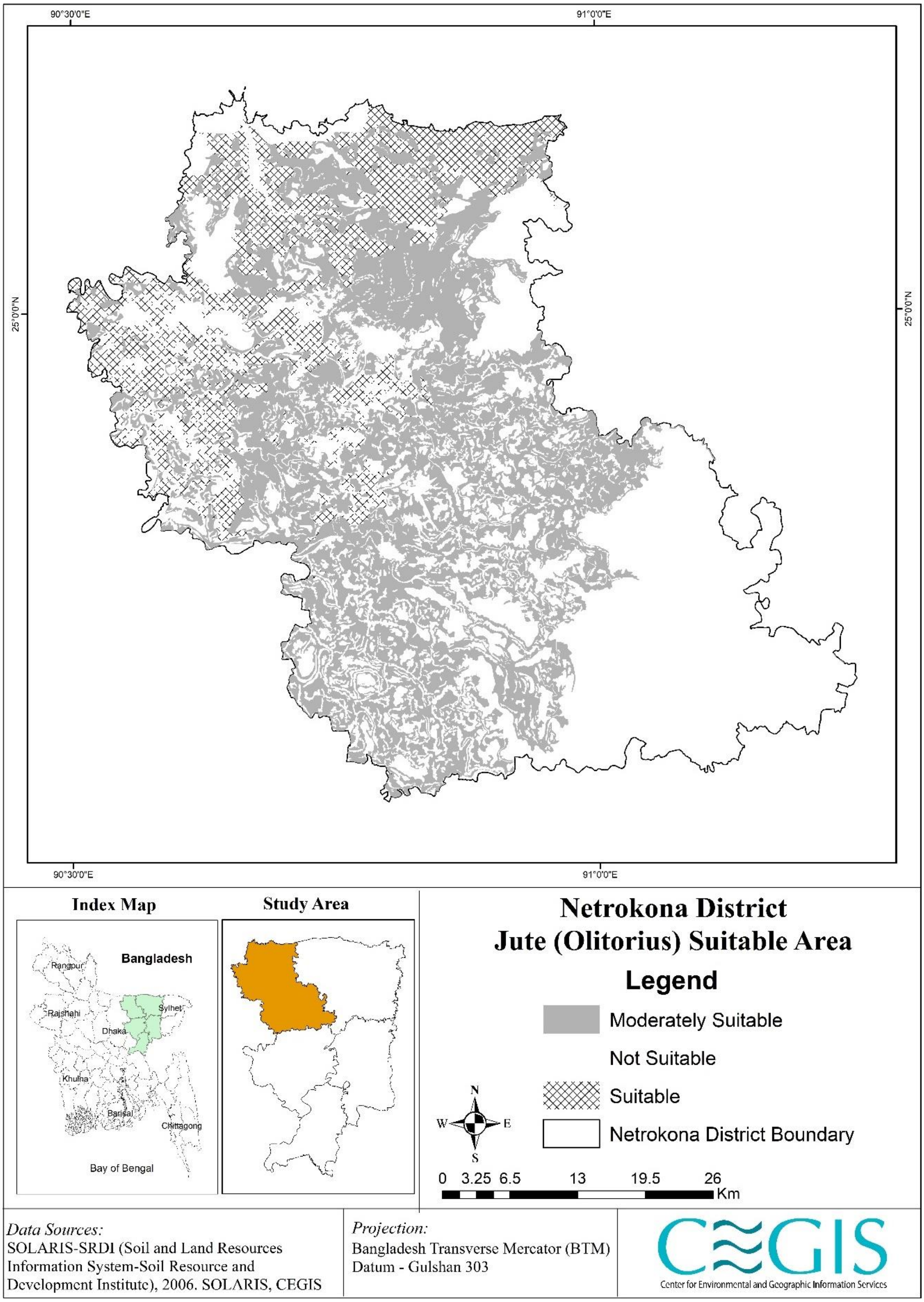
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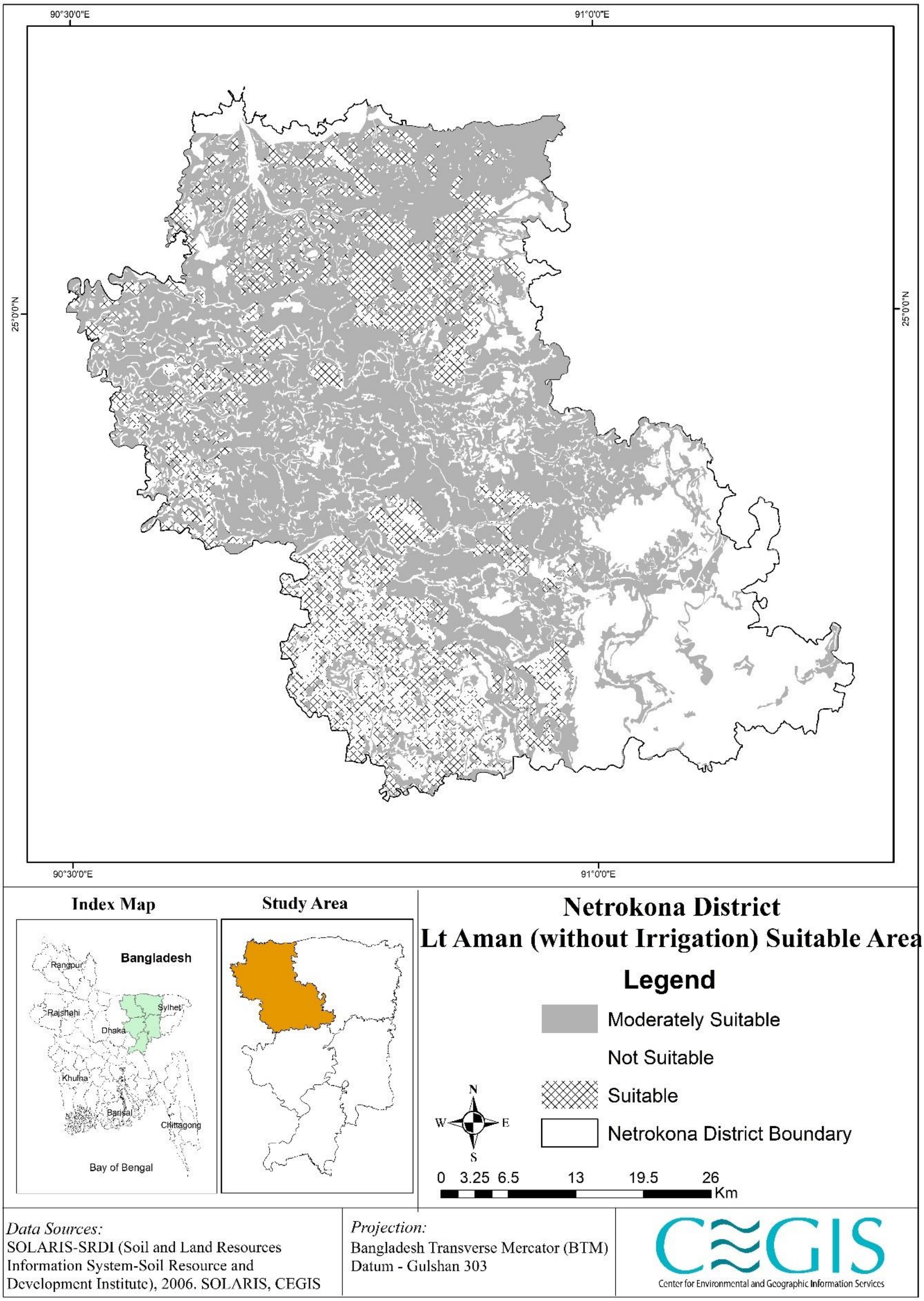
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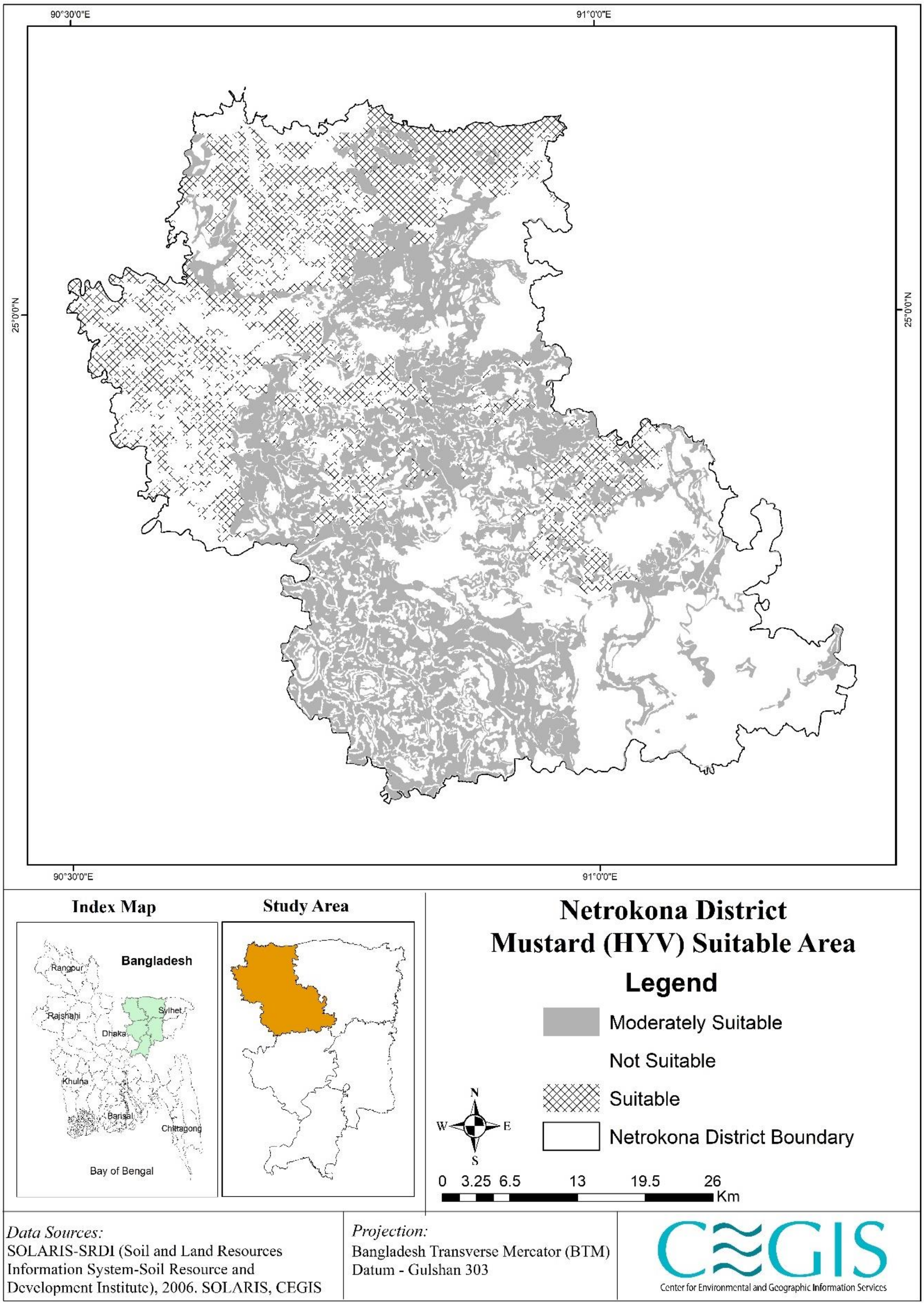
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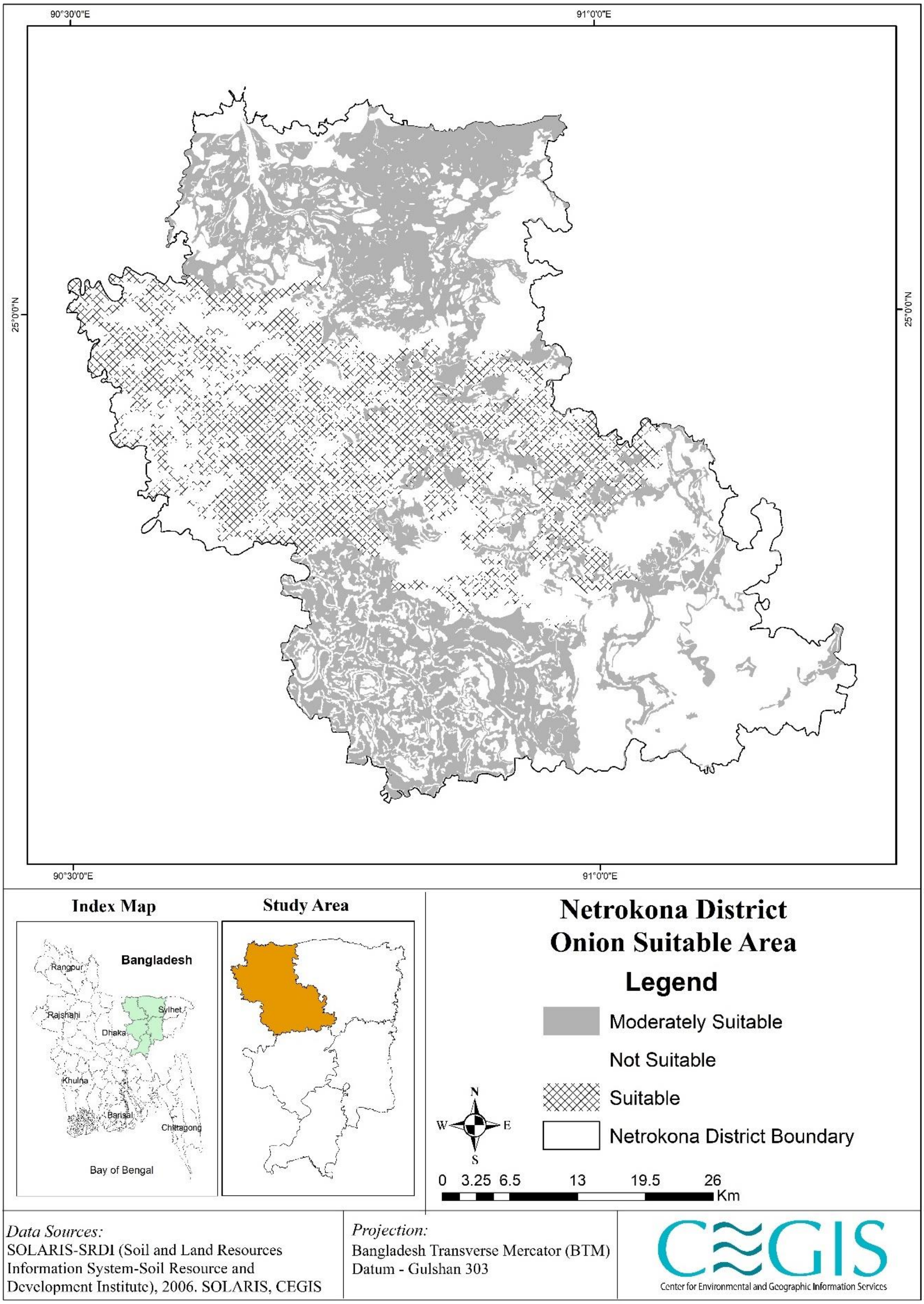

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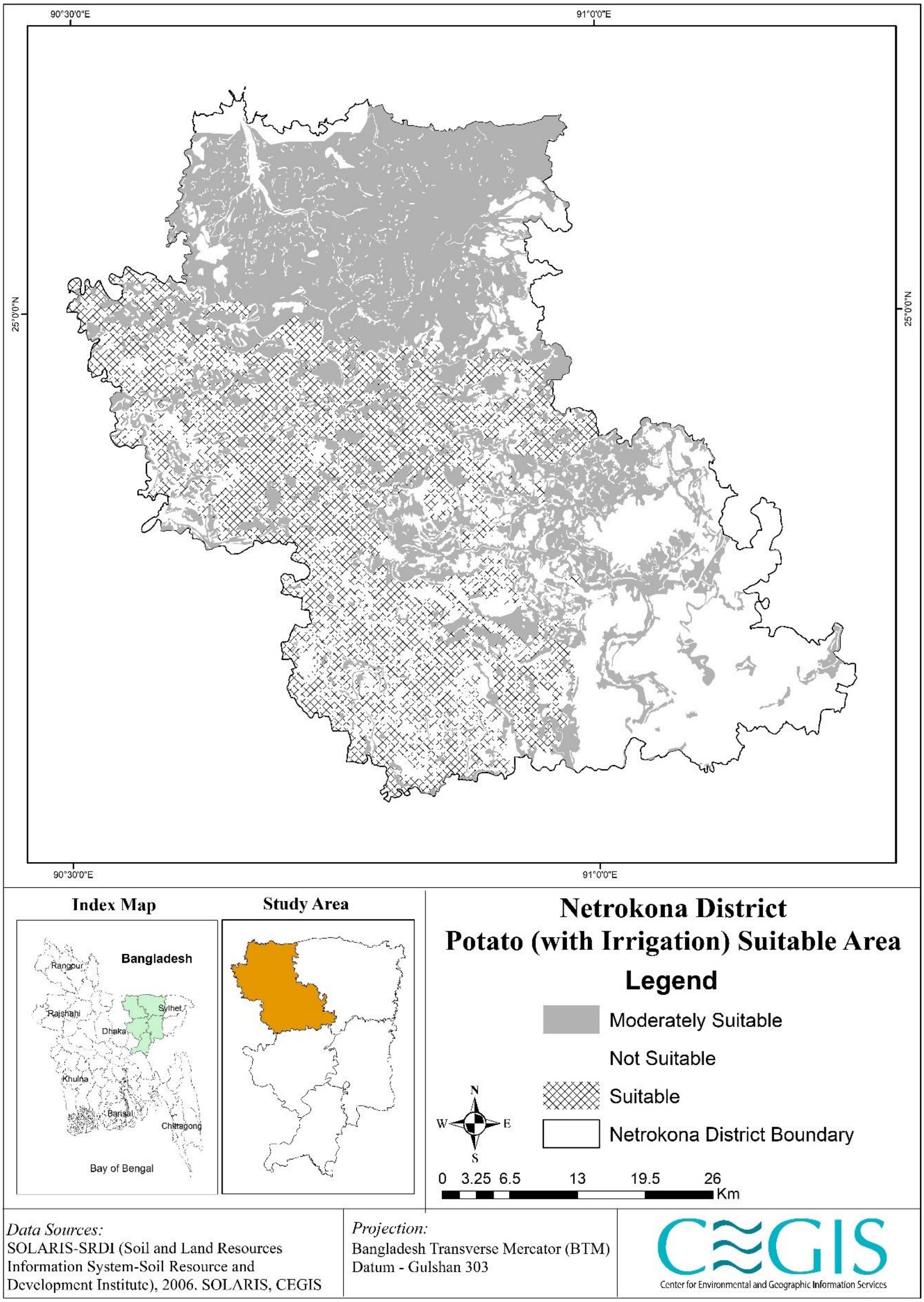
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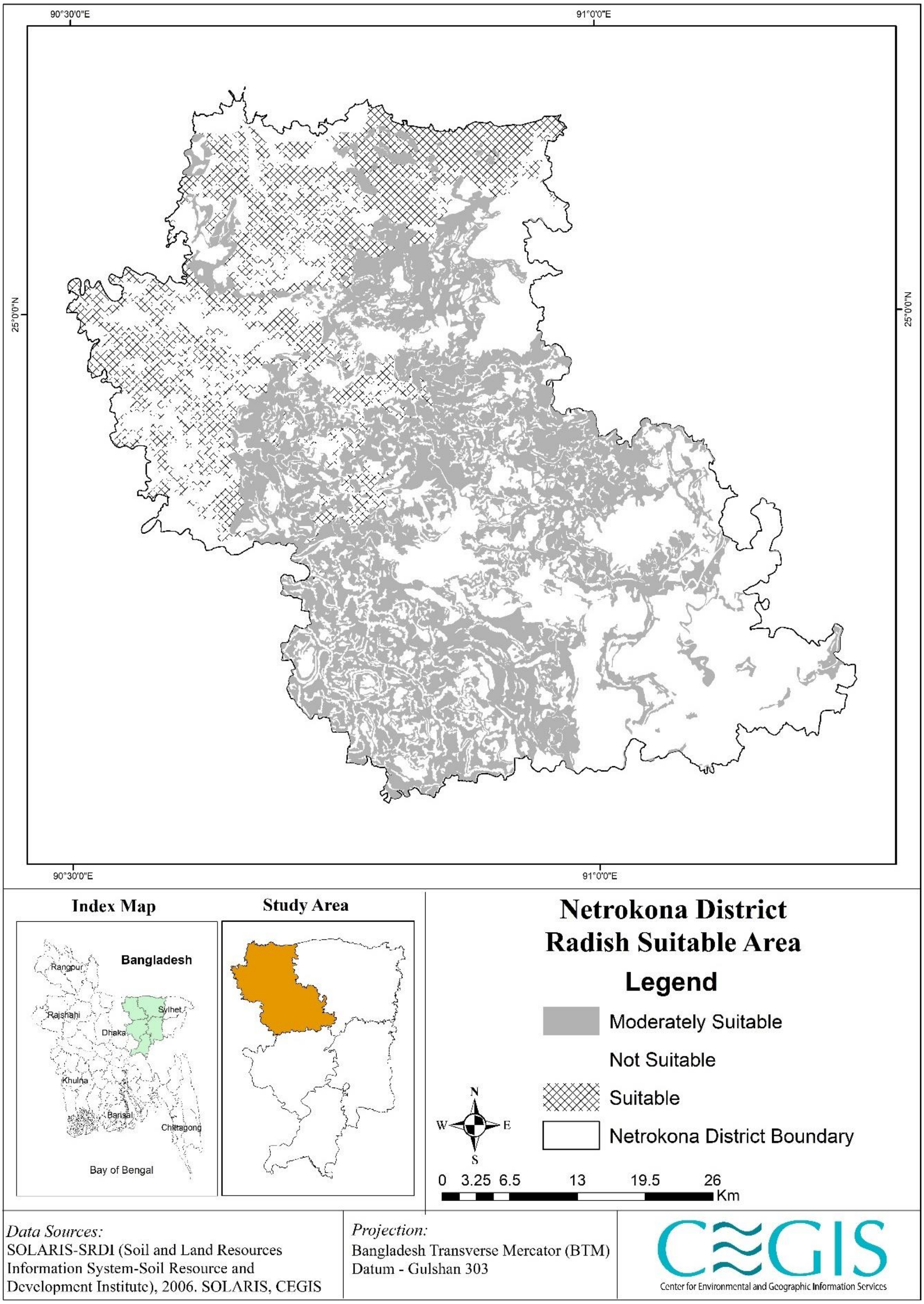
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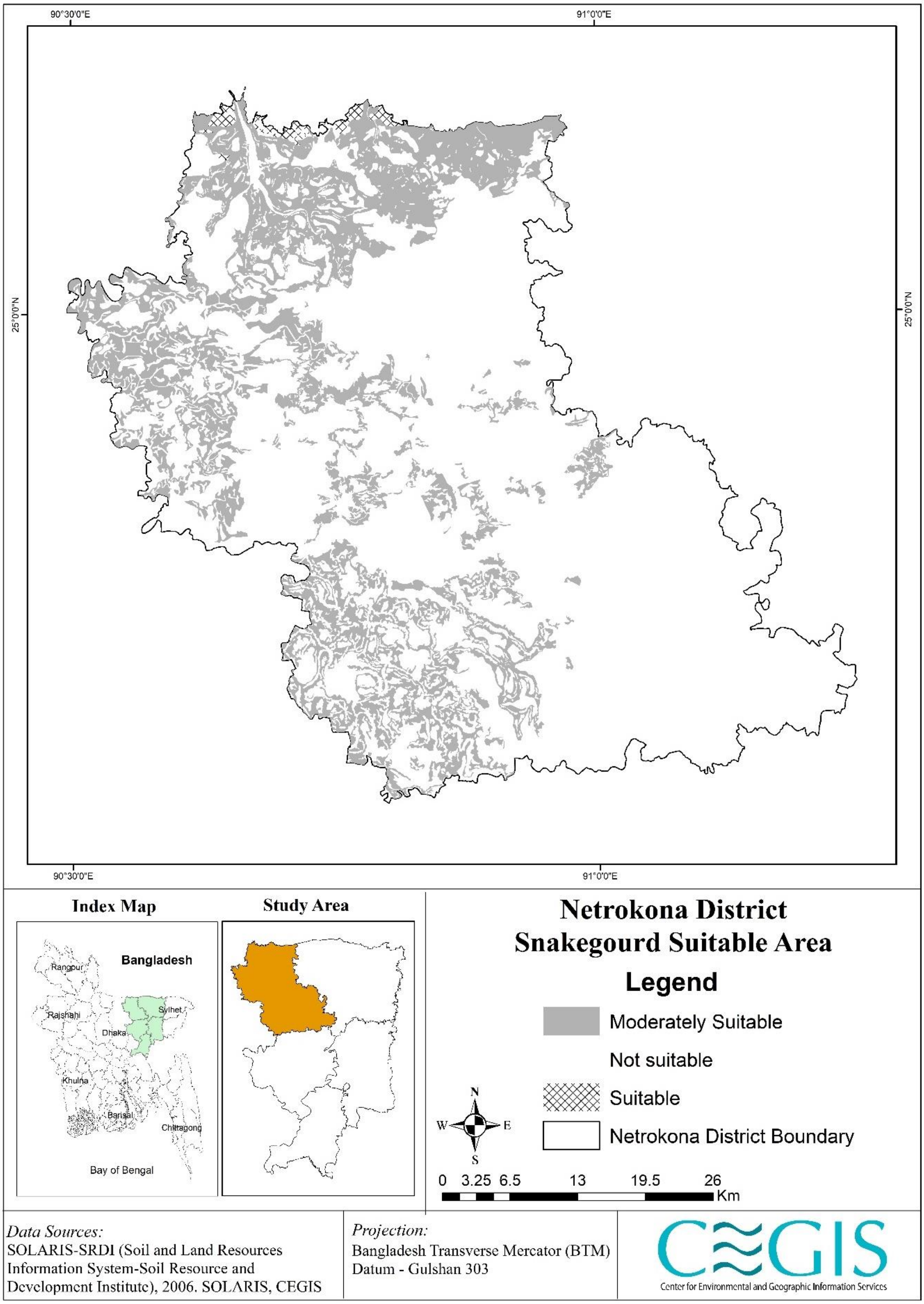
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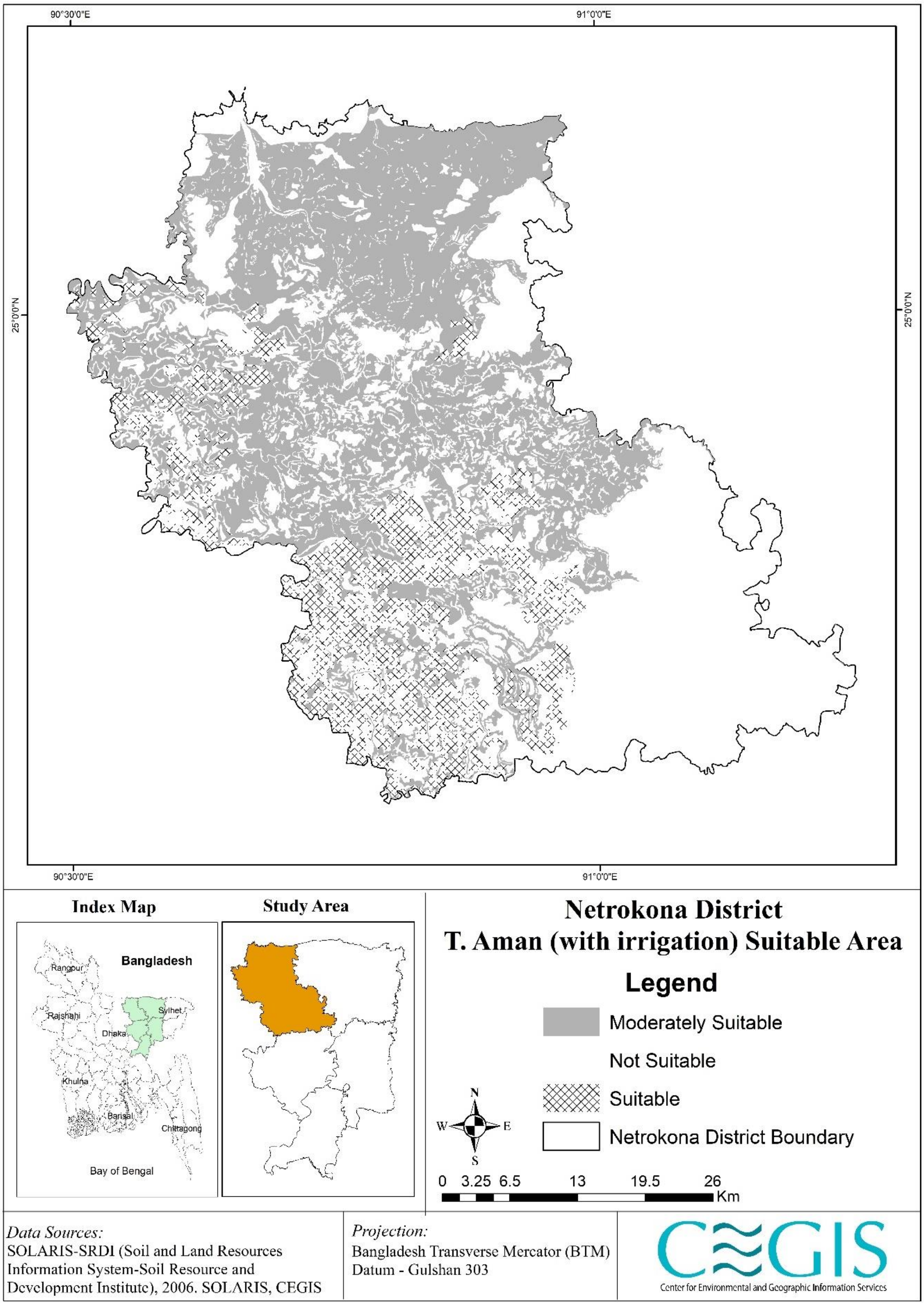
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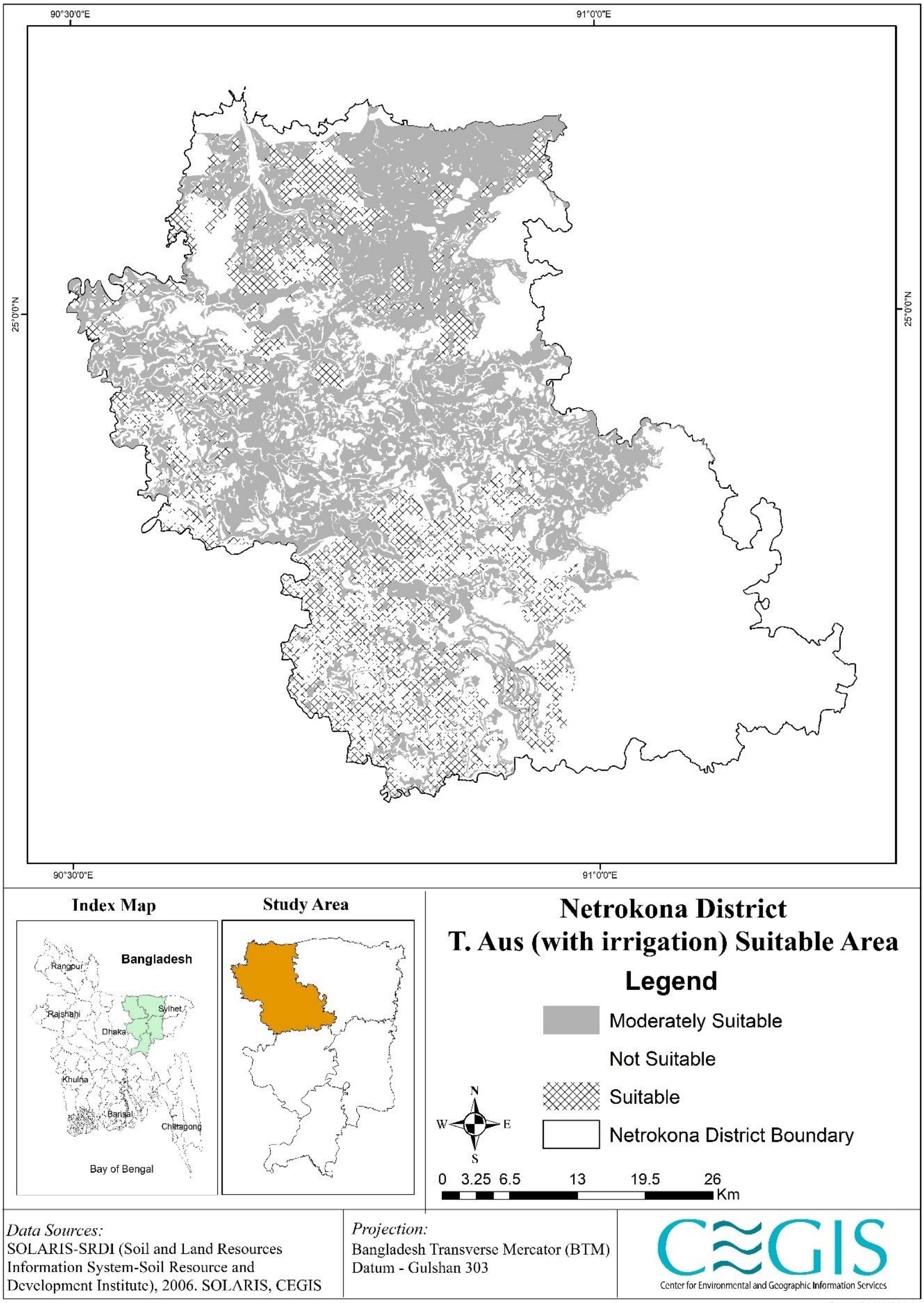
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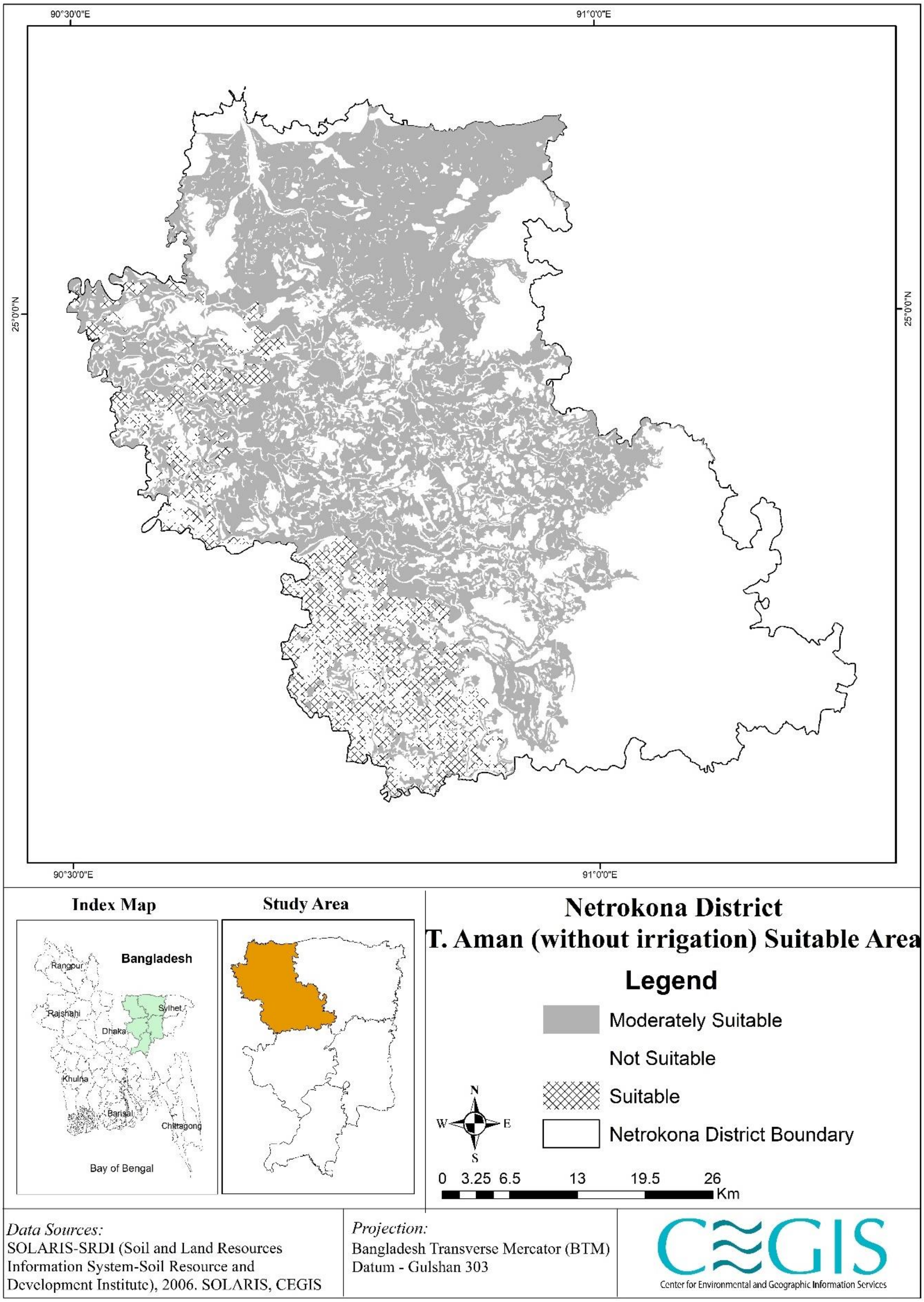
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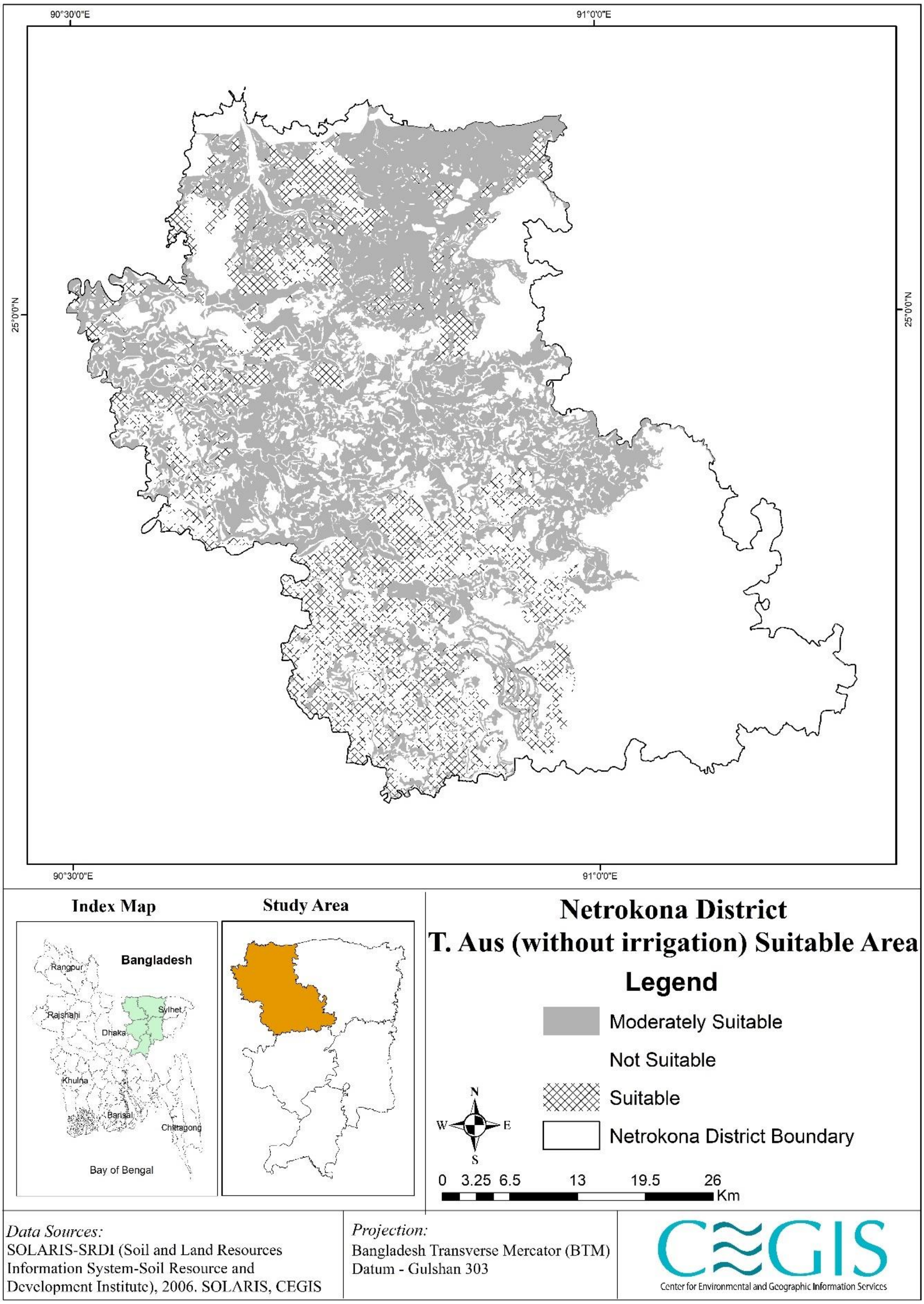

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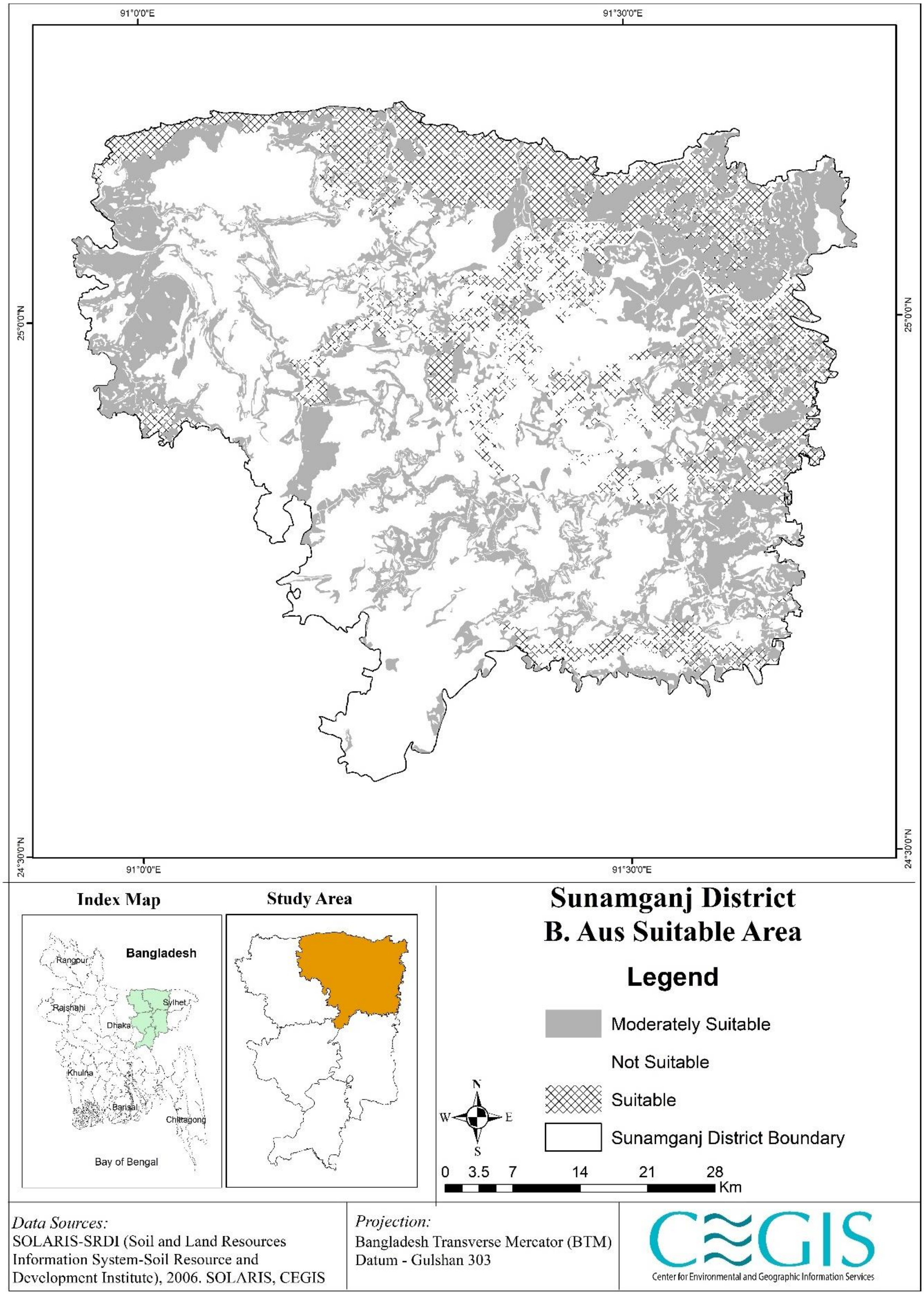
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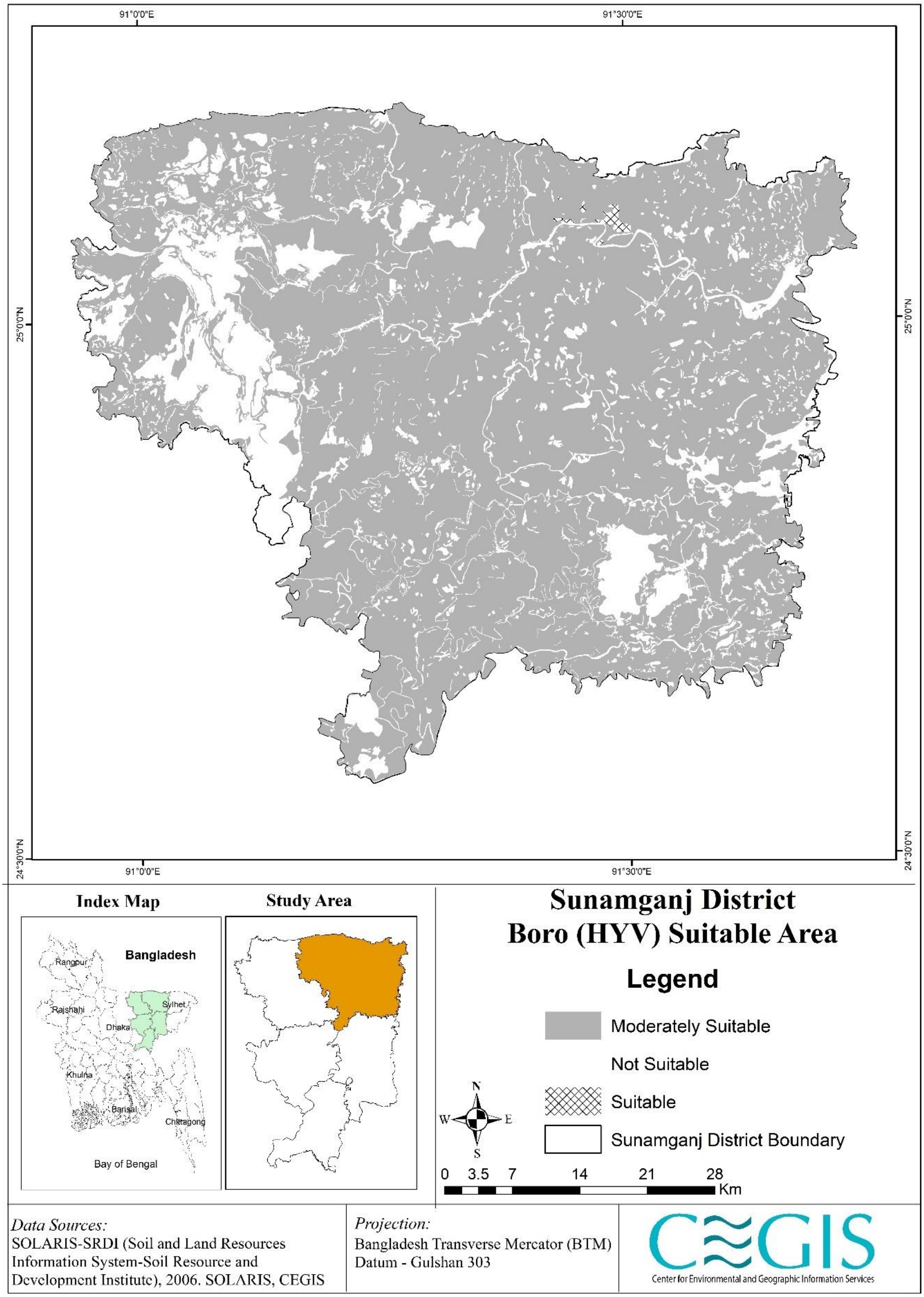
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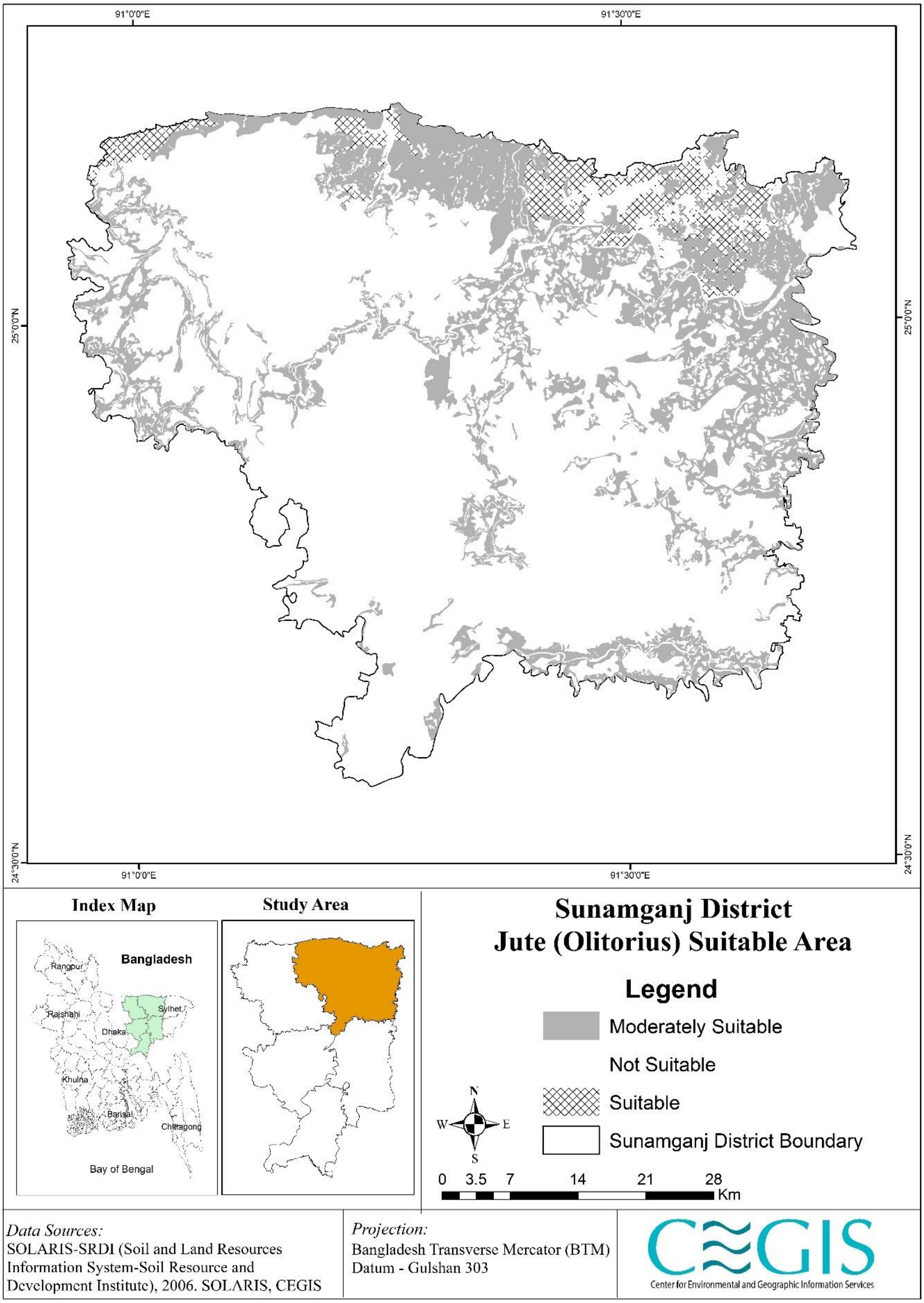

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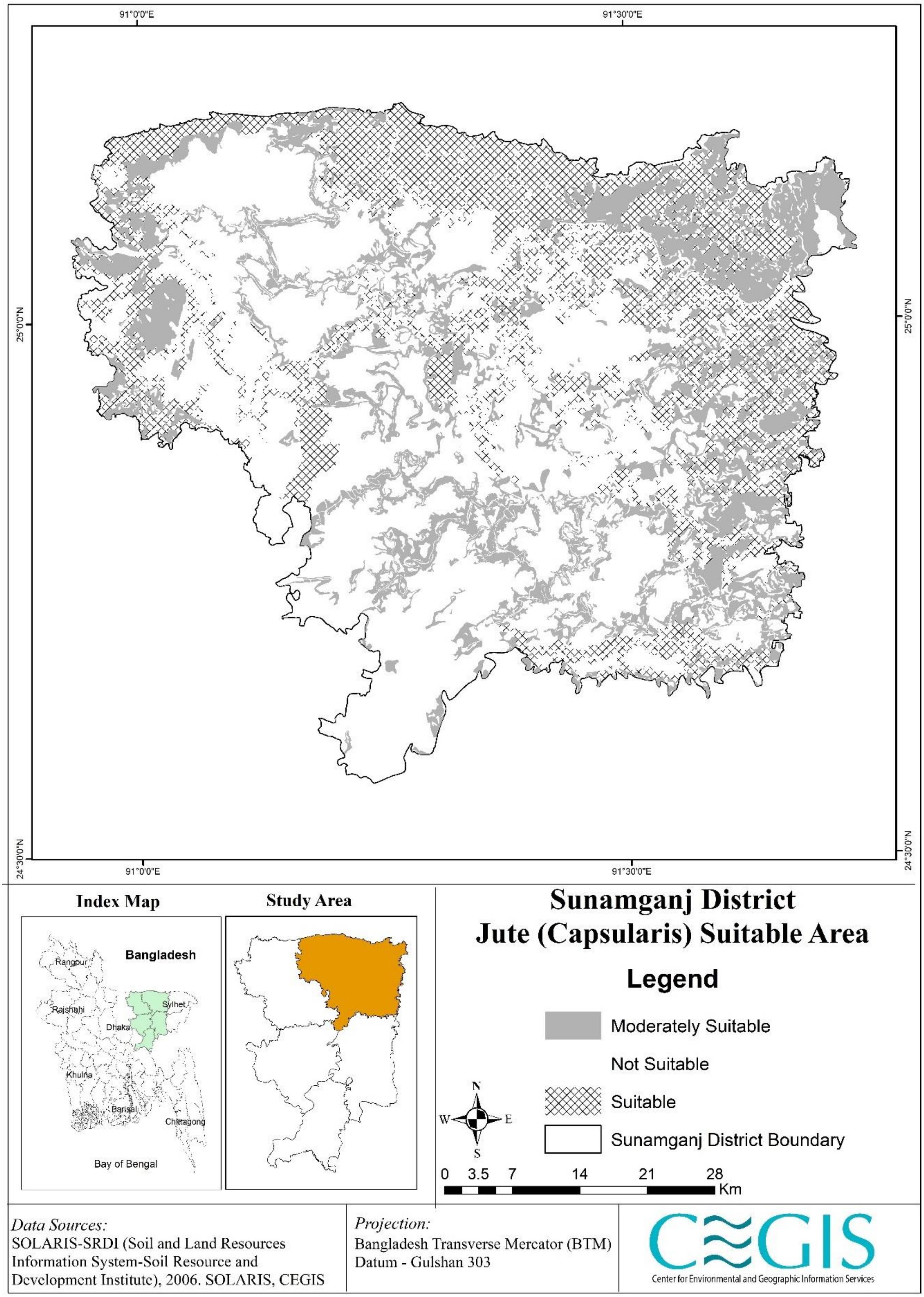

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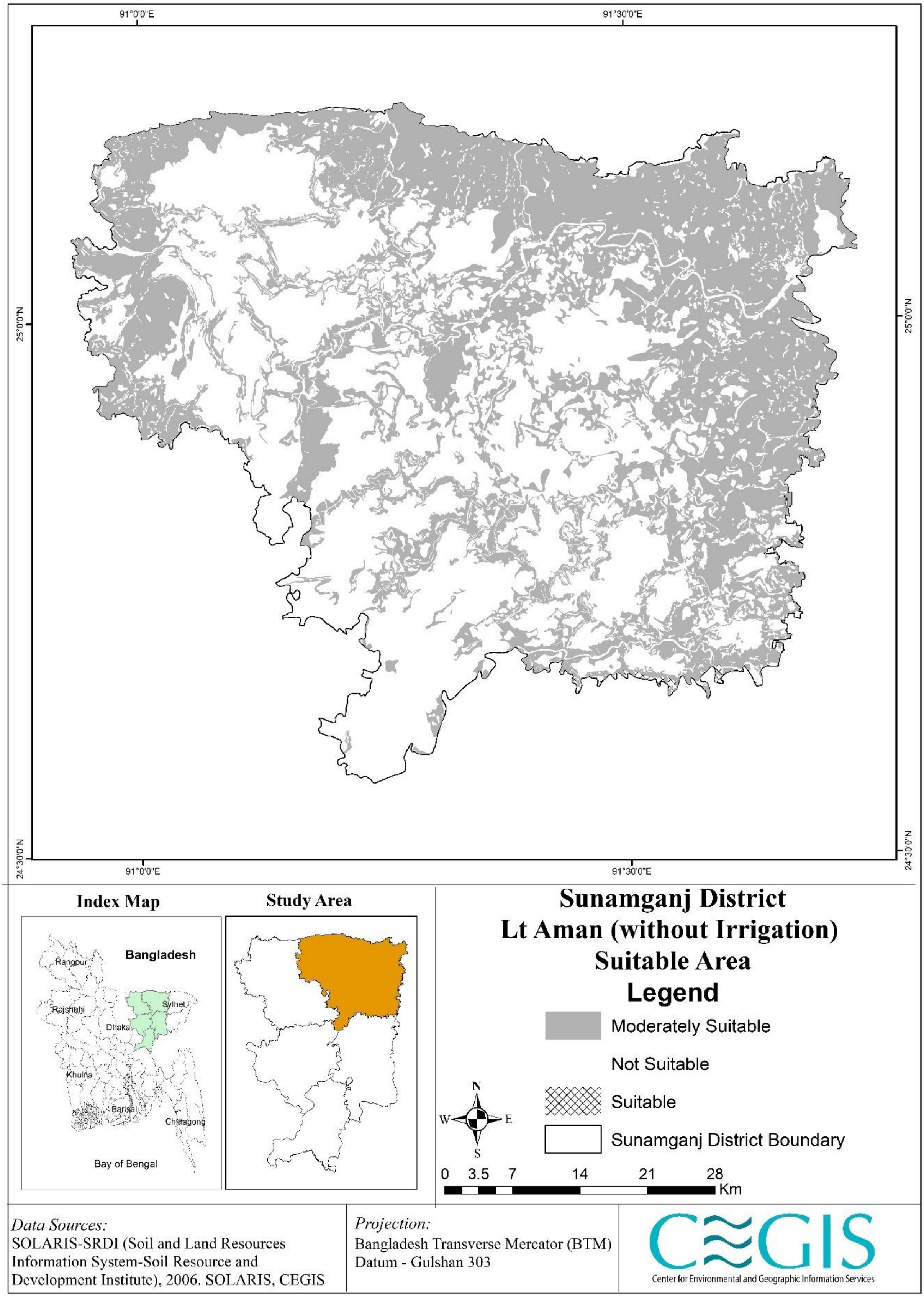
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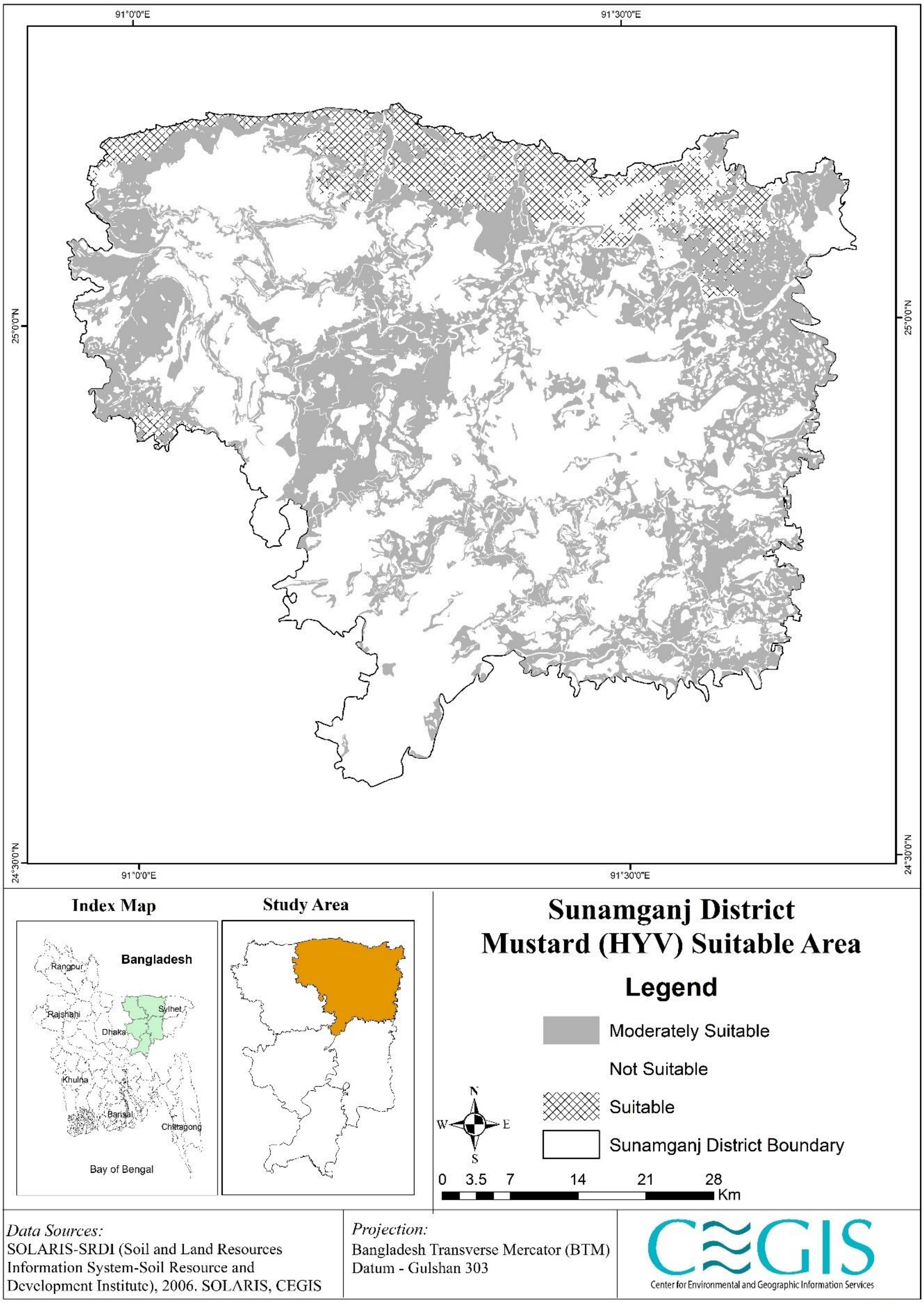

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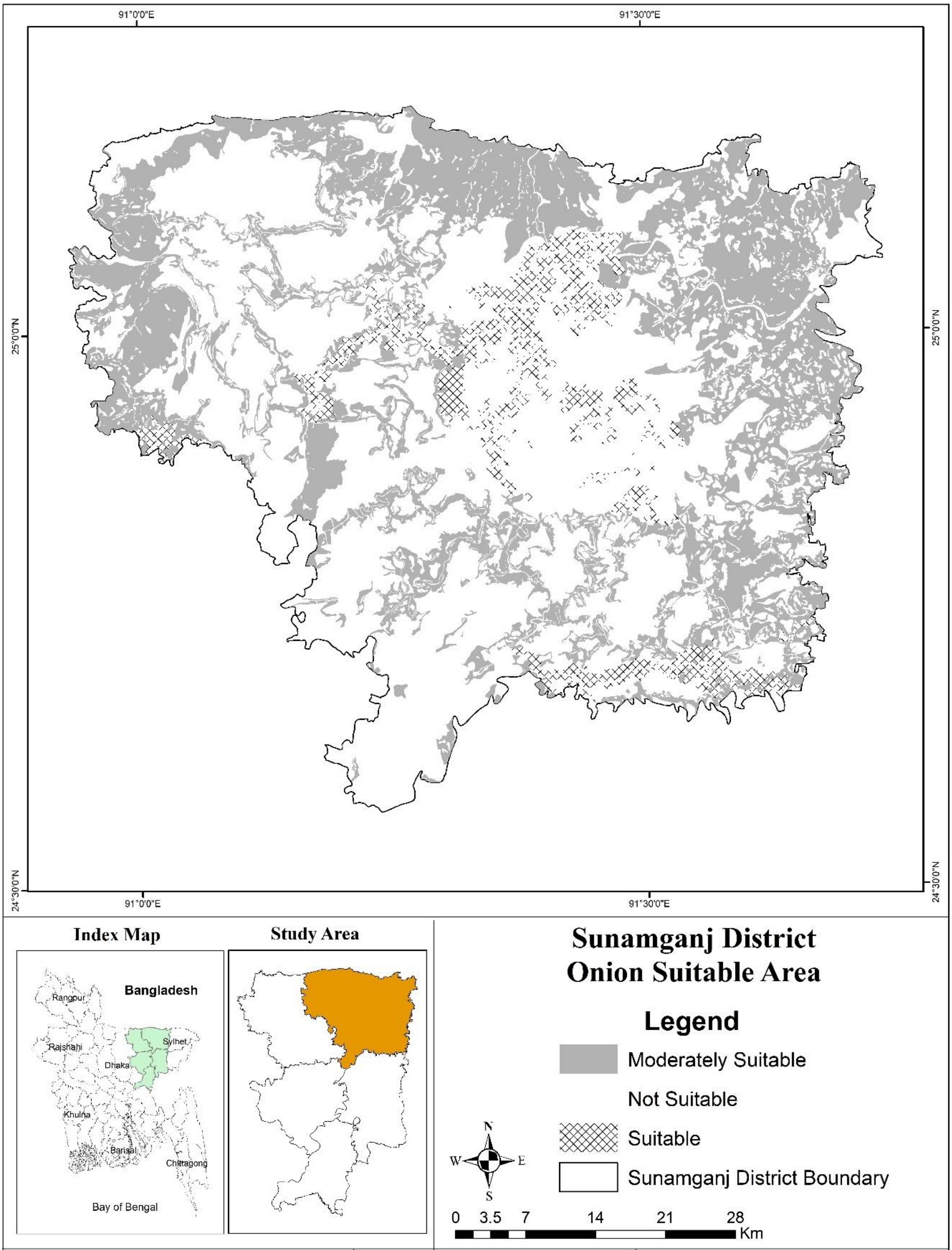

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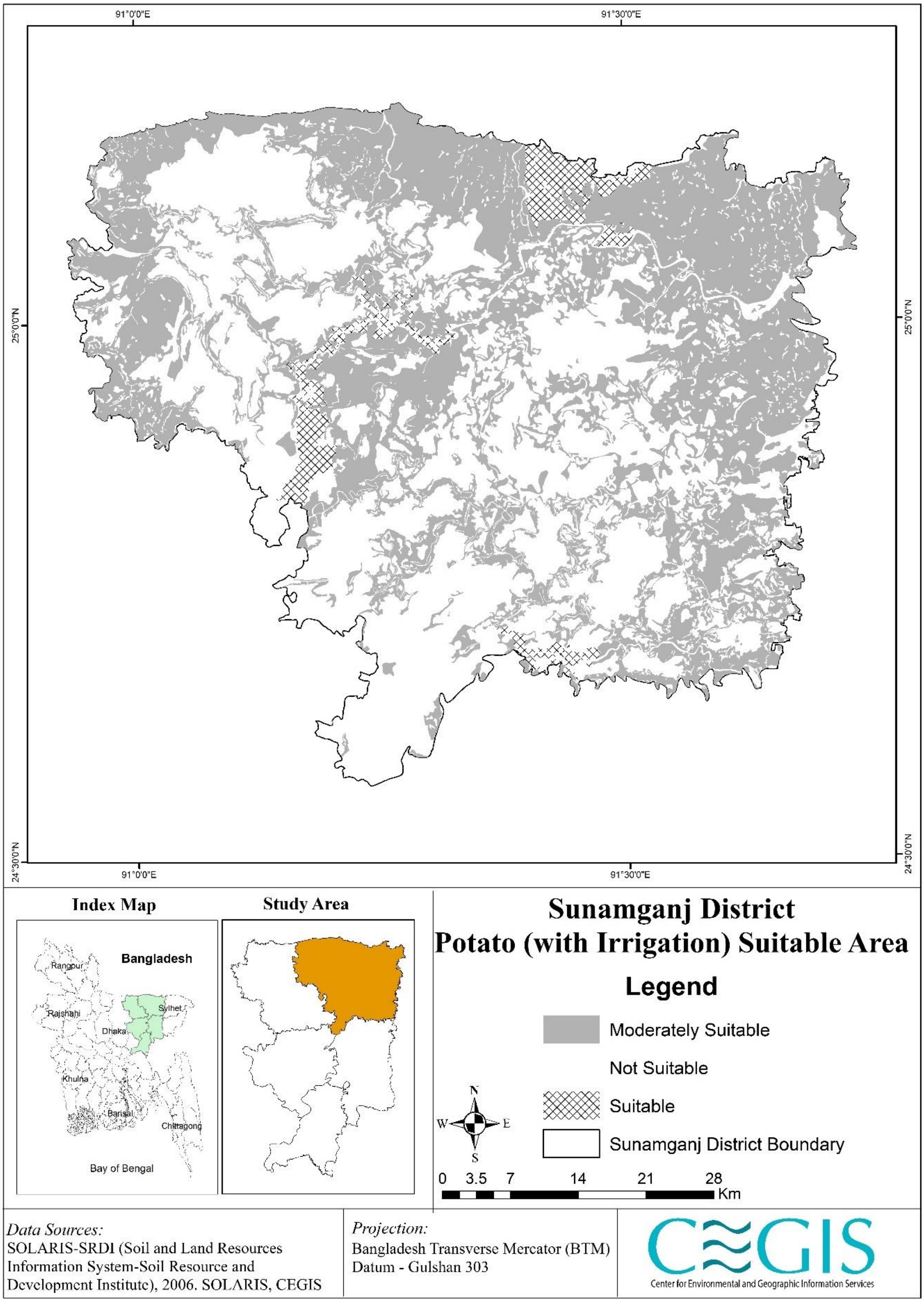
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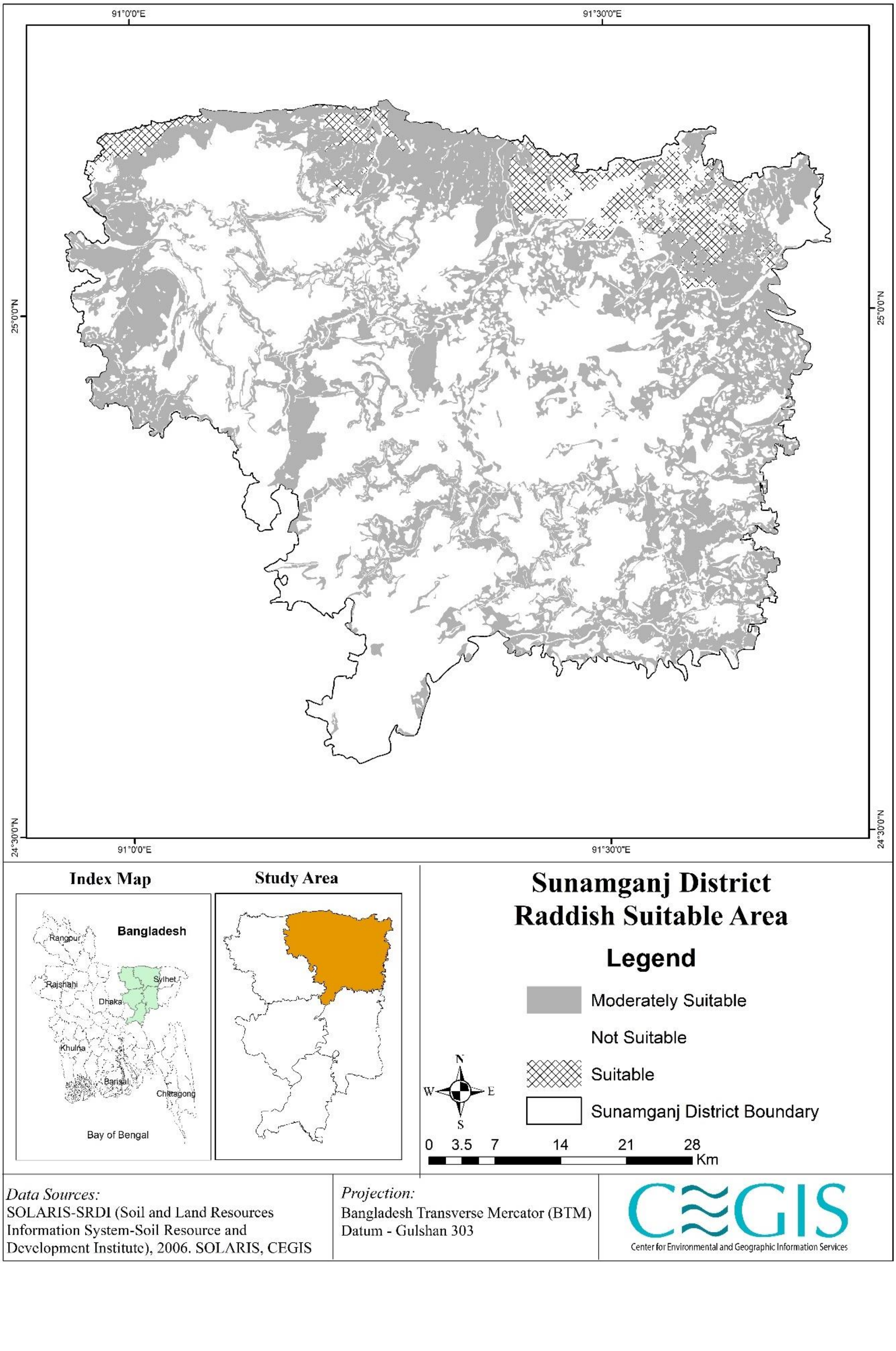
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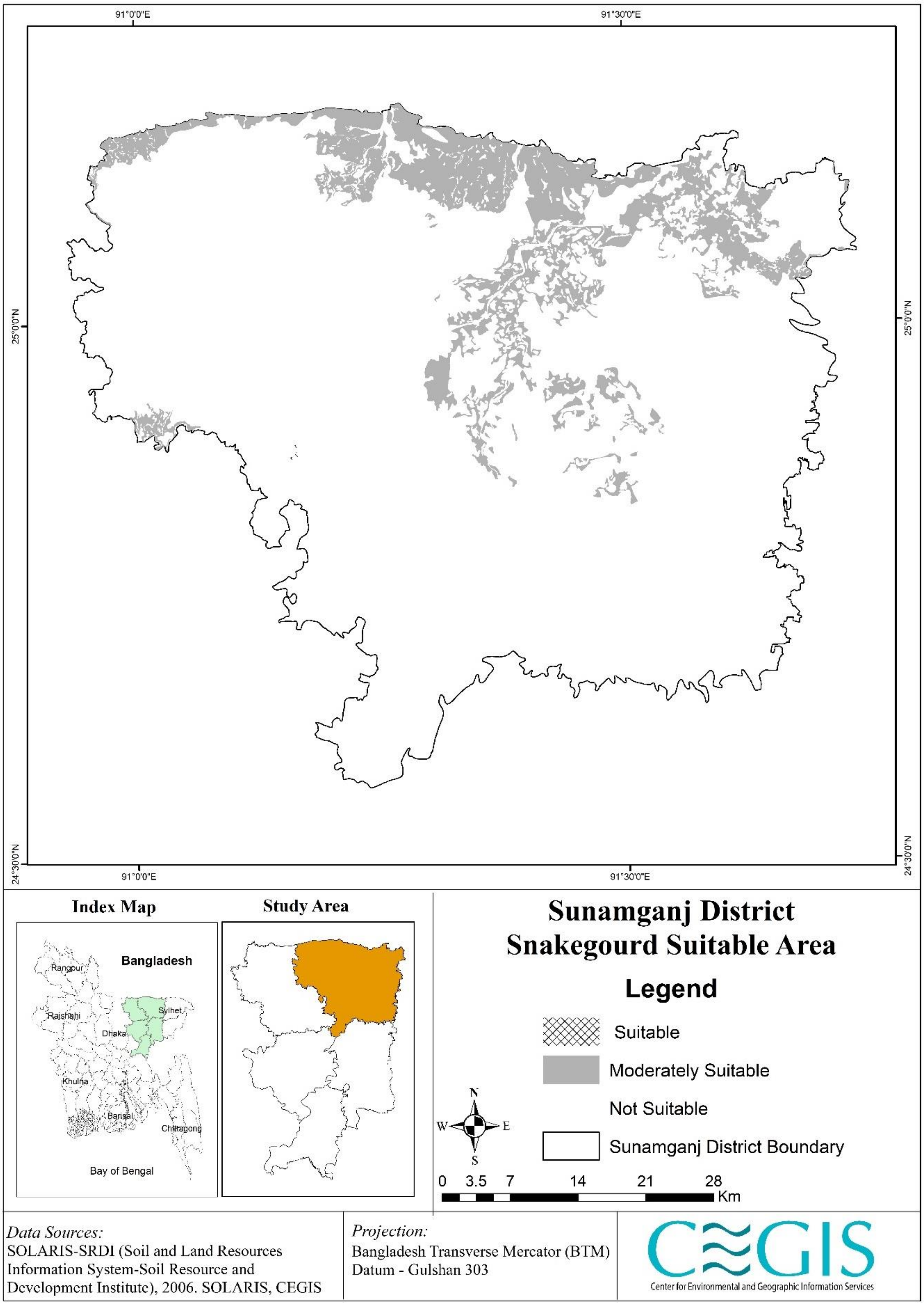
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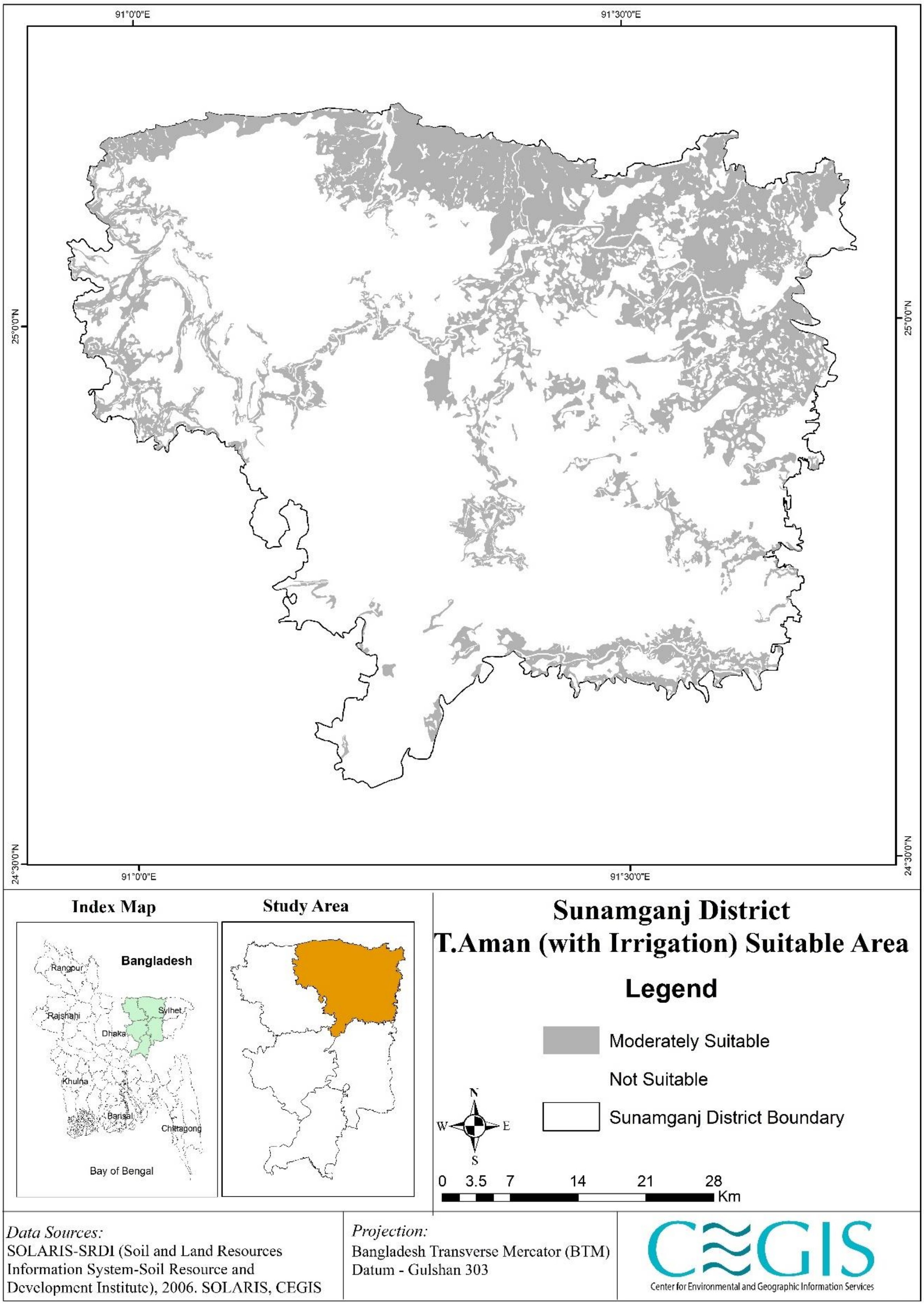
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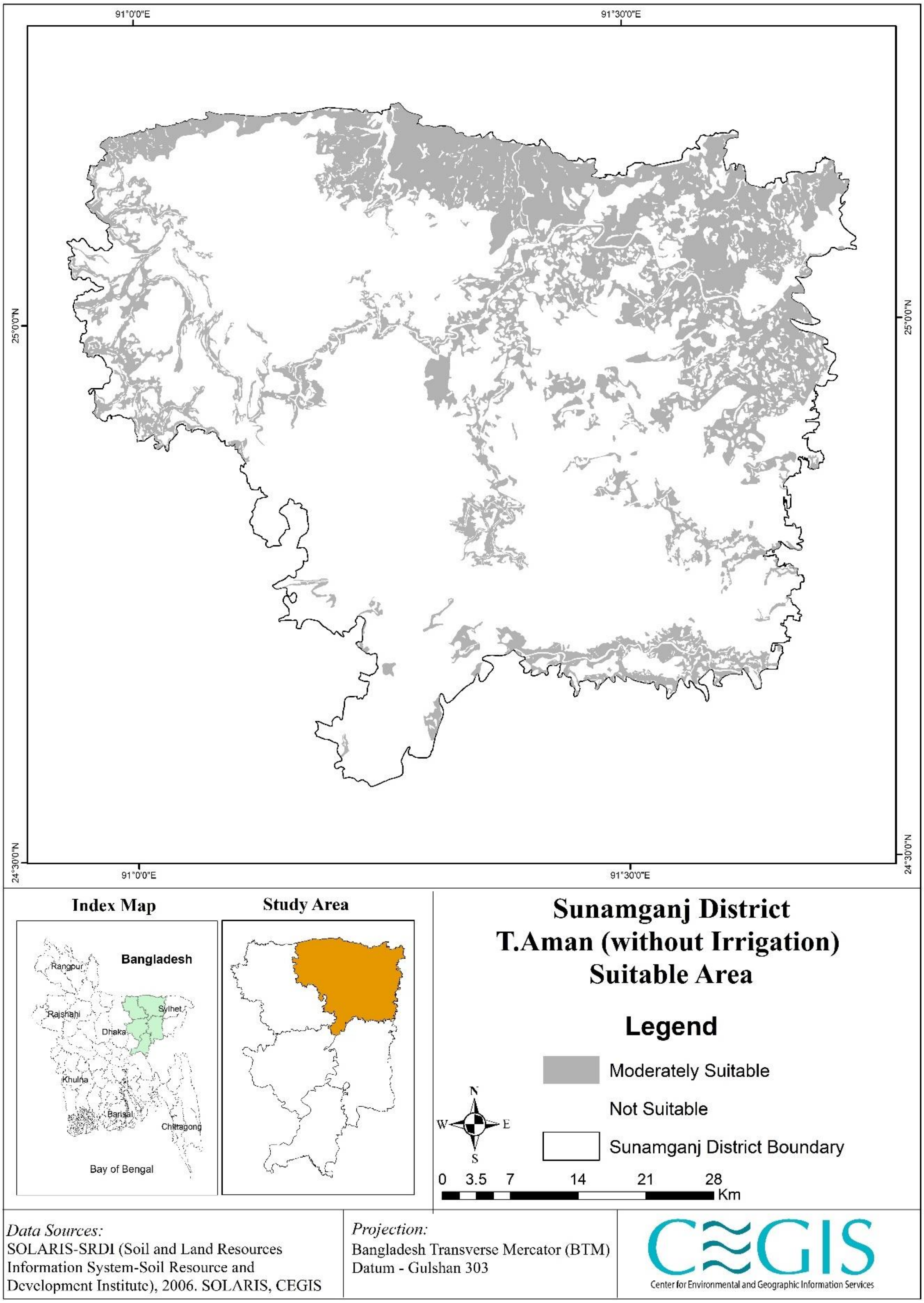
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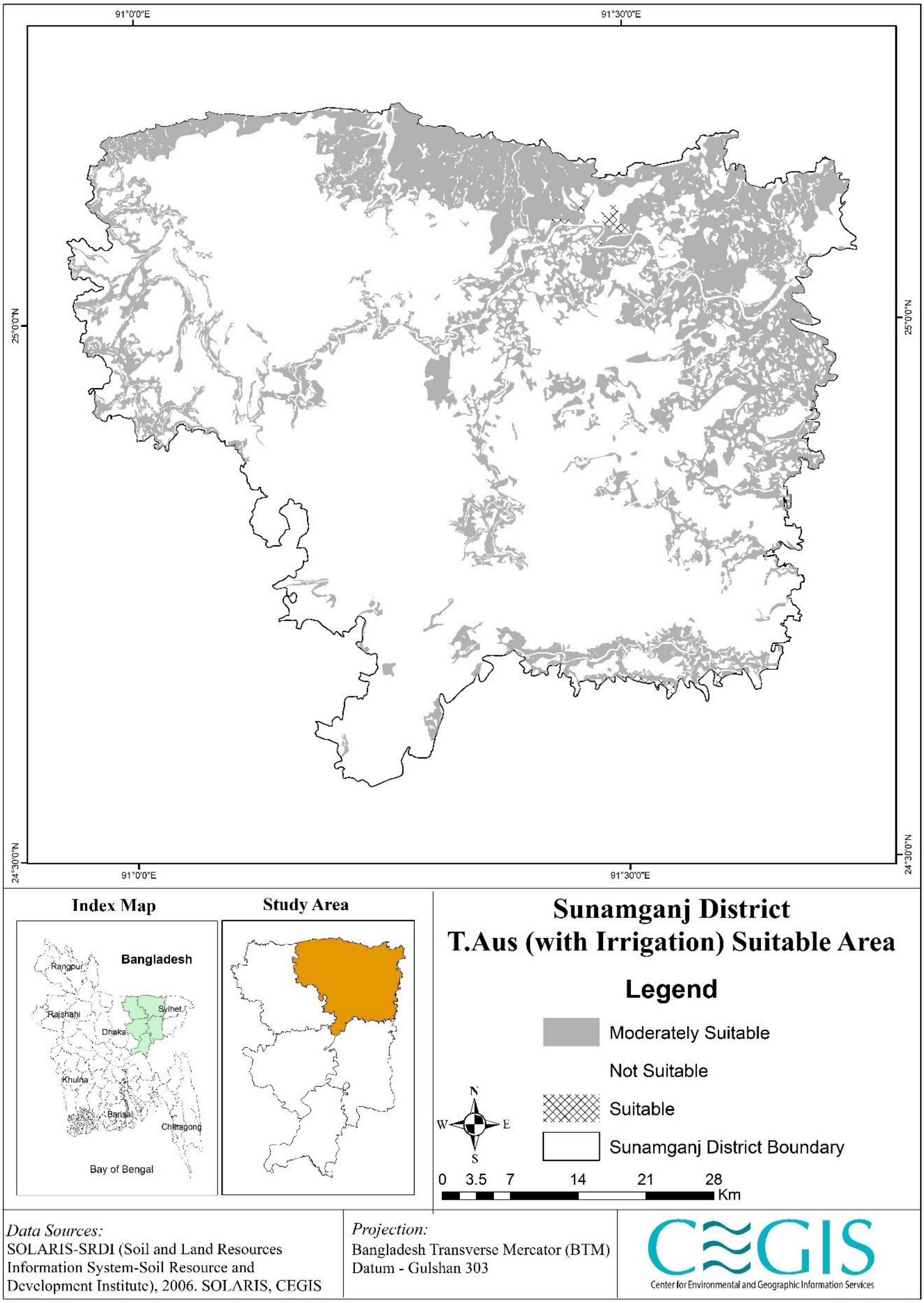
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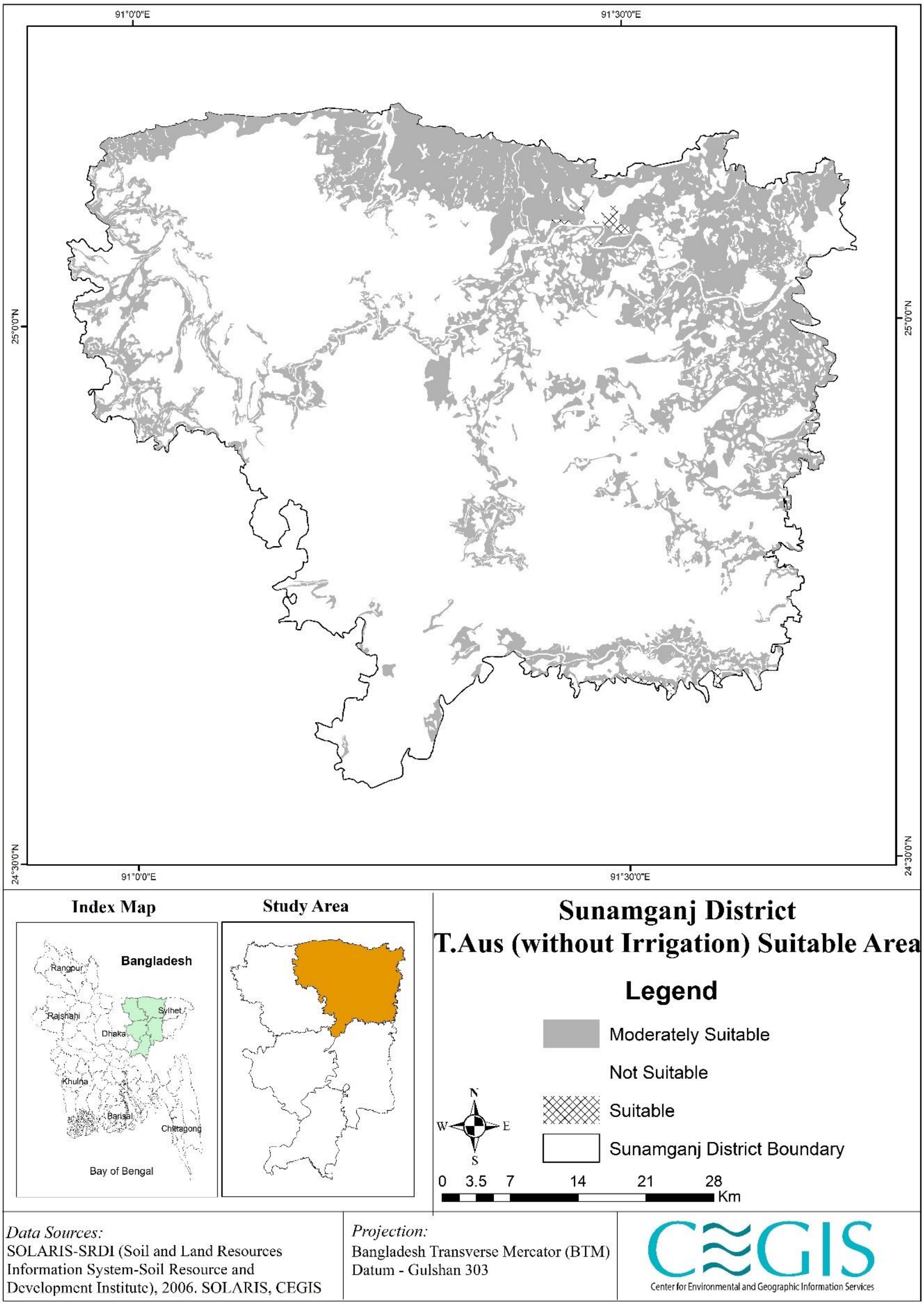
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Appendix 9: Article Submission Confirmation

North South University
Center of Excellence in Higher Education

Md. Shawkat Islam Sohel <shawkat.sohel@northsouth.edu>

Confirming submission to Global Ecology and Conservation

1 message

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Appendix 10: Comments and Responses Matrix

SL	Comments	Response
1.	What are the outputs from this project nationally and globally?	The outputs of this project are mentioned in executive summary section of this report. However, outputs are summarized below: • Highlights the potential of the economic and ecological significance of swamp tree nursery establishment & plantation in *Haor* areas; • Suggested best land management that increases the resilience of *Haor* ecosystem; • Suitable species and sites were identified for swamp plantation; • Swamp species flood flow reduction ability was quantified and suggested that mixed plantation of Hijol (*Barringtonia acutangula*), Koroch (*Pongamia pinnata*), Pitali (*Trewia nudiflora*), and Borun (*Crataeva magna*); • To quantify the impacts of tree planting and management on flood flows to help guide planting the right tree in the right place to reduce downstream flood risk; • Explored climate change mitigation potential through carbon sequestration ability of swamp forests and plantations; • Assess and evaluate forest resilience in the context of sustainable forestry, ecosystem service provision as well as recreation, sequestration, biodiversity, soil stability, GHG balance, and climate change mitigation in a wider mosaic of land use;
2.	Need to address the comments of inception report	Already addressed during inception report finalization process.
3.	Need to specify how and who are the stakeholders. As like LGED, DAE, BFD, DLS, etc.	For this whole study LGED, forest department, fisheries department, and Department of agriculture extension officers were interviewed together with local people. Please go through page 11 and the Appendix picture.
4.	Need to address the consultation Pictures	Few consultation pictures were given in the appendix section.
5.	It is necessary to specify how the *Haor* ecosystem can be harmed or damaged through the activities of LGED	To assess the impacts on *Haor* by LHED activities need different studies and different methods. Dynamism assessment of *Haor* Reforestation may not capture the whole picture of the impacts (positive or negative) of LGED activities.
6.	Please describe the combination of hazel and vetiver grass, where it will be planted	This has been addressed and please see Table 7.1 in Page 60.
7.	Pictures of the plant species and photo names are required	The pictures have been added to the report for the species of Hijol. Koroch, Murta and Vetiver.
8.	The status of plant species, such as IUCN, CITES needs to be addressed	This has been addressed and please see Table 7.1 in Page 60.
9.	Climate change impact trend in *Haor* area	In Chapter 7, we showed suitable sites for dominant species based on climate model.
10.	Need to analyze about soil parameter in the *Haor* area	Please go through Chapter 8, Page 73.
11.	Find out how much Swamp Forest is, how it relates to other sectors and the impact also?	Please go through Chapter 10.

SL	Comments	Response
12.	Need to guideline, how will be used the output of this research in future projects?	Please go through Chapter 12.
13.	Please include the name of LGED in the publications	Mr. Gopal Chandra Sarker, PD, HILIP and Md. Sadequr Rahman Bhuiyan, Climate Change Specialist of HILIP Project has been considered as Co-Authors of the Submitted article. The Confirmation of the Article Submission is Presented in Appendix 9.
14.	User manuals in English and Bengali versions are required for specific stakeholders and beneficiaries. (Officer of LGED, Local people, Owner of nurseries, etc.)	Manual preparation was not a scope of work under the study. That was a request from the LGED officers during the Draft Final Workshop. Therefore, CEGIS is going to submit the Manual in both English and Bengali Version very soon to LGED.
15.	The landuse projections should be generated district-wise and accordingly linked with the recommendations	District-wise information for the landuse has been generated.