Jagannath University Journal of Life and Earth Sciences, **8**(1) pISSN 2414-1402, eISSN 2791-1845

Research Article JnUJLES

LAND SUITABILITY ANALYSIS FOR ONION CULTIVATION IN FARIDPUR DISTRICT USING GEOSPATIAL TECHNIQUE

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Received: 03 July 2022, Accepted: 10 November 2022

ABSTRACT

Allium cepa commonly known as onion is an underground bulb-shaped vegetable considered a staple spice in Bangladeshi cuisines. The onion seeds are also called "Black Gold" by the local farmers in Bangladesh. The farmer of Faridpur District has produced almost 75 % of total onion seeds. However, in recent years, Bangladesh has faced a shortage of onions due to several geopolitical and environmental issues. To meet the enormous demand for this spice in this country, it is crucial to conduct land suitability analysis for onion production. The main objective of this research is to identify suitable sites for onion production in Faridpur district. In this study, eight different onion production influencing factors (elevation, slope, drainage density, soil texture, soil permeability, land use and land cover, rainfall, and a modified normalized difference water index) were used. The final land suitability map for onion production has been prepared by integrating these eight spatial criteria through overlay analysis in the GIS platform, where multicriteria decision-making (MCDM) techniques, for example, the analytic hierarchy process (AHP) is used to find the normalized weights of criteria before overlaying operations. The final output map has been split into five categories: highly suitable, moderately suitable, marginally suitable, moderately unsuitable, and highly unsuitable. In Faridpur district, approximately 19.48% of the total land is "highly suitable" to "moderately suitable" for onion farming. Also, about 48.16%, 28.83%, and 3.54% of the land in this study area is marginally suitable, moderately unsuitable, or highly unsuitable for growing onions. These resulting maps can be helpful for the farmers of the studied area to select suitable land for onion production. Besides, the results of this research will also help agriculture officers, planners, and policymakers make decisions in the agricultural sector.

Keywords: *Land suitability analysis, Onion (*Allium cepa*), Spatial criteria, Faridpur, GIS*

Introduction

The onion has been considered one of the most fundamental ingredients or spices in the kitchen, which generally makes the dishes tasty and spicy. This spice is commonly used in almost every

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curry and salad item (Huda *et al.*, 2008; Rana *et al.*, 2021). Onion has also been dominant in making several food items such as gravies, stew stuffing, meat, fried fish, and soups (Ali *et al.*, 2007; Hossain *et al.*, 2017). It also has a number of health benefits, like reducing inflammation, lowering triglycerides, and lowering cholesterol (Sharma *et al.*, 2017). Onion leaves and stems are also high in vitamin C and calcium. As a result, this crop has been treated as a highly valuable economic crop worldwide. China, India, and the United States are the top 3 most prominent producers of onions and produce 26%, 21%, and 3% of the world's total onion production, respectively. Faridpur, Madaripur, Kushtia, Pabna, Rajbari, Rajshahi, Manikganj, Jhenaidah, and Magura are the major onion-producing districts for commercial purposes in Bangladesh, while approximately 79% of onion production areas have been covered by these regions (BBS, 2018). In 1999, 2006, 2012, 2015, and 2017, Bangladesh cultivated 134, 769, 1159, 1704, and 1866 thousand tons of onion (BBS 2017). As per the estimation of the Department of Agricultural Extension, Bangladesh had produced 33.62 lakh tons of onions in the 2020–21 fiscal year (The Daily Star, 2022). In 2018, the onion production in the country increased by 59 percent compared to 2012–2013 (Ahmed and Hoque, 2019). From 1961 to 1970, the average production of onions in Bangladesh had increased from 159910 to 1476214 metric tons during the years of 2011 to 2018 (Mila & Parvin, 2019; Rana *et al.*, 2021). Though the quantity of onion production in our country has been increased compared to earlier period, still per unit yield rate of onion don't capable to meet the country's needs properly. As a result, Bangladesh has to import 700 to 800 thousand metric tons of onion from India which is the world's second largest onion producing country (Mila and Parvin, 2019). But in 2019, a trouble had been faced by the whole country when India announced that they do not export onion to Bangladesh for some months due to floods & heavy rain. In that period onions were selling for Tk 250 (3 USD) a kilogram, while the regular price of onion is Tk 40 (US 0.40 C) per kilogram (Rahman, 2020). After the year of 2019, almost every year this crisis has been faced by the whole country. To increase the production of onion is one of the best solutions to remove this crisis. As a result, to identify suitable land for onion production is of paramount importance which helps to increase onion production. Several researches have been done by different researchers in different places of Bangladesh to identify suitable land for different types of crops using geospatial techniques in North Western part of Bangladesh (Mostafiz *et al.*, 2021); Coastal region of Bangladesh (Hossen *et al.*, 2021), Cox's Bazar Sadar Upazila (Hoque and Hossain, 2018), Northern part (Rangpur, Lalmonirhat, Kurigram) of Bangladesh (Islam *et al.*, 2018), Panchagarh and Thakurgaon (Uddin *et al.*, 2020). Unfortunately, there is no intensive research work has been founded which considers identifying suitable land for onion cultivation. So, this study was undertaken to fill up this research gap. The main objective of this study is to combine eight parameters or thematic layers for delineating suitable land for onion production with the help of Geographic and Information System (GIS). The main outcome of this study will be very helpful to give a broader view for locating more suitable place for onion cultivation which helps to increase onion production in the study area.

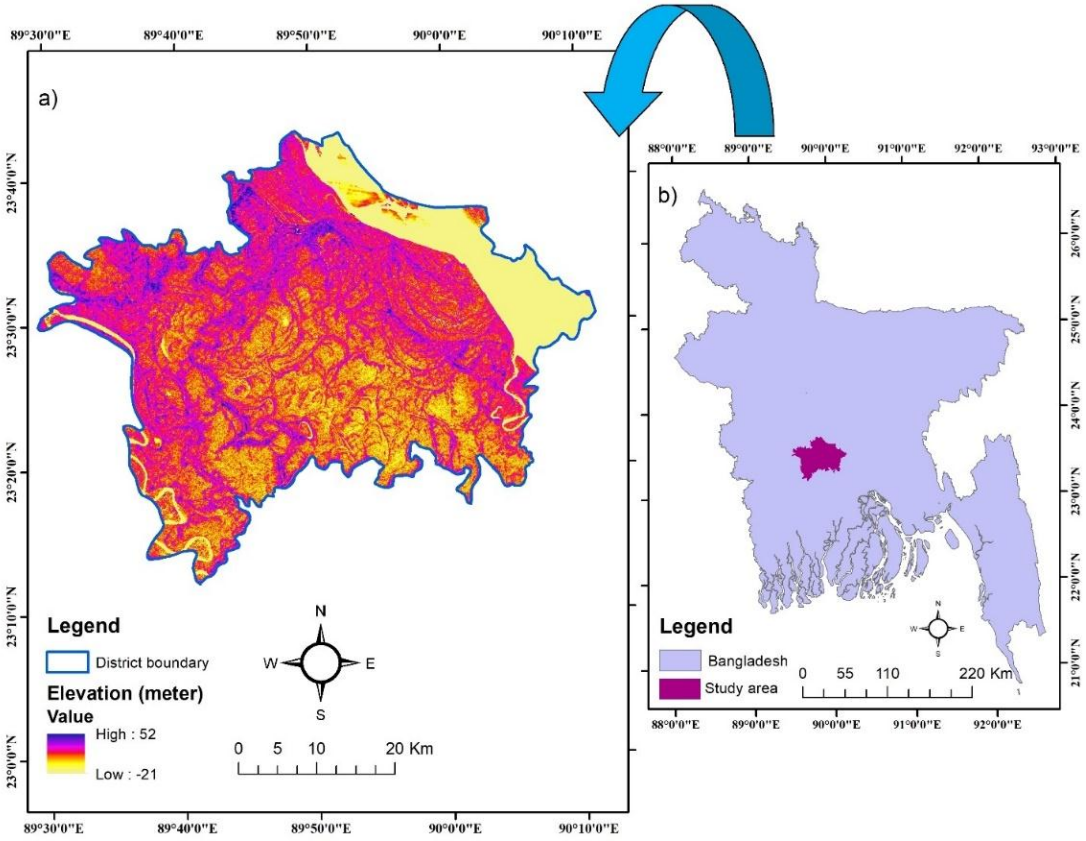

Fig. 1a) Study area (Faridpur district), 1b) Bangladesh map indicating study area as purple color.

Study area

The study was conducted in Faridpur district (Fig. 1a) which consists of nine upazila and occupying 2072.72 square kilometers. This proposed study area lies between 23°17' N to 23°40' N latitudes, and in 89°29' E to 90°11' E longitudes while it is surrounded by Shariatpur, Gopalganj, Madaripur & Rajbari districts (Islam *et al.*, 2017; Sikder, 2021). The Padma is major important permanent river which has been passed besides the Faridpur district. According to BBS 2011, approximately 2 million people live in Faridpur district, where maximum people (1.4 million) live in rural areas. May has been considered as the hottest month of the year in the study area with maximum and minimum average temperature is 33.88°C, 26.11°C respectively, and January is the coldest month having an average low of 13.33° C and high of 23.88° C. As the weather and soil of Faridpur district is suitable for onion cultivation it has been acted as a major hub for onion seed production for years. The appropriate time for onion cultivation is the 1st week of November to the 2nd week of December, while the harvesting period has been begun from the 1st week of April (Das, 2021).

Data sources & Methodology

The site suitability map for onion cultivation of Faridpur district had been evaluated by using 8 several parameters such as slope, elevation, drainage density, rainfall, soil texture, soil permeability, land use/land cover (LULC), modified normalized difference water index (MNDWI). These eight thematic layers had been collected from several secondary data sources (Table 05). Slope, elevation & drainage density maps were produced from SRTM (Shuttle Radar Topographic Mission) Digital elevation model (DEM) at 30-meter spatial resolution. Soil texture & soil permeability maps were acquired from M. Islam *et al.*, (2017) & Bangladesh Agriculture Research Council (BARC) respectively. The rainfall data had been collected from the NASA POWER Data Access Viewer to make annual rainfall map of Faridpur District from the year of 1981 to 2015. Besides, MNDWI & LULC map had been extracted from LANDSAT Image and GlobeLand30. The whole methodological steps of this research have been presented in figure 2. Eight thematic layers had been superimposed through overlay operation in Arc GIS 10.5 software to delineate land suitability map for onion farming in our studied area. Before overlaying operation, it is very necessary to convert all the vector format of maps into raster format and give normalized weight to every single parameter which is based on analytical hierarchy process. These eight thematic layers having crucial control on onion cultivation. Besides, every single parameter also had been reclassified for assigning the rank ranging from 1 to 5 according to literature review, stakeholder opinion, farmer's suggestions & field survey experience.

Analytic hierarchy process (AHP)

Analytic hierarchy process (AHP), a decision-making model which had been first built up by Saaty to decide weightage for multiple factors. This method is not only acted as a decision-making process but also revealed the consistency of decisions. In AHP, a comparison matrix ($M_{n\times n}$) has to build where n indicates the total number of criteria which is used in this research.

$$M_{n\times n} = \begin{bmatrix} 1 & x & y \\ 1/x & 1 & z \\ 1/y & 1/z & 1 \end{bmatrix}$$

Here, every element of matrix (M) describes the relative importance between two different parameters by using AHP evaluation scale (Table 2) (Saaty, 1980). Before calculating the normalized weight value of each criterion, we have to measure the geometric mean (G.M), using following Equation (1). At the later stage, Equation (2) has been adopted to calculate the normalized weightage value.

$$G.M = [\prod_{i=1}^{n} a_{ij}]^{1/n} \quad (1)$$

$$W = G.M / \sum_{i=1}^{n} G.M \quad (2)$$

The accuracy of weight determination process in AHP has been examined by using Equation (3) for calculating the value of consistency ratio (CR). For calculating consistency ratio (CR), it is highly necessary to calculate consistency index (CI) (Munkhbat & Choi, 2021). The value of CR must be equal or less than 0.1 for confirming a rational result (Saaty, 2008).

$$CR = CI/ RCI \quad (3)$$

$$CI = (\lambda max-N)/(N-1) \quad (4)$$

Here, λmax = Maximum eigenvalue; RCI = Random consistency index

Table 1. Random consistency index (RCI) Source: (Saaty, 1990)

n	1	2	3	4	5	6	7	8	9	10	11	12
RCI	0.0	0.0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48

Table 2. Evaluation scale (Likert scale) of AHP. Source: (Uyan, 2013; Saaty, 1990)

Scale	Preference degree
1	If the importance of i and j is equal
3	If i is slightly important than j.
5	If i is strongly important than j.
7	If i is extremely important than j.
9	If i is absolutely important than j.
2,4,6,8	Intermediate values.
Reciprocal of above values	If activity i has relative significance of a_{ij} when compared with activity j, then j has importance $1/a_{ij}$ when compared with i.

Table 3. Developing Comparison matrix & determining weight for 8 parameters. CR value = 0.02 and λmax= 8.21

Criteria	SL	LULC	EV	DD	ST	SP	MNDWI	RF	Weight (wi)
Slope	1	2	4	4	5	6	7	8	0.33
LULC	1/2	1	2	3	4	5	6	7	0.23
Elevation	1/4	1/2	1	2	2	3	4	5	0.14
Drainage density	1/4	1/3	1/2	1	2	3	4	5	0.11
Soil texture	1/5	1/4	1/2	1/2	1	2	3	4	0.08
Soil permeability	1/6	1/5	1/3	1/3	1/2	1	2	3	0.05
MNDWI	1/7	1/6	1/4	1/4	1/3	1/2	1	2	0.04
Rainfall	1/8	1/7	1/5	1/5	1/4	1/3	1/2	1	0.03

Table 4. Assigned weightage to all thematic layer and ranked every sub feature of each thematic layer

Thematic layer	Classes	Weight (wi)	Rank (r)
Slope	(0 - 0.8935) °	0.33	5
	(0.8936 - 1.936) °		4
	(1.937 - 3.276) °		3
	(3.277 - 5.659) °		2
	(5.66 - 37.98) °		1
LULC	Artificial surface	0.23	1
	Cultivated land		5
	Bare land		3
	Water bodies		1
	Grass land		4
	Forest		3
	wetland		2
Elevation	(-21 to 4) meter	0.14	5
	(4 to 8) meter		4
	(8 to 11) meter		3
	(11 to 23) meter		2
	(23 to 52) meter		1
Drainage density	(0 - 0.5415) km/km^2	0.11	5
	(0.5416 - 0.9097) km/km^2		4
	(0.9098 - 1.235) km/km^2		3
	(1.236 - 1.646) km/km^2		2
	(1.647 - 2.762) km/km^2		1
Soil texture	Clay	0.08	2
	Clay Loam		3
	Sandy Clay Loam		4
	Sandy Loam		5
Soil permeability	Moderate	0.05	5
	Mostly Moderate		4
	Mixed Moderate & Slow		3
	Mostly Moderate WS Slow		3
	Mostly Slow		2
	Slow		1
MNDWI	-0.4981 to -0.2564	0.04	1
	-0.2563 to -0.1547		2
	-0.1546 to 0.03188		3
	0.03189 to 0.3202		4
	0.3203 to 0.5831		15
Rainfall	(1245.992188 to 1422.02429) mm/year	0.03	3
	(1422.024292 to 1585.70251) mm/year		4

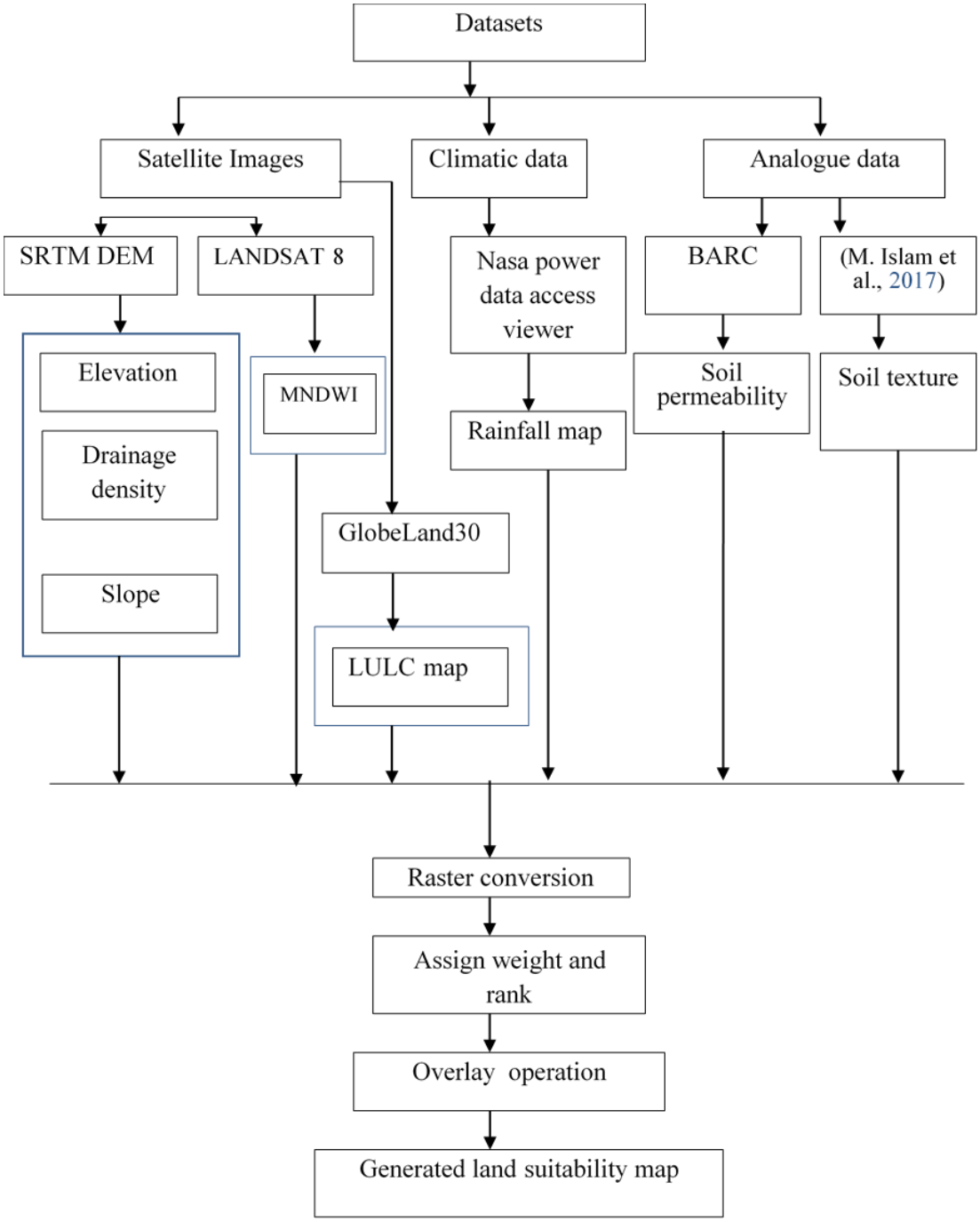

Fig. 2 Flowchart of methodology.

Table 5. Data sources

Data	Sources	Year
Study area	DIVA-GIS	N/A
Digital elevation model	(USGS 1 arc second), UTM-45, WGS 1984.	2014
Land use land cover	GlobeLand30.	2020
MNDWI	Landsat 5 (TM) & Landsat 8 OLI, United States Geological Survey Earth Explorer.	2020
Slope	DEM (USGS 1 arc second), UTM-45, WGS 1984.	2014
Drainage density	DEM (USGS 1 arc second), UTM-45, WGS 1984.	2014
Soil texture	M. Islam *et al.*, 2017	N/A
Soil Permeability	Bangladesh Agriculture Research Council (BARC).	1988
Rainfall	NASA POWER Data Access Viewer.	1981 - 2015

Results and Discussion

The following sections have been focused on the outcome & discussion of this study along with consisting of two several sections such as development of thematic layers and generation of land suitability map.

Development of thematic layers

Slope

Slope plays a crucial role for selecting suitable site of onion cultivation by determining the runoff infiltration rate and quality of sedimentation in a specific area (Biswas *et al.*, 2020, Rana *et al.*, 2022a). In this study, Arc GIS 10.5 software had been used for making slope map (Fig. 3c) and it ranges between 0 ° to 37.98 °. Besides, the slope map also had been split into 5 classes such as (0 - 0.8935) °, (0.8936 - 1.936) °, (1.937 - 3.276) °, (3.277 - 5.659) °, (5.66 - 37.98) ° which occupies 27.56%, 38.65%, 25.99%, 7.20%, 0.60% land of the study area respectively.

Elevation

The elevation map (Fig. 3g) of Faridpur district had been prepared from SRTM data and classified into 5 classes namely, (-21 to 4)m, (4 to 8)m, (8 to 11)m, (11 to 23)m, (23 to 52)m. Low elevated area is highly associated with high infiltration rate & drainage density which is very good for onion production. As a result, the class along with low elevation value was assigned the highest rank, while class having high slope value was assigned the lowest rank.

Drainage density

Drainage density has been measured with the help of several information which are based on runoff infiltration rate, relief and permeability (Roy *et al.*, 2020). Numerous landscape data, including run-off, penetration, relief, porosity, and infiltration rate, may be easily determined using drainage density (Rana *et al.*, 2022b). A high drainage density area is less favorable for producing onion than the low drainage density region. For this reason, low rank had been given to high drainage density area and vice versa. The drainage density map (Fig. 3b) of the study area were prepared by using spatial analysis tool in Arc GIS software and reclassified into 5 classes: (0 - 0.5415) km/km^2, (0.5416 - 0.9097) km/km^2, (0.9098 - 1.235) km/km^2, (1.236 - 1.646) km/km^2, (1.647 - 2.762) km/km^2.

Land use/ land cover

The LULC map of the study area is shown in figure 1a which had been derived from the GlobeLand30. Generally, GlobeLand30 provides land cover data of the whole world which resolution is 30-m and National Geomatics Center of China had been prepared it by applying a Pixel-Object-Knowledge approach. GlobeLand30 claimed that their total accuracy of LULC map is 85.72%, where Kappa coefficient is 0.82. The LULC map of Faridpur district had been divided into 7 classes: cultivated land, water bodies, forest, artificial surface, grassland, wetland & bare land.

Rainfall

Onion don't grow well neither in heavy rainfall nor in low rainfall. It grows well in that area which contains moderate rainfall along with good drainage system. The rainfall data had been derived from NASA POWER Data Access Viewer and IDW interpolation method was used for producing rainfall map (Fig. 3e) in Arc GIS software. The value of rainfall ranges between 1422.024292 mm/year to 1422.02429 mm/year in our study area.

Soil texture

Onion can be planted on several types of soil, but medium textured soils are much suitable for good production (FAO, 2009). Well drained loamy soil is much appropriate for onion growth (Gavino Jr, 2020). In this study, the spatial distribution of soil texture map (Fig. 3f) had been divided into four classes and ranked as sandy loam > clay loam > silty loam > clay. Maximum portion of the study area (68.02 %) have been dominated by clay loam texture.

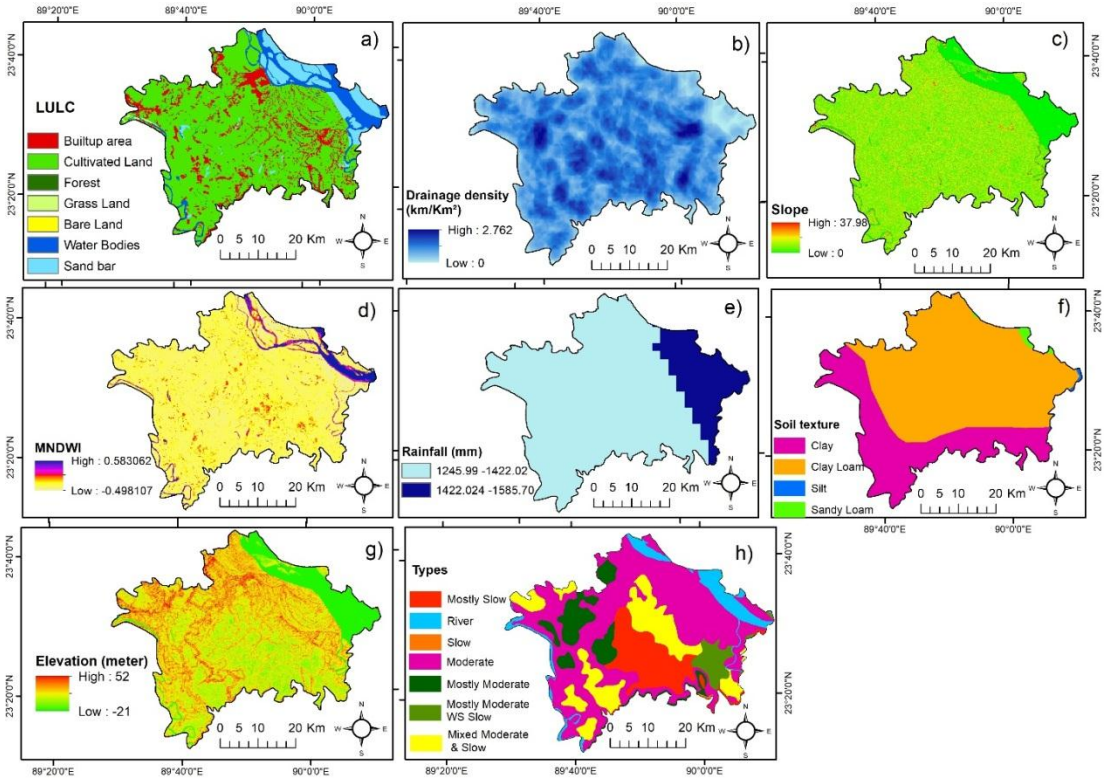

Fig. 3a) LULC map, **3b)** Drainage density map, **3c)** Slope map, **3d)** MNDWI map, **3e)** Rainfall map, **3f)** Soil texture, **3g)** elevation, **3h)** soil permeability map of the study area.

***Soil* permeability**

Soil permeability measures the rate at which fluid (air, water) flows from upper to lower soil layers and it is one of the most prominent variables for onion plant growth. The soil permeability data of Faridpur district had been collected as shapefile from the website of Bangladesh Agriculture Research Council (BARC). Then the soil permeability map (Fig. 3h) had been plotted in Arc GIS and categorized into 6 classes such as moderate, mostly moderate, mostly moderate with some slow, mixed moderate & slow, mostly slow, slow.

Modified normalized difference water index

Xu (2005) introduced the term "Modified Normalized Difference Water Index" (MNDWI) and applied this variable to identify the existence of open water bodies by removing atmospheric noise and terrain disturbances (Biswas *et al.* 2020). This index had been generated applying following Equation (5) (Xu, 2005).

$$\mathrm{MNDWI} = (\mathrm{Green} - \mathrm{SWIR}) / (\mathrm{Green} + \mathrm{SWIR}). \quad (5)$$

Finally, the MNDWI map (Fig. 3d) was divided into 5 classes, namely: (-0.4981 to -0.2564), (-0.2563 to -0.1547), (-0.1546 to 0.03188), (0.03189 to 0.3202), (0.3203 to 0.5831), which generally occupy 40.55%, 45.13%, 8.18%, 2.64%, 3.49% land of the study area respectively.

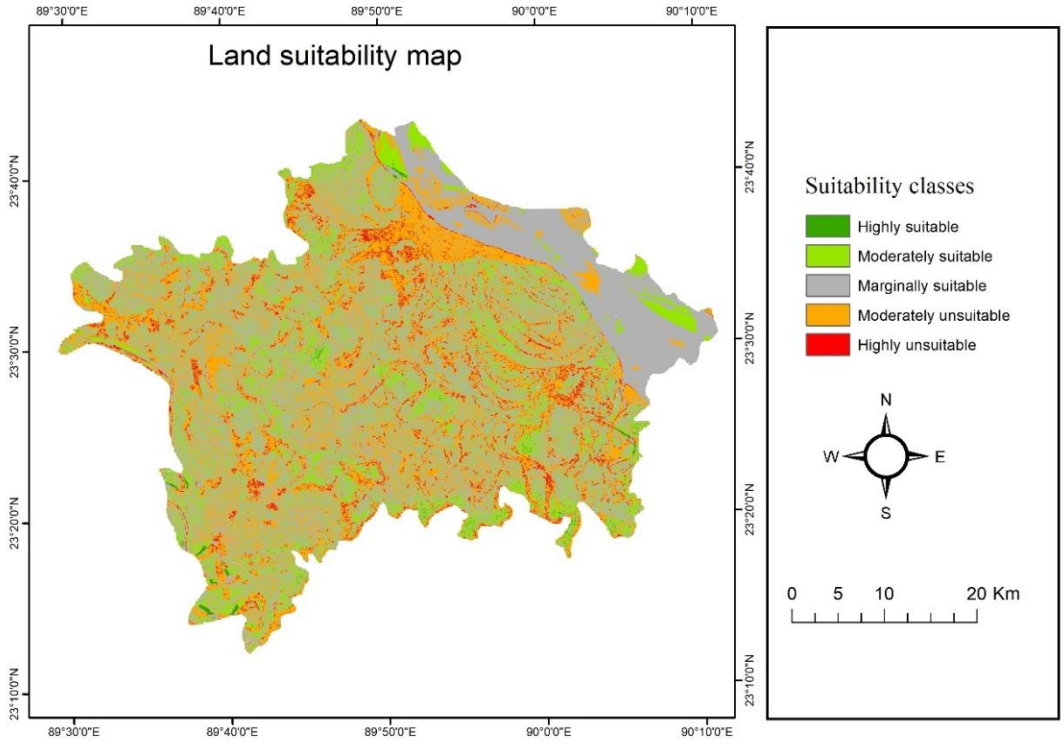

Fig. 4. Land suitability map for onion cultivation.

Generation of land suitability map

The weighted sum technique has been done a tremendous job to solve spatial complexity for selecting suitable site which is based on general measurement of dissimilar and diverse impacts. In this study, eight thematic layers had been superimposed by spatial analyst tool in Arc GIS 10.5 software, using following Equation (6).

$$\text{LSI} = \sum_{i=1}^{n} Wi \times Xi \qquad (6)$$

Here, LSI means land suitability index. Wi and Xi refers i^{th} factor weight & rank respectively. The value of LSI ranges from 1.46 to 4.81. Finally, land suitability map of Faridpur district (Fig. 4) for onion production had been categorized into five levels according to the classification of Food and Agricultural Organization (FAO). These 5 classes are highly unsuitable (1.46 to 2.5), moderately unsuitable (2.5 to 3.5), marginally suitable (3.5 to 4), moderately suitable (4 to 4.5), highly suitable (4.5 to 4.81). Higher value of elevation, slope, drainage density and lower value of rainfall, MNDWI have been represented the highly unsuitable agricultural land for onion

cultivation. On the contrary a highly suitable agriculture land for onion farming is indicator of a higher value of rainfall, MNDWI along with a lower value of slope, elevation and drainage density.

Conclusion

In recent years the price of onion creates a great suffering to the whole nation. In November 2019, the prime minister of Bangladesh stated that she had already chopped onion out from her menu due to this crisis. Increasing production along with controlling onion market can be the best solution for this problem. The main aim of this research is to identify the best suitable land for onion cultivation which also helps to increase the production rate of this crop. Several spatial data had been adopted in this study to prepare suitable map for onion cultivation. The final land suitable map has been demonstrated five classes such as highly suitable, moderately suitable, marginally suitable, moderately unsuitable, highly unsuitable which occupy 0.44%, 19.04%, 48.16%, 28.83%, 3.54% land of the study area. This research also has been revealed that 4 upazila (Char Bhadrasan, Sadarpur, Nagarkanda, Alfadanga) out of 9 upazila in Faridpur District, carrying more higher value of LSI (land suitability index) as these regions contain lower value of slope, drainage density, elevation along with a shorter distance from river. As onion can be rotten very quickly, it should be transported in a short time from field to market. That is why the transport system and road network should be modified. Further it is advised that government should control onion market by reducing several bad activities of syndicate. Finally, it can be said that this study has been provided support to policy makers, planner or farmer in the decision-making process to increase onion production in a sustainable away.

References

Ahmed, N., and Hoque, M. M. (2019). Onion Market of Bangladesh: Role of different Players and Assessing Competitiveness. https://www.bids.org.bd/page/researches/?rid=149.

Ali, M. K, Alam, M. F, Alam, M. N, Islam, M. S., Khandaker, S. M. (2007). Effect of nitrogen and potassium level on yield and quality of seed production of onion. *Journal of Applied Sciences Research*, 3(12):1889–99.

Biswas, S., Mukhopadhyay, B. P., and Bera, A. (2020). Delineating groundwater potential zones of agriculture dominated landscapes using GIS based AHP techniques: A case study from Uttar Dinajpur district, West Bengal. *Environmental Earth Sciences*, 79(302): 1–25. https://doi.org/10.1007/s12665-020-09053-9.

BBS. (2018). Yearbook of Agricultural Statistics in Bangladesh, Bangladesh Bureau of Statistics, Ministry of Planning, Government of the People's Republic of Bangladesh, Dhaka. http://www.bbs.gov.bd/site/page/3e838eb6-30a2-4 709-be85-40484b0c16c6/-. (Accessed 20 August 2020).

BBS. (2017). Year book of Agricultural statistics of Bangladesh.

Hoque, A., and Hossain, K. T. (2018). Land Suitability Assessment for Maize (Rabi) Cultivation in Cox's Bazaar Sadar Upazila, Cox's Bazaar, Bangladesh. *Journal of the Asiatic Society of Bangladesh, Science*, 44(1): 35–51. https://doi.org/10.3329/jasbs.v44i1.46544.

Das, S. K. (2021). Onion seed growers expect bumper crop. *THE DAILY STAR*. Accessed, 06 March 2021.

FAO. (2019). Food and Agriculture Organization of the United Nations. http://www.fao.org/land-water/databases-andsoftware/crop-information/onion/en, (Accessed 10 July 2019).

Gavino Jr., J. T., Ramos, E. E. and Alberto, R. T. (2020). Site Suitability Mapping of Onion in the Province of Occidental Mindoro Using Geographic Information System (GIS) Modelbuilder. *Science Asia Review*, 2(1). https://uz.edu.ph/wp-content/uploads/2020/08/SAR-VOL2.pdf#page=48, (Accessed 17 February 2022).

Hossen, B., Yabar, H., and Mizunoya, T. (2021). Land Suitability Assessment for Pulse (Green Gram) Production through Remote Sensing, GIS and Multicriteria Analysis in the Coastal Region of Bangladesh. *Sustainability*, 13(22), 12360. https://doi.org/10.3390/su132212360.

Hossain, M. M., Abdullah, F., and Parvez, I. (2017). Time series analysis of onion production in Bangladesh. *Innovare Journal of Agricultural Science*, 5(1): 1–4.

Huda, F. A., Islam, M. S., Biswas, H., and Islam, M. S. (2008). Impact Assessment Study on Selected Spice Crops Under Action Plan in Bangladesh. *Progressive Agriculture*, 19(2): 229–241. https://doi.org/10.3329/pa.v19i2.16965.

Islam, M., Hasan, M., and Farukh, M. (2017). Application of GIS in General Soil Mapping of Bangladesh. *Journal of Geographic Information System*, 09: 604–621. https://doi.org/10.4236/jgis.2017.95038.

Islam, M. M., Ahamed, T., and Noguchi, R. (2018). Land Suitability and Insurance Premiums: A GIS-based Multicriteria Analysis Approach for Sustainable Rice Production. *Sustainability*, 10(6): 1759. https://doi.org/10.3390/su10061759.

Khan, M. A., Hasan, M. K., Miah, M. A. J., Alam, M. M. and Masum, A. S. M. H. (2003). Effect of plant spacing on the growth and yield of different varieties of onion. *Pakistan Journal of Biological Science*, 6(18): 1582–1585.

Mila, F. A., and Parvin, M. T. (2019). Forecasting Area, Production and Yield of Onion in Bangladesh by Using ARIMA Model. *Asian Journal of Agricultural Extension, Economics & Sociology*, 37(4):1–12. https://doi.org/10.9734/ajaees/2019/v37i430274.

Mostafiz, R., Noguchi, R., and Ahamed, T. (2021). Agricultural Land Suitability Assessment Using Satellite Remote Sensing-Derived Soil-Vegetation Indices. *Land*, 10(2): 223. https://doi.org/10.3390/land10020223.

Rana, J., Islam, S., and Kamruzzaman, M. (2021). Growth and instability in area, production and productivity of major spices in Bangladesh. *Journal of Agriculture and Food Research*, 6: 100216. https://doi.org/10.1016/j.jafr.2021.100216

Rana, M. M. S. P., Hossain, M. A., and Nasher, N. M. R. (2022). Identification of groundwater potential zone using geospatial techniques of agriculture dominated area in Dinajpur district, Bangladesh. *Environmental Challenges*, 7: 100475. https://doi.org/10.1016/j.envc.2022.100475

Rana, M. M. S. P., and Hossain, M. A., and Huq, M. E. (2022). Application of Geospatial Techniques to Demarcate Groundwater Availability Zone in Bangladesh. *In*: Islam, A., Das, P., Ghosh, S., Mukhopadhyay, A., Das Gupta, A., and Kumar Singh, A. (eds) Fluvial Systems in the Anthropocene. Springer, Cham. https://doi.org/10.1007/978-3-031-11181-5_23

Roy, S., Hazra, S., Chanda, A., and Das, S. (2020). Assessment of groundwater potential zones using multi-criteria decision-making technique: A micro-level case study from red and lateritic zone (RLZ) of West Bengal, India. *Sustainable Water Resources Management*, 6: 1-14. https://doi.org/10.1007/s40899-020-00373-z.

Rahman, G. M. (2020). Onion crisis: this year and the year before. *NEW AGE*. (Accessed 17 September 2020).

Sikder, R. (2021). Traditional practices, formulations and dosages of medicinal plants: a survey in Faridpur District of Bangladesh. *Plants and Ecosystem*, 1:21–6.

Saaty, T. L. (1980). The analytic hierarchy process: planning, priority setting, resource allocation. *McGraw-Hill*, New York.

Saaty, T. L. (1990). How to make a decision: the analytic hierarchy process. *European Journal of Operational Research*, 48(1), 9–26.

Saaty, T. L. (2008) Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, 1(1), 83-98.

Sharma, H., Parihar, T. B., and Kapadia, K. (2017). Growth rates and decomposition analysis of onion production in Rajasthan state of India. *Economic Affairs*, 62(1): 157–161. https://doi.org/10.5958/0976-4666.2017.00039.0

The Daily Star. (2022). Onion import to continue: agriculture secretary. (in English) April 26, 2022.

Uddin, M. J., Mohiuddin, A. S. M., Ahmed, S. U., Rahman, M. K., Karim, M. A., and Saha, A. K. (2020). Suitability assessment of soils of Panchagarh and Thakurgaon for tea (Camellia sinensis L.) and orange (*Citrus aurantium* L.) cultivation. *Bangladesh Journal of Botany*, 49(3), 467–472. https://doi.org/10.3329/bjb.v49i3.49526

Uyan, M. (2013). GIS-based solar farms site selection using analytic hierarchy process (AHP) in Karapinar region, Konya/Turkey. *Renewable and Sustainable Energy Reviews*, 28, 11–17.

Xu, H. (2005). A study on information extraction of water body with the modifed normalized diference water index (MNDWI). *Journal of Remote Sensing*, 9:589–595