Land Suitability Assessment for Agriculture Using Analytical Hierarchy Process and Weighted Overlay Analysis in ArcGIS ModelBuilder

Ayush Tiwari and Sunil Ajmera

Abstract In this study, we utilize the concept of Analytical Hierarchy Process (AHP) and the functionalities of ArcGIS ModelBuilder towards a multiparametric classification of land regimes of Dewas District of Madhya Pradesh, based on their aptitude for agriculture. The study follows FAO's land suitability criteria and uses data from Landsat-8 OLI+ (NDVI, NDWI, Land Use/Land Cover), ASTER-GDEM V2 (Elevation, Slope, Drainage), ISRIC Soilgrid (Soil Characteristics), OpenStreetMaps (road/river/well proximity) and India WRIS (Groundwater Depth). The methodology involves defining the evaluation criteria, creating Pairwise Comparison Matrix (PWCM), assigning relative degree of importance to the 18 chosen parameters, preparing raster maps, performing Weighted Overlay Analysis (WOA) in ArcGIS ModelBuilder to generate the land suitability map and comparing it to the land use/land cover map. The results help us identify the potentials and constraints of land parcels for agriculture, designating 17.8% (1,24,970 ha) area as highly suitable, 57.3% (4,02,294 ha) area as moderately suitable and 24.9% (1,74,818 ha) area as marginally suitable. The suitability analysis can help build justified land use policies and devise logical agrarian management strategies by recommending agricultural exclusivity in highly suitable areas.

Keywords AHP · Weighted overlay analysis · Pairwise comparison matrix · ModelBuilder · Landsat-8 OLI+

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1 Introduction

India possesses 2.4% of world's geographical area, 4% of world's renewable water resources and holds 18% of world's population [1]. India's total food grain production during 1999–2000 was 208MT, during 2006–2007 it was 209.2 MT and it needs to be raised to 350 MT by 2050 [2, 3] to feed the expected population of 1390M. On the contrary, since 1995–1996, the average size land holding has decreased from 1.41 hectares to 1.15 hectares which accounts for a decrease in cultivable land at the rate of 30,000 ha/year. With an increase in population, decrease in percentage of farmers and with problems like drought and floods in various states, one can fathom the seriousness of the issue [4].

Madhya Pradesh (M.P.) is the second largest state of India. Its population growth rate is 20.4%, higher than that of India (17.6%) [5]. According to Directorate of Census Operation of M.P., District Dewas has tenth largest urban population and fourteenth largest urban area of M.P. [6]. Lowering groundwater levels, excessive fluoride content in groundwater, late commencing and erratic rainfall are regular scenes in Dewas. According to Central Ground Water Board's Aquifer Mapping Report, only 50% of district's net sown area is actually irrigated [7]. According to District Census Handbook, Dewas (2011), there has been 19.53% increase in its population between 2001 and 2011 [8]. The rate and the extent of urbanization in Dewas may challenge its agriculture scene in future.

A land regime once urbanized cannot be reclaimed again for agriculture. Post urbanization, agriculture can only be practiced on what is left open, irrespective of its appropriateness. Wastelands in India assume 67 Mha of the land use pattern, out of this cultivable wasteland constitute 20%. Clearly, there is a mismatch between land aptitude and land use. Land use should be in conjunction with its inherent capability to achieve long sustained agricultural productivity. In order to increase crop output and achieve food security, crops must be grown in areas where they are best suited. To generate the maximum agricultural production, land regimes must be utilized in an environmentally compassionate, socially justified and economically feasible manner. It is often observed that the land is either overused or underused or improperly used without examining its potential and constraints for that intended purpose. In order to increase/maintain the productivity per land unit, crops must be grown in areas where they are best suited. Remote Sensing and GIS-based Land Suitability Assessments (LSAs) should be performed before every major land-use-related decision to assure respectable use of natural resources and to control any unsustainable shifts and transformations.

LSA is an inter-disciplinary approach defined by FAO [9] as 'The analysis of land performance when used for a specified purpose, involving the execution and interpretation of anatomization-based surveys and studies of land forms, soils, vegetation, climate and other characteristics of land in order to identify and make a comparison of promising kinds of land use in terms of suitability to the objectives of the evaluation'. Land is categorized into spatially distributed agriculture potential zones based on soil and terrain characteristics and hydroclimatic constraints [10].

Through Analytical Hierarchy Process (AHP), dissimilar inputs from these parameters are combined and processed to form a single index of evaluation [11, 12]. AHP can integrate huge amount of heterogeneous data and deduce the relative weights of the parameters [13–15] facilitating the selection of best alternative amongst multiple options [16]. In this study, we combine the concept of AHP with geospatial modelling and create a decision support system to classify the district's land regimes and identify the potential land parcels for agriculture. In order to stop conversion of agriculture land for non-agricultural purposes, the government has formulated the National Policy for Farmers 2007 (NPF 2007) [17] and the National Rehabilitation and Resettlement Policy 2007 (NRRP 2007) [18]. The present study aims to make the implementation of these policies easier and more accurate.

2 Study Area

Dewas lies between 20°17′N and 23°20′N latitude and 75°54′E and 77°08′E longitude, falling under Survey of India Toposheets 46M, 46N, 55A, 55B and 55F and UTM zone WGS1984 43N [19]. Dewas covers an area of 7020.84 km² with a population of 1,563,715 [8]. It is situated at an altitude of 555.5 m above mean sea level. It falls under Agro-Ecological Sub-Region 5.2 (hot semi-arid moist eco-region) [20]. The district has six administrative blocks: Tonk Khurd, Dewas, Sonkach, Kannod, Khategaon and Bagli as shown in Fig. 1. There are three national highways (NH-3, NH-86, NH-59A). The average annual rainfall is 1083 mm. Narmada, Kali Sindh and Kshipra are the three main rivers. There are four physiographic regions, such as Dewas Plateau, Vindhyan Range, Kali Sindh Basin and Middle Narmada Valley. Hydrogeology is largely Basalt. Black cotton soil is the major soil type. Groundwater contains alkaline earth–bicarbonate. There are two major drainage basins: The Ganga (North) and The Narmada (South). Groundwater is 'alkaline earth–bicarbonate (Sangemini)' and accounts for 82% of irrigation. The principal crops are soya bean, wheat, groundnut and cotton [21].

3 Methodology

3.1 Preparation of Parameter Maps

The District Administrative Boundary shapefile is obtained from DivaGIS [22]. The units of the parameters are shown separately in Table 4. All the maps are projected (geometric correction) to World Geodetic System (WGS) 1984 datum and Universal Transverse Mercator (UTM) Zone 43N (Fig. 2).

The digital elevation model given in Fig. 3 is prepared using ASTER GDEM V2 product [23] for 21 January 2018. The DEM is a [1 × 1] degree tile and has a spatial
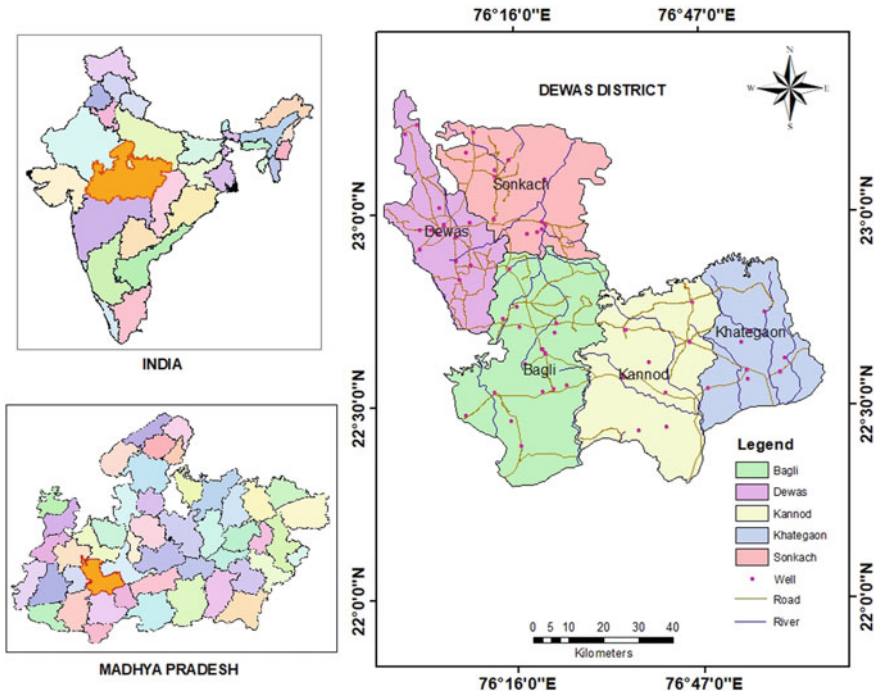
Fig. 1 Study area

resolution of 30 m. The slope map given in Fig. 4 is derived from the DEM using 'Slope' Spatial Analyst tool.

The drainage density map is prepared using 'ArcHydro Tools' extension [24] for ArcGIS. Consecutive terrain processing operations, fill sink < flow direction < flow accumulation < stream definition < stream segmentation < stream order, are performed on the DEM to obtain the drainage map given in Fig. 5. 'Line Density' tool is applied on the drainage map to obtain drainage density map given in Fig. 6. Efficient drainage prevents cases of waterlogging or excessive infiltration.

The multi-temporal (*MTL.txt) Landsat-8 OLI+ image for 26 February 2018 (Path: 146/Row: 44) given in Fig. 7 obtained from USGS Earth Explorer [25] is subjected to automatic cloud detection and haze removal (radiometric correction) using PCI Geomatica. Iso-cluster unsupervised classification is performed in ArcGIS to prepare the land use/land cover map given in Fig. 8 which is then verified from Google Earth [26].

Net Differential Vegetation Index (NDVI). Map shown in Fig. 9 is prepared from Landsat-8 Band-4 and Band-5 in 'Raster Calculator' as shown in Eq. 1.

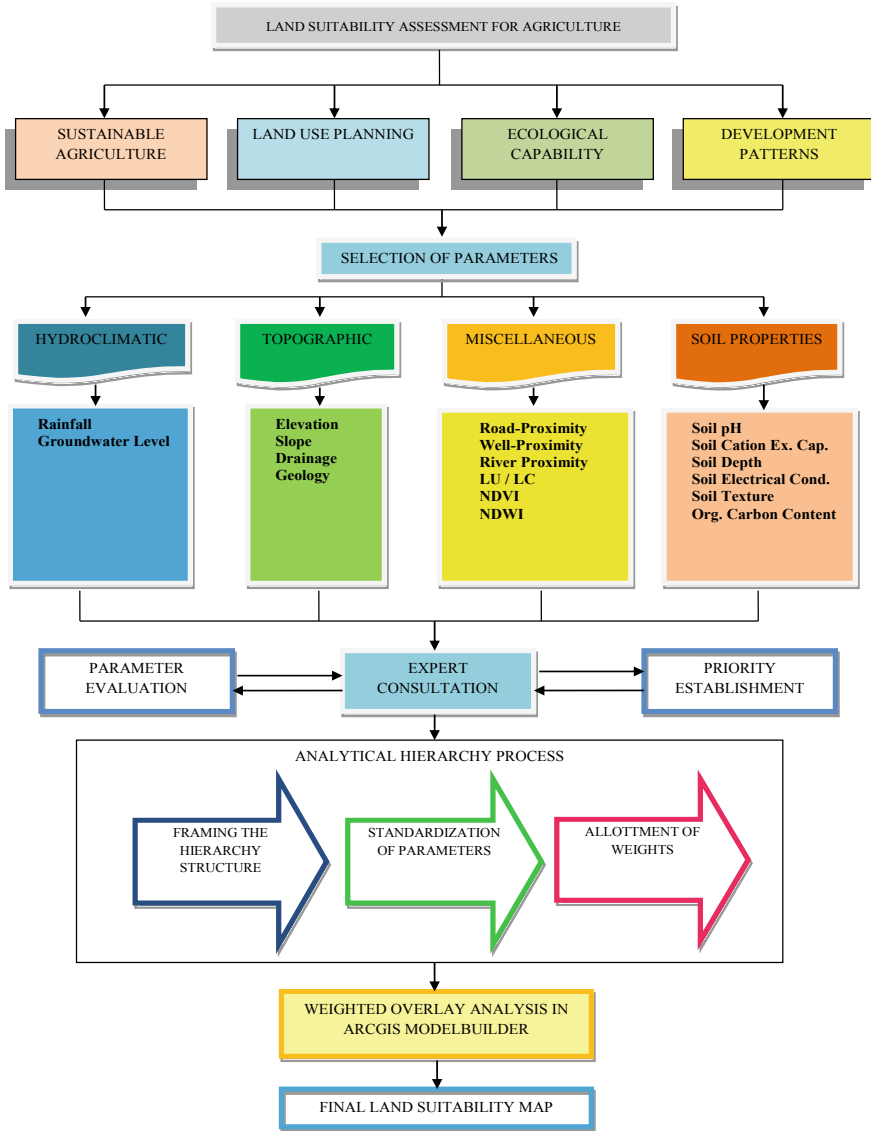$$(\text{Band}_5 - \text{Band}_4)\big/(\text{Band}_5 + \text{Band}_4) \tag{1}$$

Fig. 2 Flow chart of land suitability assessment methodology

NDVI is used for estimating vegetation health from remote sensing data. NDVI is a numerical indicator that uses red and NIR bands of the electromagnetic spectrum to detect the regions of live green vegetation (regions with greener vegetation are good for agriculture practices). According to USGS's band designations for Landsat-8 OLI+ satellite image given in Table 1, healthy vegetation (chlorophyll) reflects near-infrared light and absorbs red light.
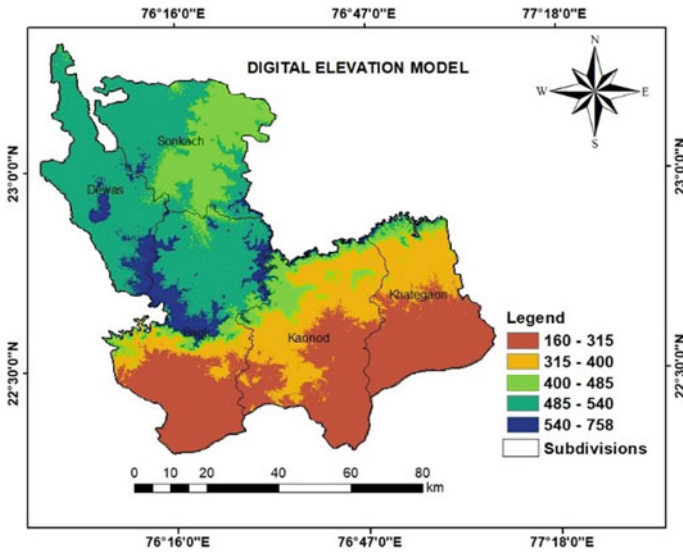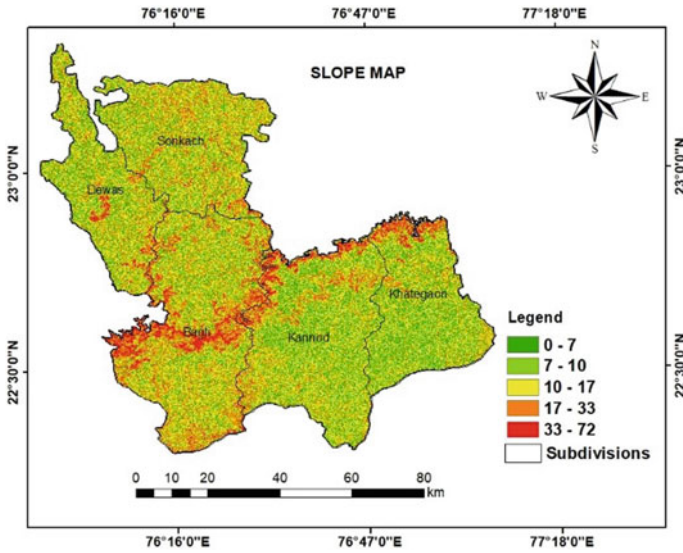
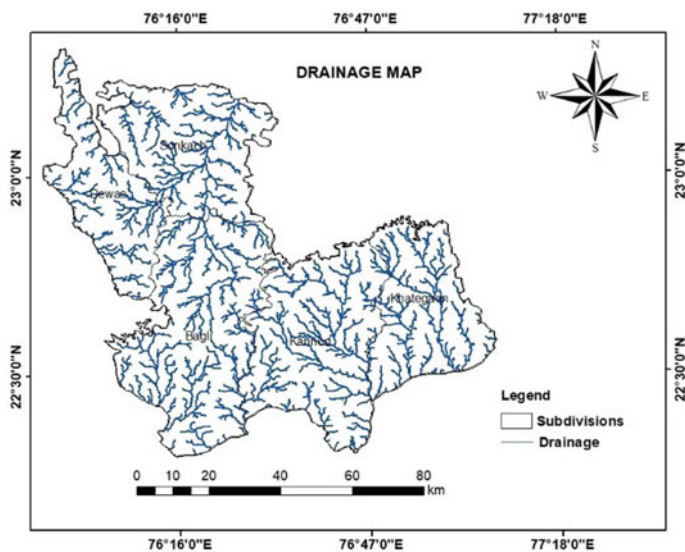**Fig. 3** Digital elevation model

Fig. 4 Slope map

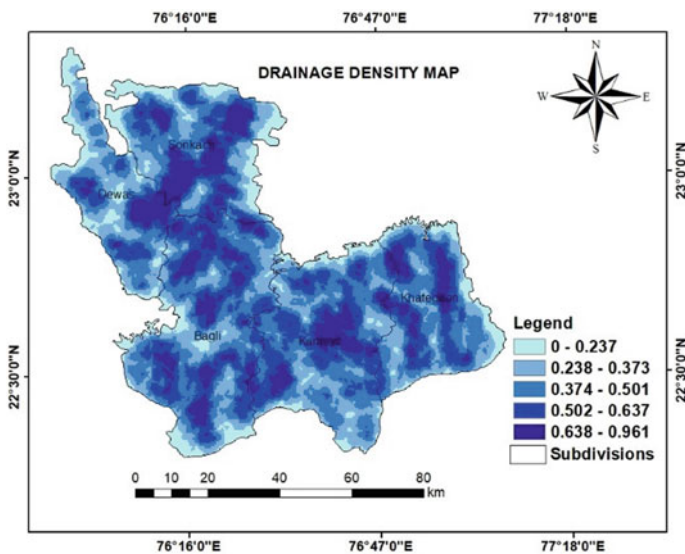**Fig. 5** Drainage map

Fig. 6 Drainage density map

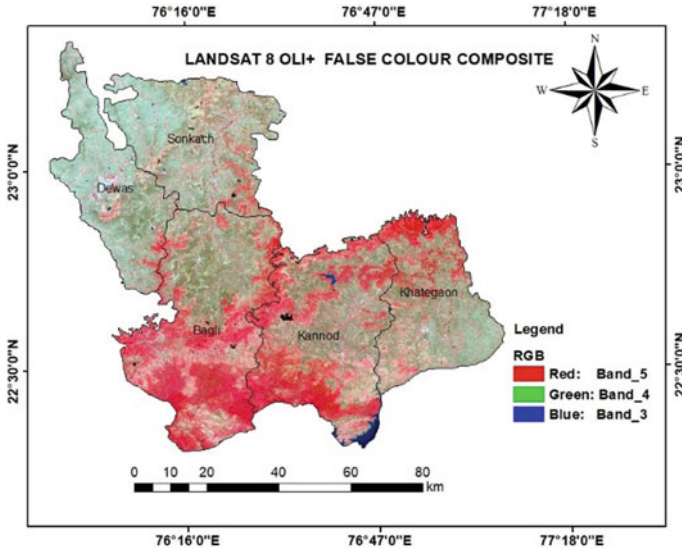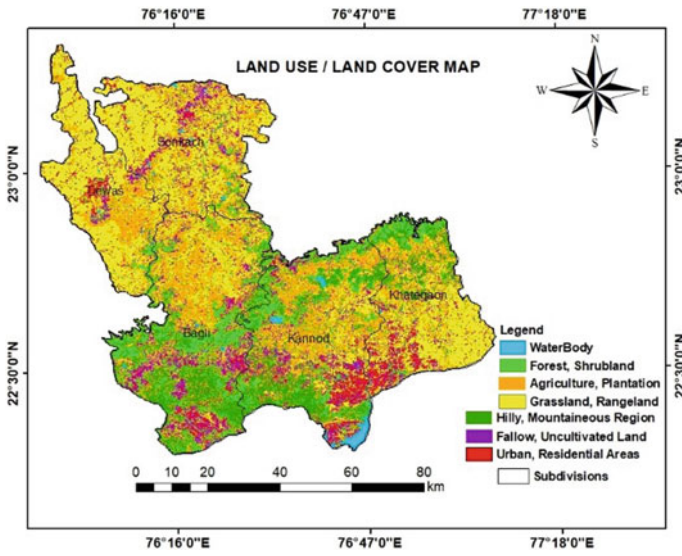**Fig. 7** Landsat-8 OLI+ FCC image

Fig. 8 Land use/land cover map
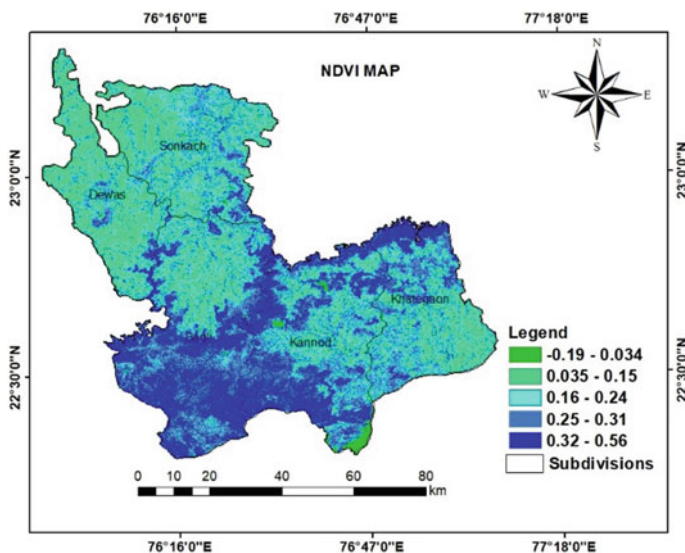
Fig. 9 NDVI map

Table 1 Band designations for Landsat-8 OLI+ satellite

No.	Band number	Wavelength (μm)	Use
1.	Band-4 (red)	0.636–0.673	Focuses on biomass content and shorelines
2.	Band-5 (near-infrared NIR)	0.851–0.879	Discriminates moisture content of soil and vegetation; penetrates thin clouds
3.	Band-6 (shortwave infrared SWIR) 1	1.566–1.651	Improved moisture content of soil and vegetation and thin cloud penetration

Source USGS Earth Explorer [27]

Normalized Difference Water Index (NDWI). Map shown in Fig. 10 is prepared from Landsat-8 Band-5 and Band-6 in 'Raster Calculator' as shown in Eq. 2

$$(Band_6 - Band_5)\big/(Band_6 + Band_5) \tag{2}$$

NDWI detects the changes in liquid water content of spongy mesophyll of vegetation canopies. SWIR shows changes in the water content of mesophyll, whereas NIR shows changes in leaf internal structure and its dry matter content, and hence the equation.

The road proximity map shown in Fig. 11 is developed from the road network shapefile using 'Euclidean Distance' Spatial Analyst Tool. The road network shows
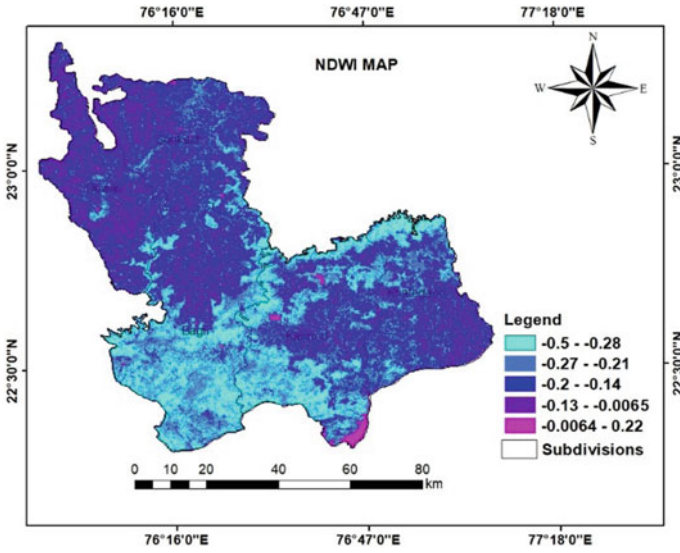
Fig. 10 NDWI map

Fig. 11 Road proximity map

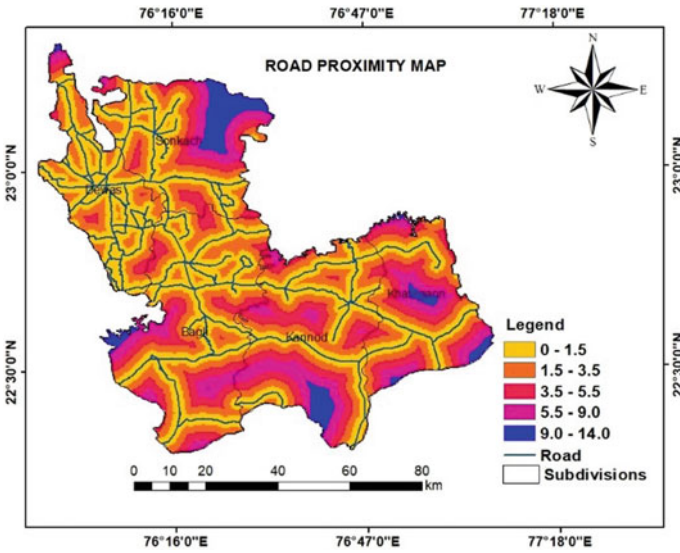a line layer of road systems like national highways, state highways and major roads. The river proximity map shown in Fig. 12 and well proximity map shown in Fig. 13 are prepared in the same manner and show a line layer of river systems (Narmada, Kali Sindh and Kshipra) and a point layer of wells, respectively. The road shapefile and
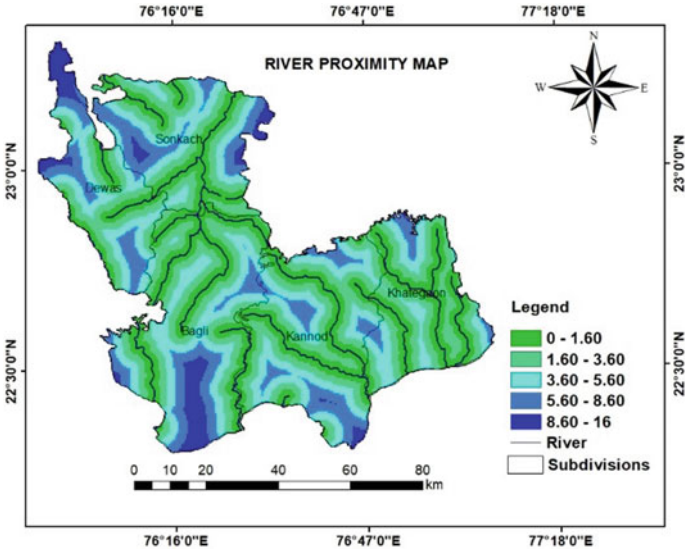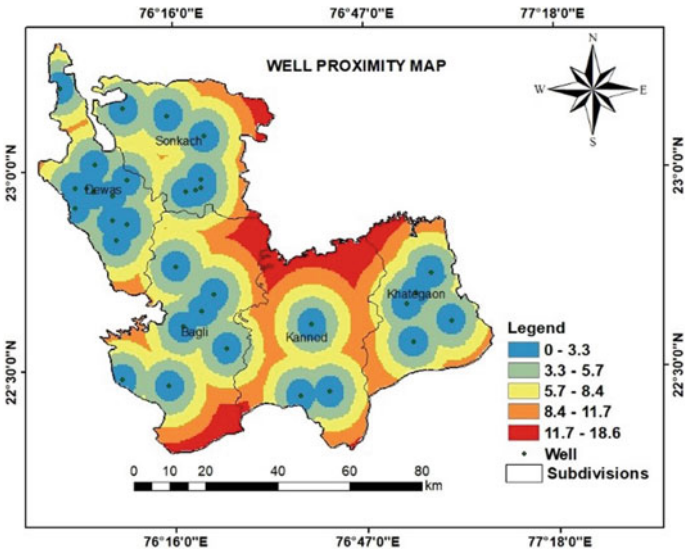

Fig. 12 River proximity map
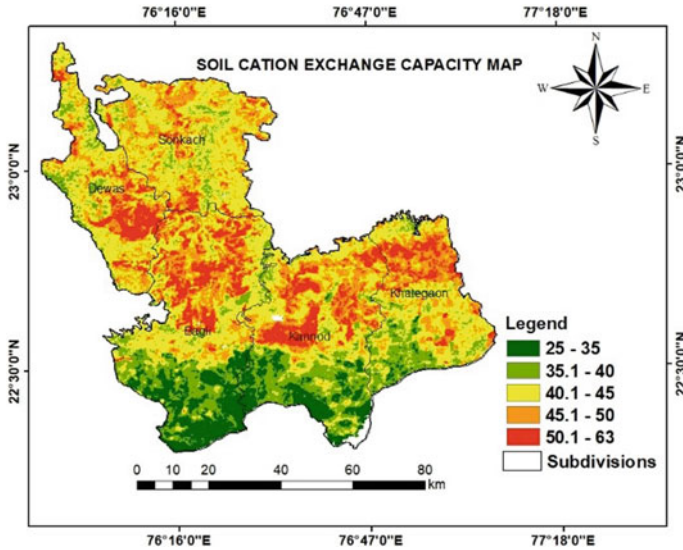

Fig. 13 Well proximity map

Fig. 14 Soil cation exchange capacity map

river shapefile are obtained from *OpenStreetMap* via *Geofabrik* [28]. The proximity maps are verified from 1:50,000 Survey of India (SOI) Toposheets (46M, 46N, 55A, 55B and 55F) [29].

Soil Cation Exchange Capacity (CEC) map shown in Fig. 14, Soil Organic Carbon Content (OCC) map shown in Fig. 15, Soil pH map shown in Fig. 16 and Soil Depth map shown in Fig. 17 were available from ISRIC SoilGrids [30]. CEC is the measure of negatively charged content present in soil that holds ions like calcium (Ca2+), magnesium (Mg2+) and potassium (K+) through electrostatic forces and stops them from being leached down the soil profile. It is the nutrient retention capacity of the roots [31].

OCC is a direct measure of soil fertility. OCC affects water holding capacity, nutrient availability and maintains soil structure. Soil pH is the degree of acidity/alkalinity of soil. For majority of crops, the optimal range of pH is from 5.8 to 6.8. Crops rarely survive extreme pH environments. Soil depth basically depends on the nature of the parent material on which soils were formed. For a well-drained friable soil, the maximum root depth of crops can be 200 cm. Lower depth of soil restricts plant rooting, hinders overall growth and ultimately the yield.

Soil Electrical Conductivity (EC) map shown in Fig. 18 is prepared using the remote sensing data of 202 soil sampling sites obtained from KrishiKosh [32]. The data is imported into ArcGIS as a point shapefile, followed by subjection to Inverse Distance Weighted (IDW) Interpolation tool. EC is a direct measure of salinity of soil. Plants are detrimentally affected, both physically and chemically, by excess salts in some soils and by high levels of exchangeable sodium in others. EC depends on the amount of moisture held by soil particles [33].
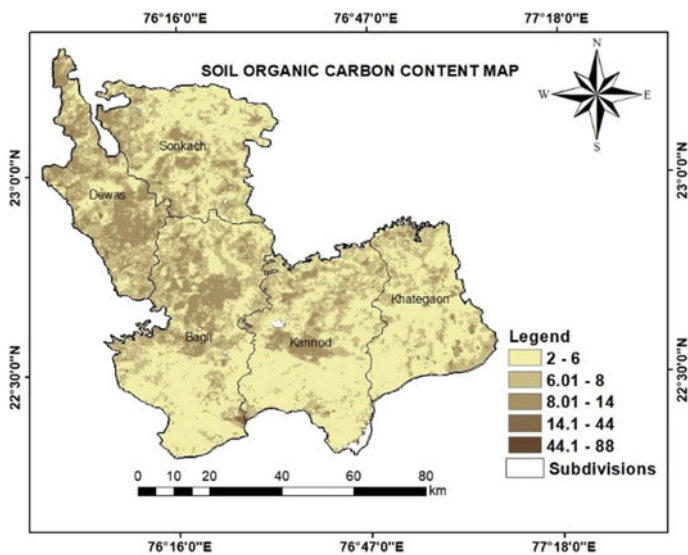
Fig. 15 Organic soil carbon content map
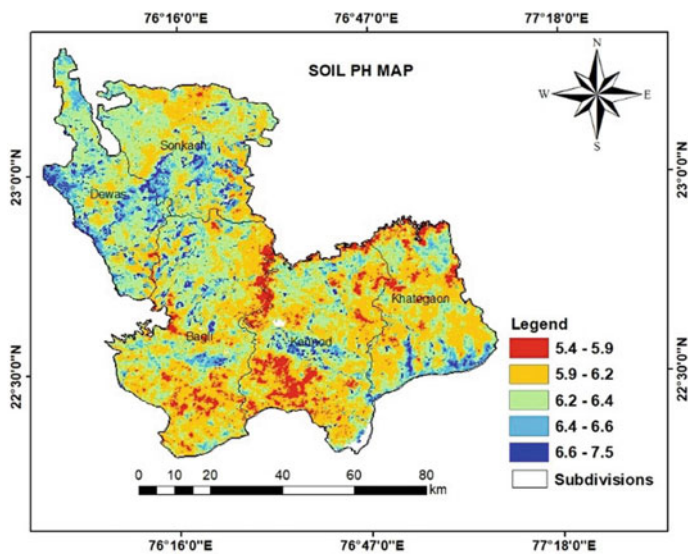
Fig. 16 Soil pH map
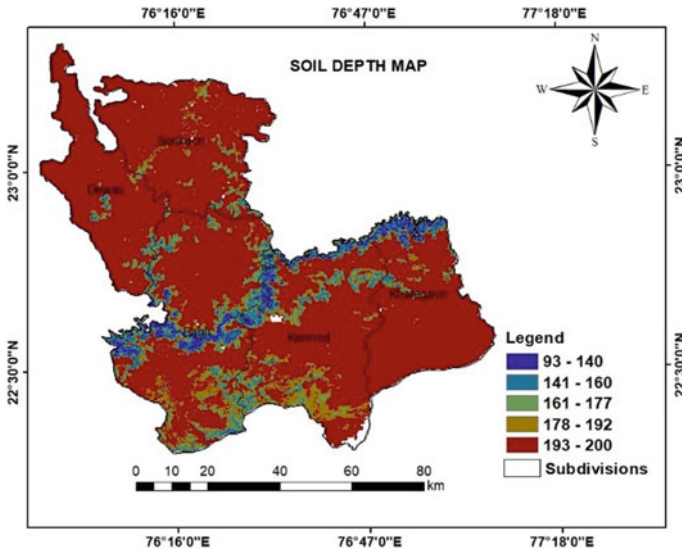
Fig. 17 Soil depth map
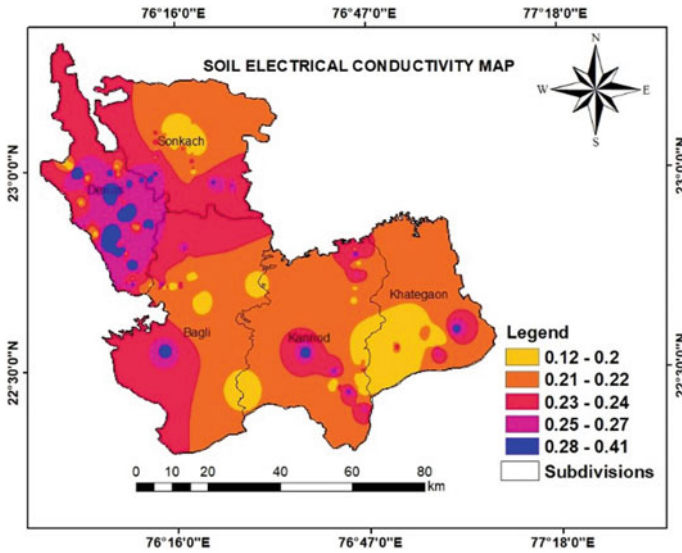
Fig. 18 Soil electrical conductivity map
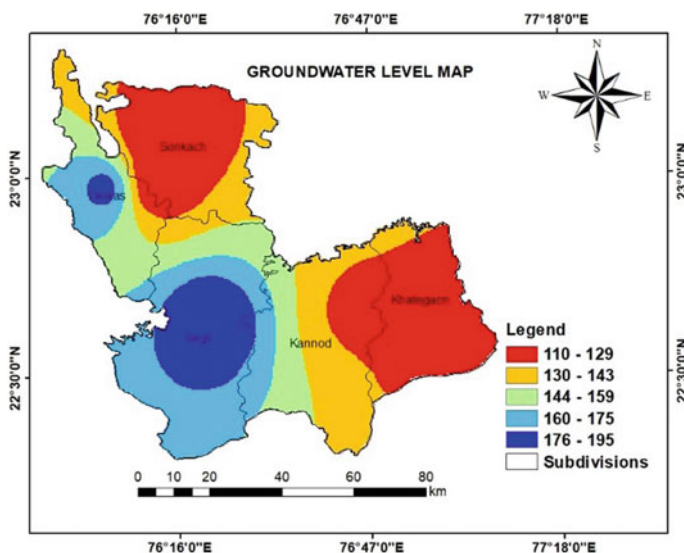
Fig. 19 Groundwater level map

The location of wells and groundwater level data are obtained from India-WRIS [34] and CGWB's Aquifer Mapping Report [7]. A point shapefile containing the coordinates of the wells and their respective water level depths is created. The groundwater depth map given in Fig. 19 is prepared using IDW tool. The annual average rainfall map given in Fig. 20 is prepared in the same manner using rainfall data (2004–2014) from Global Weather Data for SWAT [35].

The soil texture map given in Fig. 21 is prepared in QGIS Desktop 2.18 using 'Soil Texture' plug-in [36]. Soil texture is determined by the relative proportions of sand (0.05–2 mm), silt (0.002–0.05 mm) and clay (<0.002 mm) [37]. The inputs of sand map and clay map are given and the output is generated based on the rules of soil texture triangle. The geology map given in Fig. 22 is digitized from its photo image [7] using ArcScan tool and converted to raster format using 'Polyline to Raster' conversion tool.

3.2 Analytical Hierarchy Process

To assign a relative degree of importance (weight) to every parameter based on a fundamental scale [14], AHP priority calculator is used [38]. The scale ranges from 1 (equal significance) to 9 (extreme significance) as shown in Table 2. Comparisons are performed for different pairings of 18 parameters using Pairwise Comparison Matrix (PWCM) as shown in Table 3. The total number of pairwise comparisons is calculated as shown in Eq. 3:
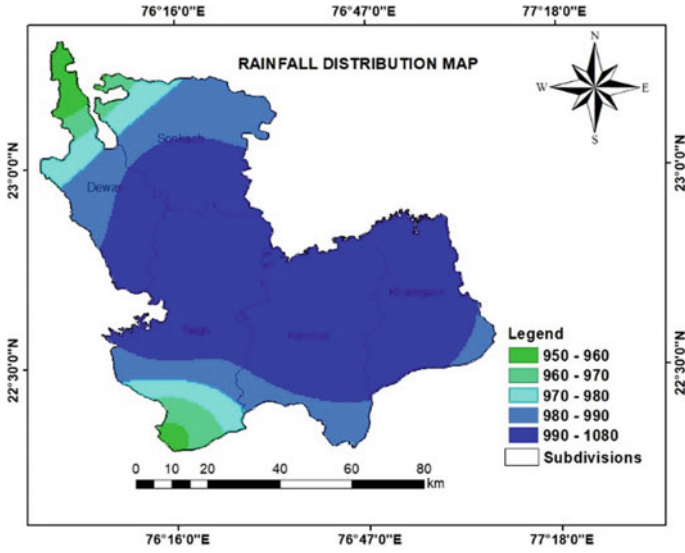
Fig. 20 Annual rainfall distribution map
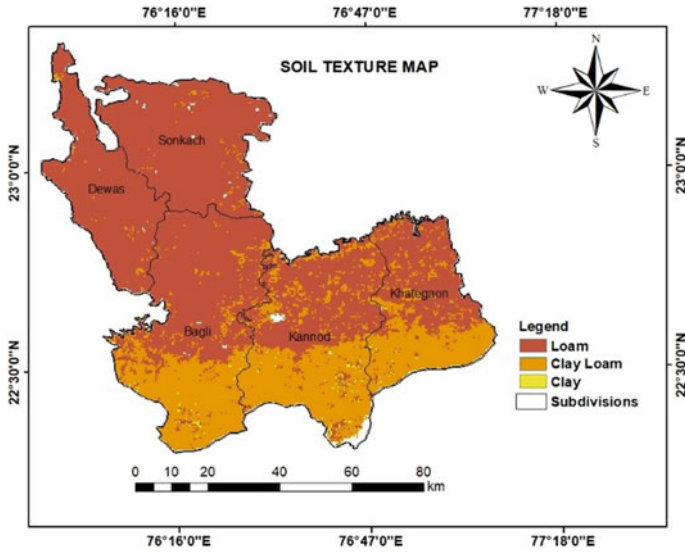
Fig. 21 Soil texture map
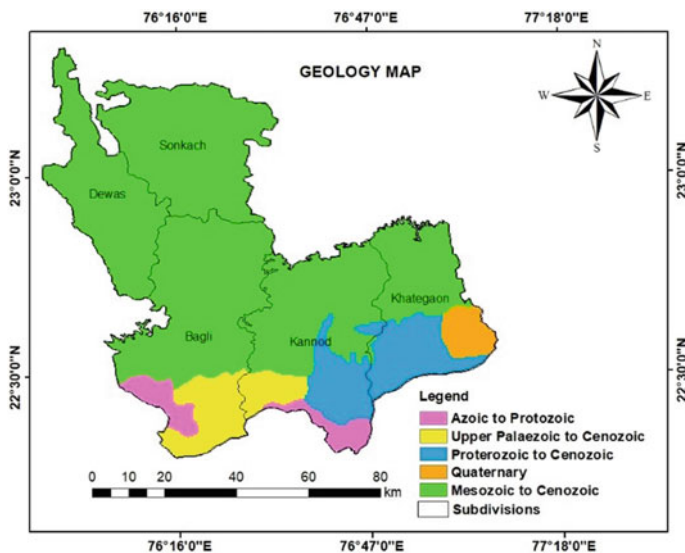
Fig. 22 Geology map

Table 2 The fundamental scale for pairwise comparison matrix [14]

Rank	Definition	Explanation
1	Equal importance	Two criteria enrich equally to the objective criteria
3	Low importance of one over another	Judgments and experience slightly favour one criterion over another
5	Strong or essential importance	Judgments and experience strongly favour
7	Established importance	A criterion is strongly favoured (dominance established in practice)
9	Absolute or high importance	The evidence favouring one criterion over another is of the highest probable order of affirmation
2, 4, 6, 8	Intermediate values between two adjacent importance or judgements	When adjustment is needed

$$PC = (n(n-1)/2) \tag{3}$$

where 'n' is the number of parameters. Hence, for $n = 18$, $PC = 153$. Consistency ratio, an indicator of the degree of consistency/efficiency of AHP analysis, is calculated as shown in Eq. 4:

$$CR = (CI/RI) \tag{4}$$

Table 3 Pairwise comparison matrix for AHP-MCDM

Para.	E	S	L	VI	GW	O	R	T	C	EC	WI	PH	GEO	DR	ROP	RIP	SD	WEP
E	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9
S	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9
L	1/2	1/2	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9
VI	1/2	1/2	1/2	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8
GW	1/3	1/3	1/2	1/2	1	2	2	3	3	4	4	5	5	6	6	7	7	8
O	1/3	1/3	1/3	1/2	1/2	1	2	2	3	3	4	4	5	5	6	6	7	7
R	1/4	1/4	1/3	1/3	1/2	1/2	1	2	2	3	3	4	4	5	5	6	6	7
T	1/4	1/4	1/4	1/3	1/3	1/2	1/2	1	2	2	3	3	4	4	5	5	6	6
C	1/5	1/5	1/4	1/4	1/3	1/3	1/2	1/2	1	2	2	3	3	4	4	5	5	6
EC	1/5	1/5	1/5	1/4	1/4	1/3	1/3	1/2	1/2	1	2	2	3	3	4	4	5	5
WI	1/6	1/6	1/5	1/5	1/4	1/4	1/3	1/3	1/2	1/2	1	2	2	3	3	4	4	5
PH	1/6	1/6	1/6	1/5	1/5	1/4	1/4	1/3	1/3	1/2	1/2	1	2	2	3	3	4	4
GEO	1/7	1/7	1/6	1/6	1/5	1/5	1/4	1/4	1/3	1/3	1/2	1/2	1	2	2	3	3	4
DR	1/7	1/7	1/7	1/6	1/6	1/5	1/5	1/4	1/4	1/3	1/3	1/2	1/2	1	2	2	3	3
ROP	1/8	1/8	1/7	1/7	1/6	1/6	1/5	1/5	1/4	1/4	1/3	1/3	1/2	1/2	1	2	2	3
RIP	1/8	1/8	1/8	1/7	1/7	1/6	1/6	1/5	1/5	1/4	1/4	1/3	1/3	1/2	1/2	1	2	2
SD	1/9	1/9	1/8	1/8	1/7	1/7	1/6	1/6	1/5	1/5	1/4	1/4	1/3	1/3	1/2	1/2	1	2
WEP	1/9	1/9	1/9	1/8	1/8	1/7	1/7	1/6	1/6	1/5	1/5	1/4	1/4	1/3	1/3	1/2	1/2	1

Where E is elevation, S is slope, L is land use/land cover, VI is NDVI, GW is groundwater level, O is organic carbon content, R is annual average rainfall, T is texture, C is cation exchange capacity of soil, EC is electrical conductivity of soil, WI is NDWI, GEO is geology, DR is drainage density, ROP is road proximity, RIP is river proximity, SD is soil depth up to bedrock, WEP is well proximity

Table 4 Average RI for corresponding matrix size [14, 43, 44]

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59
n	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
RI	1.60	1.61	1.62	1.63	1.63	1.64	1.65	1.65	1.66	1.66	1.67	1.67	1.67	1.68	1.68

where RI is the random index. RI depends on the order of the matrix as shown in Table 4 [13]. For $n = 18$, RI is 1.62 [14]. CI is the consistency index. It is expressed as shown in Eq. 5:

$$CI = (\lambda_{max} - n) / (n - 1) \tag{5}$$

where 'λ_{max}' is the principle eigenvector and 'n' is the order of the matrix [12]. If CR < 0.10, it means that an acceptable level of consistency is achieved [13], the weights calculated are meaningful and valid [39]. In this case, CR is 0.04. The synthesized matrix is shown in Table 5. The ranking of parameters is given in Table 6. The results of AHP analysis are given in Table 7.

AHP-MCE calculates the 'weight' of every parameter by calculating the eigenvalue corresponding to the highest eigenvector of the matrix and normalizing the sum of all the parameters to unity [40, 41]. In this case, eigenvector solution is obtained after six iterations. The weights, hence, computed from AHP analysis are converted into percent for further processing in Weighted Overlay Analysis (WOA) in ArcGIS ModelBuilder. ModelBuilder is a dynamic, interactive and heavily customizable geoprocessing application of ArcGIS. It is used for data integration and data analysis. It can be regarded as a visual programming language for generating workflows. ModelBuilder is used to create, edit and manage custom-based models for a diverse stream of applications. Models are automated GIS workflows that string together sequences of geoprocessing tools that need GIS data as the initial input [42].

3.3 Weighted Overlay Analysis

Reclassification/Standardization: Initially, all the parameters have diverse and dissimilar units. Standardization converts the measurement to uniform units [39] for further processing in WOA. The parameters lose their dimensions [45]. The sub-criteria are brought to a common suitability scale ranging from 1 to 10 as shown in Table 8 in order to eliminate their inherent vagueness.

Overlaying: The reclassified raster layers are overlaid by multiplying the values of their sub-criteria by their corresponding weight value [40] as shown in Eq. 6. The combined weight of all input maps should be

Table 5 Synthesized matrix for AHP-MCDM

Para.	E	S	L	VI	GW	O	R	T	C	EC	WI	PH	GEO	DR	ROP	RIP	SD	WEP
E	0.177	0.177	0.235	0.192	0.21	0.174	0.181	0.154	0.157	0.136	0.138	0.122	0.123	0.109	0.11	0.1	0.1	0.091
S	0.177	0.177	0.235	0.192	0.21	0.174	0.181	0.154	0.157	0.136	0.138	0.122	0.123	0.109	0.11	0.1	0.1	0.091
L	0.088	0.088	0.117	0.192	0.14	0.174	0.136	0.154	0.126	0.136	0.115	0.122	0.105	0.109	0.096	0.1	0.089	0.091
VI	0.088	0.088	0.058	0.096	0.14	0.116	0.136	0.115	0.126	0.109	0.115	0.101	0.105	0.094	0.096	0.087	0.089	0.081
GW	0.058	0.058	0.058	0.048	0.07	0.116	0.09	0.115	0.094	0.109	0.092	0.101	0.087	0.094	0.082	0.087	0.078	0.081
O	0.058	0.058	0.038	0.048	0.035	0.058	0.09	0.077	0.094	0.082	0.092	0.081	0.087	0.078	0.082	0.075	0.078	0.071
R	0.044	0.044	0.038	0.031	0.035	0.029	0.045	0.077	0.063	0.082	0.069	0.081	0.07	0.078	0.069	0.075	0.067	0.071
T	0.044	0.044	0.029	0.031	0.023	0.029	0.022	0.038	0.063	0.054	0.069	0.061	0.07	0.062	0.069	0.062	0.067	0.061
C	0.035	0.035	0.029	0.024	0.023	0.019	0.022	0.019	0.031	0.054	0.046	0.061	0.052	0.062	0.055	0.062	0.055	0.061
EC	0.035	0.035	0.023	0.024	0.017	0.019	0.014	0.019	0.015	0.027	0.046	0.04	0.052	0.047	0.055	0.05	0.055	0.051
WI	0.028	0.028	0.023	0.019	0.017	0.014	0.014	0.012	0.015	0.013	0.023	0.04	0.035	0.047	0.041	0.05	0.044	0.051
PH	0.028	0.028	0.018	0.019	0.014	0.014	0.011	0.012	0.01	0.013	0.011	0.02	0.035	0.031	0.041	0.037	0.044	0.04
GEO	0.024	0.024	0.018	0.015	0.014	0.011	0.011	0.009	0.01	0.009	0.011	0.01	0.017	0.031	0.027	0.037	0.033	0.04
DR	0.024	0.024	0.016	0.015	0.011	0.011	0.009	0.009	0.007	0.009	0.007	0.01	0.008	0.015	0.027	0.025	0.033	0.03
ROP	0.021	0.021	0.016	0.013	0.011	0.009	0.009	0.007	0.007	0.006	0.007	0.006	0.008	0.007	0.013	0.025	0.022	0.03
RIP	0.021	0.021	0.014	0.013	0.009	0.009	0.007	0.007	0.006	0.006	0.005	0.006	0.005	0.007	0.006	0.012	0.022	0.02
SD	0.019	0.019	0.014	0.011	0.009	0.008	0.007	0.006	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.006	0.011	0.02
WEP	0.019	0.019	0.012	0.011	0.008	0.008	0.006	0.006	0.005	0.005	0.004	0.005	0.004	0.005	0.004	0.006	0.005	0.01

Table 6 Ranking of parameters

Parameter	Weight	Rank
Elevation	15.2	1
Slope	15.2	2
Land use/land cover	12.5	3
NDVI	10.5	4
Groundwater	8.6	5
Organic carbon content	7.2	6
Rainfall	5.9	7
Soil texture	4.9	8
Cation exchange capacity	4.0	9
Electrical conductivity	3.3	10
NDWI	2.7	11
Soil pH	2.3	12
Geology	1.9	13
Drainage density	1.6	14
Road proximity	1.3	15
River proximity	1.1	16
Soil depth	0.9	17
Well proximity	0.8	18

Table 7 Results of AHP analysis

Number of parameters	18
Number of pairwise comparisons	153
Consistency ratio	4.4%
Principal eigenvalue	19.218
Eigenvector solution	6 iterations
Delta	4.5E−8

$$\text{LSS} = \sum_{i=1}^{n} W_i X_i \tag{6}$$

where LSS = l and suitability score, W_i = weight of the suitability parameter, X_i = score of the sub-criteria of the suitability parameter, n = number of suitability parameters.

Addition: All the resulting cell values are finally added. The area falling under each suitability class is determined using 'Zonal Geometry as Table' Spatial Analyst Tool.

Table 8 Weights of main criteria and scores of sub-criteria

No.	Cri.	Wt.	Sub-criteria	Unit	Sc.	No.	Cri.	Wt.	Sub-criteria	Unit	Sc.
1.	E	15.2	160–315	m	10	10.	EC	3.3	0.12–0.2	dS/m	2
			315–400		6				0.21–0.22		4
			400–485		4				0.23–0.24		6
			485–540		2				0.25–0.27		8
			540–758		1				0.28–0.41		10
2.	S	15.1	0–7	%	10	11.	WI	2.7	−0.5–0.28	N/A	2
			7–10		8				−0.27–0.21		4
			10–17		6				−0.2–0.14		6
			17–33		4				−0.13–0.0665		8
			33–72		2				−0.0064–0.22		10
3.	L	12.5	Water body	m	0	12.	PH	2.3	5.4–5.9	N/A	7
			Agriculture land		10				5.9 – 6.2		10
			Grassland, Rangeland		7				6.2–6.4		9
			Hills, mountains		1				6.4–6.6		5
			Forest		3				6.6–7.5		5
			Fallow, uncultivated land		10						
			Urban areas		0						
4.	VI	10.5	−0.19–0.034	N/A	2	13.	GEO	1.9	Azoic to Protozoic	N/A	2
			0.035–0.15		4				Upper Paleozoic to Cenozoic		5
			0.16–0.24		6				Proterozoic to Cenozoic		6
			0.25–0.31		8				Quaternary		9

(continued)

Table 8 (continued)

No.	Cri.	Wt.	Sub-criteria	Unit	Sc.	No.	Cri.	Wt.	Sub-criteria	Unit	Sc.
									Mesozoic to Cenozoic		10
5	GW	8.6	0.32–0.56		10	14.	DR	1.6	0–0.237	km²	10
			110–129	m	2				0.238–0.373		8
			130–143		4				0.374–0.50		6
			144–159		6				0.502–0.637		4
			160–175		8				0.638–0.961		2
			176–195		10						
6.	O	7.2	2–6	g/kg	1	15.	ROP	1.3	0–1.5	km	10
			6.01–8		3				1.5 – 3.5		8
			8.01–14		5				3.5–5.5		6
			14.1–44		7				5.5–9.0		4
			44.1–88		10				9.0–14.0		2
7.	R	5.9	950–960	mm	1	16.	RIP	1.1	0–1.60	km	10
			960–970		3				1.60–3.60		8
			970–980		5				3.60–5.60		6
			980–990		7				5.60–8.60		4
			990–1080		10				8.60–16.0		2
8.	T	4.9	Loam	N/A	10	17.	SD	0.9	93–140	m	2
			Clay loam		7				141–160		5
			Silt loam		5				161–177		6
			Water		0				178–182		9
			Silt		1				193–200		10

(continued)

Table 8 (continued)

No.	Cri.	Wt.	Sub-criteria	Unit	Sc.	No.	Cri.	Wt.	Sub-criteria	Unit	Sc.
9.	C	4.0	25–35	cmolc per kg	2	18.	WEP	0.8	0–3.3	km	10
			35.1–40		4				3.3–5.7		8
			40.1–45		6				5.7–8.4		6
			45.1–50		8				8.4–11.7		4
			50.1–63		10				11.7–18.6		2

4 Results and Discussions

The land suitability assessment model is given in Fig. 23. The final land suitability map for agriculture is given in Fig. 24. The analysis designates 17.8% (1,24,970 ha) area as highly suitable, 57.3% (4,02,294 ha) area as moderately suitable and 24.9% (1,74,818 ha) area as marginally suitable for agriculture. A niche-based multiparametric LSA was performed in accordance with FAO (1976). The assessment faced internal variability and complexity with abundance of highly localized features. Weighted overlay analysis allowed strategic delineation of suitability regimes by integrating the diverse spatial layers encompassing 18 different environmental themes, terrain specifics and hydroclimatic vistas. The relative degree of importance between parameters was realized after considering the subjective opinions of farmers and local experts which made the results more original at grassroot level. The study benefitted from online availability of remote sensing data.
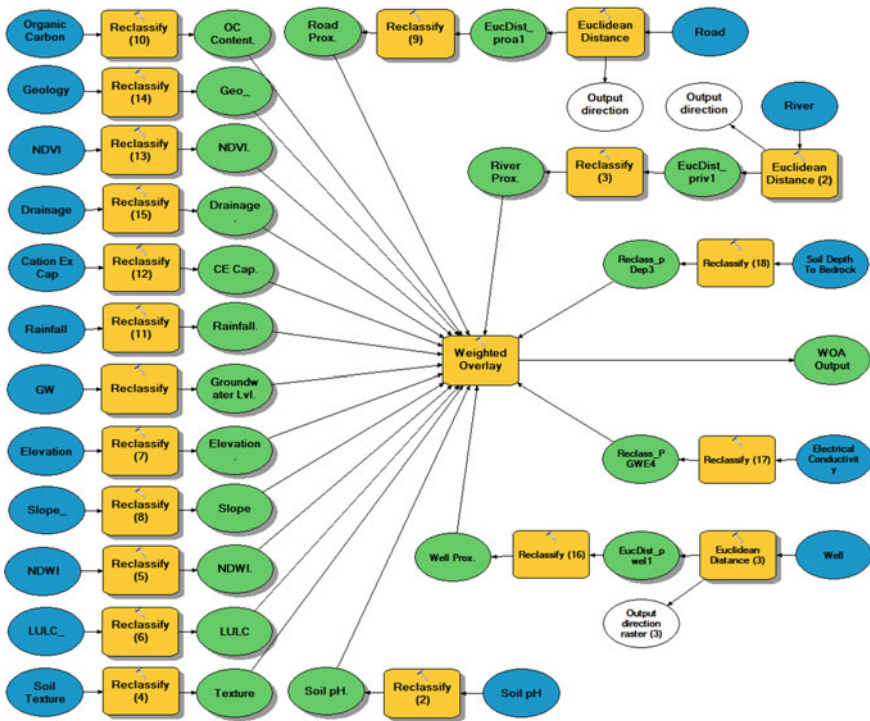

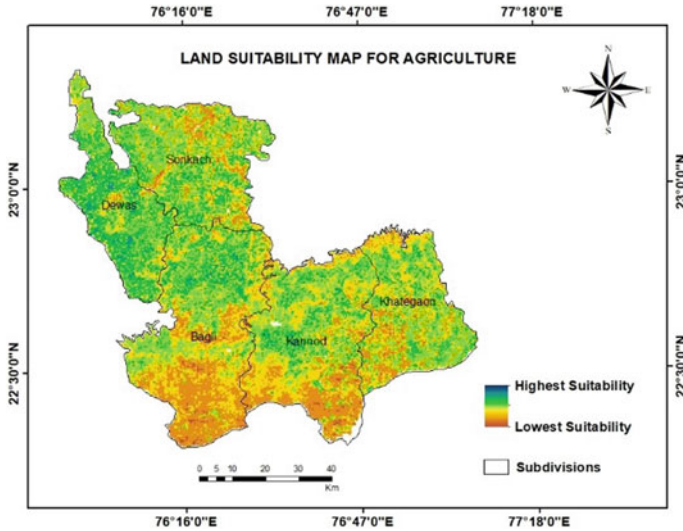Fig. 23 Land suitability assessment model

Fig. 24 Land suitability map for agriculture

5 Conclusion

The aim of this research was to create a comprehensive guideline integrating AHP with ArcGIS ModelBuilder that can classify the district into land parcels based on their suitability for agriculture. In highly suitable areas, large-scale agriculture can be practiced and appreciable production can be expected. In moderately suitable areas, irrigation method should be chosen carefully and soil management must be performed. In marginally suitable areas, farming will be risky and should be limited. The results of this study help us identify the inherent potentials and constraints of land for agriculture whilst accounting for the rigidity of the existing land use pattern.

References

1. Kumar A, Dubey OP, Ghosh, SK (2014) GIS based irrigation water management. 3
2. Natural Resources Census. NRSA/LULC/1:250K/2008-03. National Land Use and Land Cover Mapping Using Multi-Temporal AWiFS Data. National Remote Sensing Agency, Department of Space, Govt. of India
3. National Water Policy (2012) Ministry of water resources, government of India, New Delhi. http://mowr.gov.in/sites/default/files/NWP2012Eng6495132651_1.pdf

4. Indiatimes. With 30 K Hectares Cultivable Land Decreasing Per Year, Food Surplus India Might Become Food Deficient in Future. https://www.indiatimes.com/news/india/with-population-on-the-rise-and-agricultural-land-shrinking-india-might-become-food-deficient-254964.html

5. Urban Development Sector Profile, Department of Industry Policy and Promotion, Government of M.P

6. Trends in Urbanization. Directorate of Census Operation Madhya Pradesh. http://censusmp.nic.in/censusmp/All-PDF/3Trendsinurbanization21.12.2011.pdf

7. Government of India, Ministry of Water Resources, River Development and Ganga Rejuvenation, Central Ground Water Board, Aquifer Mapping Report (2015–16), Dewas District, Madhya Pradesh, North Central Region, Bhopal, August, 2016. https://cgwb.gov.in/AQM/NAQUIM_REPORT/MP/DEWAS.pdf

8. District Census Handbook, Dewas (2011) Census of India. Government of India http://censusindia.gov.in/2011census/dchb/2320_PART_B_DCHB_DEWAS.pdf

9. FAO (1976) A framework for land evaluation, Soil Bulletin 32. Food and agriculture organization of the United Nations. http://www.fao.org/docrep/t0715e/t0715e06.htm

10. Bandyopadhyay S, Jaiswal RK, Hegde VS, Jayaraman V (2009) Assessment of land suitability potentials for agriculture using a remote sensing and GIS based approach. Int J Remote Sens 4(879–895)

11. Aldababseh A, Temimi M, Maghelal P, Branch O, Wulfmeyer V (2018) Multi-criteria evaluation of irrigated agriculture suitability to achieve food security in an arid environment. Sustainability 10(3):803

12. Saaty RW (1987) The analytic hierarchy process—what it is and how it is used. Mathematical modelling 9(3–5):161–176

13. Saaty TL (1977) A scaling method for priorities in hierarchical structures. J Math Psychol 15:234–281

14. Saaty TL (1980) The analytic hierarchy process: planning, priority setting, resource allocation. McGraw Hill International, New York

15. Saaty TL, Vargas LG (1991) Prediction, projection, and forecasting: applications of the analytic hierarchy process in economics, finance, politics, games, and sports, Kluwer Academic Publishers

16. Jankowski P (1995) Integrating geographical information systems and multiple criteria decision-making methods. Int J Geogr Inf Syst

17. National Policy for Farmers (2007) Department of Agriculture & Cooperation. Ministry of Agriculture. Government of India. http://agricoop.nic.in/sites/default/files/npff2007%20%281%29.pdf

18. National Rehabilitation and Resettlement Policy (2007) Ministry of Rural Development. Government of India. http://dolr.gov.in/sites/default/files/National%20Rehabilitation%20%26%20Resettlement%20Policy%2C%202007.pdf

19. Alan Morton. UTM Grid Zones of the World. http://www.dmap.co.uk/utmworld.htm

20. Sarkar A (2008) Geo-spatial approach in soil and climatic data analysis for agro-climatic suitability assessment of major crops in rainfed agroecosystem, Indian Institute of Remote Sensing (IIRS), Agriculture and Soils Division, Master of Science, Andhra University, Dehradun, India

21. Central Research Institute for Dryland Agriculture. Indian Council of Agricultural Research. Agriculture Contingency Plan for District Dewas. http://www.crida.in/CP2012/statewiseplans/madhya%20pradesh/MP5-Dewas-26.6.2012.pdf

22. DivaGIS. http://www.diva-gis.org/Data

23. Advanced Space Thermal Emission Radiometer Global Digital Elevation Model Version 2 (ASTER GDEM V2). National Aeronautics and Space Administration Land Processes Distributed Active Archive Center (NASA LP-DAAC). https://gdex.cr.usgs.gov/gdex/

24. ArcHydro Tools for ArcGIS 10.x. http://downloads.esri.com/archydro/archydro/Setup/

25. United States Geological Survey Earth Explorer. https://earthexplorer.usgs.gov/

26. Google Earth. https://www.google.com/intl/en_in/earth/

27. United States Geological Survey Earth Explorer. Frequently Asked Questions. https://www.usgs.gov/faqs/what-are-best-landsat-spectral-bands-use-my-research?qtnews_science_products=0#qt-news_science_products

28. OpenStreetMap. Geofabrik. https://download.geofabrik.de/asia/india.html
29. Survey of India. Department of Science and Technology. Government of India. http://soinakshe.uk.gov.in/
30. International Soil Reference and Information Centre. Soilgrids. https://soilgrids.org/
31. Permaculture Research Institute. Permaculture News. https://permaculturenews.org/2016/10/19/soils-cation-exchange-capacity-effect-soil-fertility/
32. KrishiKosh. An Institutional Repository of Indian National Agricultural Research System. http://krishikosh.egranth.ac.in/
33. Nevada Climate Change Portal. http://sensor.nevada.edu/NCCP/Education/Clark%20Activities/Articles/Electric%20Conductivity%20of%20Soil.aspx
34. India-Water Resources Information System. http://www.india-wris.nrsc.gov.in/
35. National Centers for Environmental Prediction. Climate Forecast System Reanalysis. Global Weather Data for SWAT. https://globalweather.tamu.edu/
36. QGIS Python Plugins Repository. Soil Texture. https://plugins.qgis.org/plugins/SoilTexture/
37. University of Rhode Island. Rhode Island Stormwater Solutions. Importance of Soil Texture. https://web.uri.edu/riss/files/Importance-of-Soil-Texture.doc
38. Business Performance Management Singapore. AHP Online System—AHP-OS. AHP Priority Calculator. Klaus D. Goepel. https://bpmsg.com/academic/ahp.php
39. Lee GK, Chan EH (2008) The analytic hierarchy process (AHP) approach for assessment of urban renewal proposals. Soc Indic Res 89(1):155–168
40. Effat HA, Hassan OA (2013) Designing and evaluation of three alternatives highway routes using the Analytical Hierarchy Process and the least-cost path analysis, application in Sinai Peninsula. Egypt. Egypt J Remote Sens Space Sci 16(2):141–151. https://doi.org/10.1016/j.ejrs.2013.08.001
41. Pramanik MK (2016) Site suitability analysis for agricultural land use of Darjeeling district using AHP and GIS techniques. Model Earth Syst Environ 2(2):56
42. A quick tour of ModelBuilder. https://desktop.arcgis.com/en/arcmap/10.3/analyze/modelbuilder/a-quick-tour-of-modelbuilder.htm
43. Chang CW, Wu CR, Lin CT, Chen HC (2007) An application of AHP and sensitivity analysis for selecting the best slicing machine. Comput Ind Eng 52(2):296–307
44. Alonso JA, Lamata MT (2006) Consistency in the analytic hierarchy process: a new approach. Int. J. Uncertainty Fuzziness Knowl Based Syst 14(04):445–459
45. Cengiz T, Akbulak C (2009) Application of analytical hierarchy process and geographic information systems in land-use suitability evaluation: a case study of Dümrek village (Çanakkale, Turkey). Int J Sustain Dev World Ecol 16(4):286–294. https://doi.org/10.1080/13504500903106634