Identification of Ground Water Potential Zones Using GIS and Remote Sensing Techniques in the Case of Odiyo Watershed, Ethiopia

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Research

Keywords: Analytical hierarchical process, Weighted Overlay Analysis, Potential groundwater zone, GIS and RS

Posted Date: May 19th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-239478/v1

Abstract

Background: The current study conducted to analysis the bottom water potential zones in Odiyo watershed. The study relies on the secondary data, which is collected from concern department and through internet. Totally nine parameters are consider for the study like drainage density, elevation, geology, geomorphology, land use and land cover, lineaments, rainfall pattern, slope gradient and soil texture. The chosen parameters are prepared and classified in GIS environment, then weightage for every parameter and its classes are assigned using Analytical Hierarchical Process, and eventually, weighted overlay analysis in ArcGIS accustomed discover the result.

Results: The result relived that, about 183.87ha (0.613%) areas are having very high, 4846.23ha (16.18%) area are having high, 19229.4 ha (64.19%) having moderate, 5645.7ha (18.855) having low and 48.6ha (0.16%) area are having very low potential of well water.

Conclusions: The knowledge on strength of ground water supported ground water zones help in management and development of the groundwater within the study area.

1. Background

Ground water resources are a crucial resource for its use in domestic, agriculture and industries purposes. There has been an incredible increase within the demand for groundwater thanks to increase in population, advanced irrigation practices, and industrial usages (Jha et al., 2007). Hence, unscientific exploitation and improper use of water policy are possible factors. Therefore, the assessment of groundwater resources is critical for sustainable management. Most groundwater potential investigation techniques (i.e., geophysical methods, ground based survey, and exploratory drilling) are uneconomical and time consuming and large data sets (Nampak, pradhan, and Manap, 2014; Singh and prakash). However, an integrated GIS and remote sensing study can provide the suitable platform for the convergent analysis of enormous volumes of information and quite higher cognitive process techniques for groundwater exploration.

Recently, several studies are applied using weighted overlay analysis for assessing groundwater potential zones (Tolche, 2020; Andualem & Demeke, 2019; Das, Pal, Malik, & Rabin Chakrabortty, 2019; Hussein, Govindu, & Nigusse, 2016; Ibrahim-Bathis & Ahmed, 2016; Kumar, Herath, Avtar, & Takeuchi, 2016; Magesh, Chandrasekar, & Soundranayagam, 2012; Rahmati, Samani, Mahdavi, Pourghasemi, & Zeinivand, 2014). Among many determent factors of the occurrence and movement of groundwater, topography, geomorphology, lithology, geological structures, lineaments, porosity, slope, drainage patterns, rainfall, LULC, water quality, depth to water, net groundwater recharge, and climate may be listed as examples (Tolche, 2020; Andualem & Demeke, 2019; Elewa & Qaddah, 2011; Jaiswal, Mukherjee, Krishnamurthy, & Saxena, 2003; Jha, Chowdhury, Chowdary, & Peiffer, 2007; Murthy & Mamo, 2009). Hence, the factors are a different per researcher, and consequently, the results vary (Magesh et al., 2012).

Groundwater potential zone mapping in Odiyo watershed will have a big effect within the sub basin furthermore because the country. Since the watershed is that the major part to contribute to Omo River; mapping the underground water will enhance sustainable management of groundwater resources within the country. As a result, the current study interested to delineate the groundwater potential zones by using remote sensing and GIS technologies within the study area. Nine determinant factors, namely, lithology, slope, LULC, rainfall, lineaments, geomorphology, elevation, soil texture and drainage density, were accounted for within the study.

2. Study Area

The study area Odiyo watershed is found within the center portion of Omo basin, Ethiopia. Geographically, the study site is situated between latitude 7°7′0” to 7°25′0” n and longitude 36°23′0” to 36°40′30” e with an aerial extent of 315.52 km^2 (Fig. 1) .the elevation of the area ranges from 3219 to 1190m above average sea level. In step with the national meteorology report, the mean annual rainfall of the area is varies from 1536.7 to 1644.9mm and the mean annual temperature ranges from 12.4^{o}c to21.5 ^{o}c.

3. Methodology

In order to identify the ground water potential zone within the study area various kinds of data and software are used (Table 1).All criteria employed during this study were first geo-referenced and converted into a raster format to make ready for reclassification and standardization. Following, all the factors were reclassified using ArcGIS spatial analysis tool supported their groundwater availability rank. Their levels of groundwater availability were decided supported data collected from the varied scientific literature. Thus, all the factors were classified into five classes (very high, high, moderate, low and very low) with values ranging from 1 to 5, where 1 represents very low and 5 represents very high. For each criterion, Weights were derived in IDRISI software using AHP methods. All the standardized criteria were combined using weighted overlay analysis to produced ground water Potential Zones Map of the study area. The sources of the quality data used for the delineation of groundwater Potential Zones Map and availability levels were supported published scientific literature as indicated in Table 2. The overall framework of the research study analysis is presented in Fig. 2.

Table 1
Summary of data types and their sources

No	Type of data	Source of data	Scale/Resolution /Format	Functions
1	Landsat 8 Operational Land Imager (OLI) satellite image	USGS	30*30m	Used to generate lineament density map of the study area
2	Spot 6	EGIA	1.5*1.5m	Used to generate Land use Land cover map of the study area
3	A digital elevation model (DEM)	SRTM	30*30m	Used to derive slope, elevation, Geomorphology and drainage density map
4	The rainfall data of 36 years(1980–2016)	NMA	Excel Format	Used to generate Rainfall map of the study area
5	geological data	Ethiopian geological survey	at a scale of 1: 250,000	Used to generate Geological map of the study area
6	Soil data	Food and agricultural organization	Shape File	To develop Soil map of the study area

Table 2
Criteria considered for Groundwater potential zone selection.

Criteria	Unit	Class	Value	Ground water availability	Source
		Clay	1	Very low	
Soil texture	Class	Clay loam	2	Low	(Tripathi *et al*,2017; FAO, 1998)
		Sandy clay loam	3	Moderate	
		Sandy loam	4	High	
		Sandy and wetland	5	Very high	
LULC	Class	Others	1	Very low	
		Built up	2	Low	
		Waterbody	3	Moderate	(Mahalingam and Vinay, 2015).
		Agricultural area	4	High	
		Forest	5	Very high	
Geology	Class	-	1	Very low	
		Metamorphic rocks	2	Low	(Mwega *et al.*, 2013)
		Igneous rocks	3	Moderate	
		-	4	High	
		Sedimentary rocks	5	Very high	
Geomorphology	Class	Salt crust	1	Very low	
		Salt domes and Layer	2	Low	
		Hills, plateaus and Badlands	3	Moderate	(Ghodratabadi and Feizi, 2015)
		Plain surfaces between 500 and 1000 m	4	High	
		Mountain with an altitude of 500 meters.	5	Very high	

Table 3
Software and materials employed in the study

Drainage density	**Km/km2**	**Areas with low drainage** **density was characterized as high groundwater recharge areas**	**(Ibrahim-bathis and ahmed, 2016;**
			; Rahmati et al., 2015;
			Yildiz, 2004; rajaveni et al., 2017;
			Andualem and demeke, 2019;
			Tolche,2020)
Lineament density	Km/km^2	Areas having high lineament density	
		Was characterized as	(Yeh et al., 2016;
		High groundwater recharge areas	Nampak et al., 2014;
			Naghibi et al., 2017;
			Rajaveni et al.; 2017;
			; Mukherjee et al., 2012)
Rainfall	mm	The ground water is high if the rainfall is high and it is low if rainfall is low.	(Mahalingam & vinay, 2015)
Elevation	m	Lower the elevation higher the ground water potential	(Gedebo,2005)
Slope	%	the flat slopes decrease the runoff and increase the infiltration of surface water into ground, which can increase the ground water recharge	(Tolche, 2020;maheswaran et al., 1999;mahalingam & vinay, 2015; andualem and demeke, 2019)

Software used	**Purpose**
ERDAS IMAGIN 2015	Digital image processing like image enhancement, image preprocessing, layer stacking, Classification…
ArcGIS 10.5	Integration of spatial and non-spatial data, thematic map generation and also for map layout preparation
MS Office	Documentation, statistical analysis and presentation
GPS	For collecting of GCP points
IDRISI 32	calculate weights for each factors using relative importance value and combine
Google Earth	Used as supplementary for accuracy of the classification.
Geomatica2017	To generate fault from DEM

4. Results And Discussion

4.1.1 Drainage density

The drainage density has an inverse relation with the permeability of aquifers and plays a significant role within the runoff distribution and level of infiltration (Ibrahim-Bathis and Ahmed, 2016; Rahmati et al., 2015; Yildiz, 2004; Rajaveni et al., 2017;

Tolche, 2020). The drainage density of the study area was prepared from the digital elevation model (30 m x 30 m resolution) in ArcGIS 10.5 platform. The drainage density has been classified into five classes (Table 4 and Fig. 3)

Table 4
Drainage density class with respective Ground water availability.

Drainage class	Ground water availability	Value	Area (ha)	Area (%)
3.20–5.11	very low	1	1540.867	4.883016
3.20–2.28	Low	2	4915.437	15.57705
2.28–1.44	Moderate	3	8636.156	27.36803
1.44–0.54	High	4	4722.647	14.9661
0-0.54	very high	5	11740.53	37.2058

4.1.2 Lineament density

Lineament density is directly proportional to groundwater potential (Andualema and Demeke, 2019). Areas with high lineament density are good for groundwater potential zones (Yeh et al., 2016; Nampak et al., 2014; Naghibi et al., 2017; Rajaveni et al.; 2017; Mukherjee et al., 2012;; Tolche,2020). The Lineament density of the study area was prepared Landsat 8 (OLI) satellite image captured in January 2020 in Geomatic 17 platform. Then Lineament density has been classified into five classes (Table 5 and Fig. 4)

Table 5
Lineament density class with respective Ground water availability.

Lineament class	Ground water availability	Value	Area (ha)	Area (%)
0–022	very low	1	11689.41	37.04381
0.22–0.64	low	2	8463.812	26.82187
0.64–1.10	moderate	3	6321.204	20.03194
1.10–1.69	high	4	3855.088	12.2168
1.69–2.90	very high	5	1226.121	3.885585

4.1.3. Rainfall

The possibility of ground water is high if the rainfall is high and it is low if rainfall is low (Mahalingam and Vinay, 2015). This study has been considering the annual mean rainfall from the year 1980 to 2016. the worth of annual mean values are plated on the respective rain gage stations and also the interpolation method Krigging has been wont to learn the distribution of rainfall within the study area. Once the spatial distribution of rainfall has been found the study area has been classified into five zones supported the equal interval (Table 6 and Fig. 5)

Table 5
Rainfall class with respective Ground water availability.

Rainfall class	Ground water availability	Value	Area (ha)	Area (%)
1537–1554	very low	1	4248.45	13.45838
1554–1566	low	2	8105.67	25.67741
1566–1580	moderate	3	14348.34	45.45315
1580–1606	high	4	3456.27	10.94889
1606–1645	very high	5	1408.59	4.462178

4.1.4 Elevation

Water tends to store at lower topography instead of the upper topography. Higher the elevation lesser the ground water potential and the other way around as Gedebo,(2005) citied in Mahalingam and Vinay,(2015). For this study elevation data having 30meter spatial resolution has been created supported the ASTER DEM. The study area's elevation ranges between 1189meters to 3163 meters from the mean water level, this value are classified equally into five classes (Table 7 and Fig. 6)

Table 7
Elevation class with respective Ground water availability.

Elevation class	Ground water availability	Value	Area (ha)	Area (%)
2758–3163	very low	1	5299.02	16.78641
2442–2758	low	2	6188.4	19.60382
2127–2442	moderate	3	9012.87	28.55127
1728–2127	high	4	6340.68	20.08622
1189–1728	very high	5	4726.35	14.97229

4.1.5. Slope

Slope determines the speed of infiltration and runoff of surface water, the flat surface areas can hold and drain the water within the bottom, which might increase the ground water recharge whereas the steep slopes increase the runoff and reduce the infiltration of surface water into ground (Mahalingam and Vinay, 2015). The slope of the study area has been calculated in percent supported the DEM model which was supported the ASTER data. The slope has been classified into five classes (Table 8 and Fig. 7)

Table 8
Slope class with respective Ground water availability.

Slope class	Ground water availability	Value	Area (ha)	Area (%)
17.01–26.28	very low	1	1874.34	5.937596
12.42–17.01	low	2	4428.27	14.02802
8.45–12.42	moderate	3	6795.09	21.52571
4.78–8.45	high	4	9931.41	31.46105
0.29–4.78	very high	5	8538.21	27.04762

4.1.6 Soil Texture

The rate of infiltration largely depends on the grain size and related hydraulic characteristics of the soils (Fashae et al., 2014). Soil texture of the study area is studied from the soil data collected from agricultural department. The study reveals three soil texture class in odiyo watershed namely clay and clay loam. Rank of soil has been assigned on **the premise** of their infiltration rate (Tripathi *et al*, 2017). Clay and clay loam soil have low infiltration rate (Table 9 and Fig. 8)

Table 9
Soil texture class with respective Ground water availability.

Texture class	Ground water availability	Value	Area (ha)	Area (%)
Clay	very low	1	1990.17	6.304526
Clay Loam	low	2	29577.15	93.69547

4.1.7. Land use and Land cover (LU/LC)

The surface covered by vegetation like forests and agriculture traps and holds the water in root of plants whereas the built-up and rocky land use affects the recharge of groundwater by increasing runoff during the rain, so it is necessary to check what quite features are covered the study area's land surface. The spot 6 satellite image has been used for the study to seek out the land use and land cover of study area. The supervised classification method has been used with maximum likelihood. The results of the study found the study area covered by six different classes like agricultural land, forest, built-up, water body, bare and others (Table 10 and Fig. 9).

Table 10
LULC class with respective Ground water availability.

LULC class	Ground water availability	Value	Area (ha)	Area (%)
Others	very low	1	3197.958	10.14243
Built up	low	2	25.5708	0.081099
Water body	moderate	3	13458.87	42.68527
Agriculture	high	4	1336.882	4.239967
Forest	very high	5	13511.2	42.85123

4.1.8 Geomorphology

Geomorphology reflects various landform and topographical features. Surface water is one in every of the important geomorphological agents within the development and shaping of landscapes and landforms; thus hydro-geomorphological studies are of importance in planning and execution of groundwater exploration (Fashae et al. 2014). Geomorphic features within the study area are dominated by hill, and mountain. It is classified in terms of groundwater potentiality (Table 11 and Fig. 10) supported pervious literature (Ghodratabadi and Feizi, 2015)

Table 11
Geomorphology class with respective Ground water availability.

Geomorphology class	Ground water availability	Value	Area (ha)	Area (%)
Hills	moderate	3	1937.745	6.142923
Mountain	very high	5	29606.61	93.85708

4.1.9 Geology

Groundwater occurrence and its movement depend on the geological setting. Major geological classification of the watershed is ingenious rocks. Geological features of the study area are later classified in terms of groundwater potentiality (Table 12 and Fig. 11) based on pervious literature (Mwega, 2013).

Table 12
Geomorphology class with respective Ground water availability.

Geology class	Ground water availability	Value	Area (ha)	Area (%)
Igneous rock	Moderate	5	31544.35	100

4.2. Weight assignment to parameters

The results of the study indicate that the consistency ratio is 0.03. this is less than 0.1 which is acceptable to continue and apply the AHP method analysis (Saaty,1980).Based on the IDIRISI_AHP weight derivation module, the following eigenvector weights for all criteria considered for groundwater potential zone selection were generated (Table 14).In summary, the results of the AHP weight derivation reveals that parenthetically, soil texture plays an important role with the best score weight of 31.21% followed by geology,geomorphology,LULC, rainfall, lineament density, drainage density, elevation and slope with score weight of 22.23%, 15.55%, 10.75%, 7.39%, 5.07%, 3.5%, 2.47% and 1.83%, respectively. A region having high lineament density was given high weight and the other way around (Ibrahim-Bathis and Ahmed, 2016; Naghibi et al., 2017; Nampak et al., 2014; Yeh et al., 2016). a part having high drainage density was assigned very low weight (Tolche,2020;Andualem & Demeke, 2019; Ibrahim-Bathis & Ahmed, 2016; Rahmati et al., 2014).whereas steep slope area assigned to low weight (Andualem & Demeke, 2019; Hussein et al., 2016; Ibrahim-Bathis & Ahmed, 2016).

Table 13
Pair wise comparison in 9 point continuous scale.

	Texture	Geology	Geomorphology	LULC	Rainfall	Lineament	Drainage	Elevation	Slope
Texture	1								
Geology	1/2	1							
Geomorphology	1/3	1/2	1						
LULC	1/4	1/3	1/2	1					
Rainfall	1/5	1/4	1/3	1/2	1				
Lineament	1/6	1/5	1/4	1/3	1/2	1			
Drainage	1/7	1/6	1/5	1/4	1/3	1/2	1		
Elevation	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	
Slope	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1

Table 14
Weights derived by calculating the principal eigenvector of pair wise comparison matrix.

Factor	Eigenvector Weight	Percentage (%)
Soil texture	0.3121	31.21
Geology	0.2223	22.23
Geomorphology	0.1555	15.55
LULC	0.1075	10.75
Rainfall	0.0739	7.39
Lineament	0.0507	5.07
Drainage	0.035	3.5
Elevation	0.0247	2.47
Slope	0.0183	1.83
	1	**100**
Consistency ratio = 0.03, consistency is acceptable.		

4.3 Delineation of groundwater potential zones

After the weightage of each parameter has been determined. Finally, ‘Spatial overlay method in Arc GIS environment is employed to conduct overly analysis to get the intended result. The results of overlay analysis has been classified into five classes as very low, low, moderate, high and very high (Fig. 12). From the results of classification it is been found that, about 183.87ha (0.613%)

areas are having very high, 4846.23ha (16.18%) area are having high, 19229.4 ha (64.19%) having moderate, 5645.7ha (18.855) having low and 48.6ha (0.16%) area are having very low potential of ground water (Table 15). Very high and high groundwater potential zones are concentrated within the area where, high lineament density was illustrated united of the basic factors for groundwater potential zonation (Ibrahim-Bathis & Ahmed, 2016).The low to very low potential zones are mainly distributed within the areas having high drainage density. Hence, the groundwater potential in these areas may be not sufficient for irrigation and other livelihood requirements. Therefore, groundwater development activities preferred to be performed in high groundwater prospective zones.

Table 15
Groundwater potential area and percentage of the study area.

Ground water availability	Value	Area (ha)	Area (%)
very low	1	48.6	0.16225
low	2	5645.7	18.84803
moderate	3	19229.4	64.19686
high	4	4846.23	16.17902
very high	5	183.87	0.613845

5. Conclusion

The study on groundwater potential through integration and weightage overlay analysis in GIS environment using physical parameters that influence the groundwater is being successfully applied during this study. The methodology begins with the preparation of thematic layers from different data sources and next deriving the weights using overlay analysis to search out groundwater potential. The weightage is assigned to different layers and overlaid to realize the intended result groundwater potential zones of odiyo watershed. The thematic layers are first assigned the weightage supported the precise importance of the category in individual parameters. The layers are then overlaid and therefore the result's then classified into five class supported groundwater availability to namely; very high, high, and moderate, low and very low. The knowledge obtained on the groundwater prospectus of the study area will be accustomed identify and extract the potable water for the domestic and irrigational purposes.

Declarations

Ethics approval and consent to participate

Informed consent was obtained from all student participants involved in the study. All participants freely agreed to participate in the study without reservation.

Funding

The authors are not received any fund.

Consent for publication

Consent to publish individual data in any form was obtained from the participants interviewed.

Availability of data and materials

Not applicable' for that section

Competing interest

The authors declare no competing interests.

Authors’ contributions

Habtamu D and Dereje B conceived and designed the work validated the method section. Both authors participated in the analysis, validation and writing of the paper. Both authors read and approved the final manuscript.

Acknowledgment

The authors are highly indebted to all secondary data provider organizations. The authors are also grateful to those individuals who assist in different stages of this work. We acknowledge the comments from anonymous reviewers.

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Figures

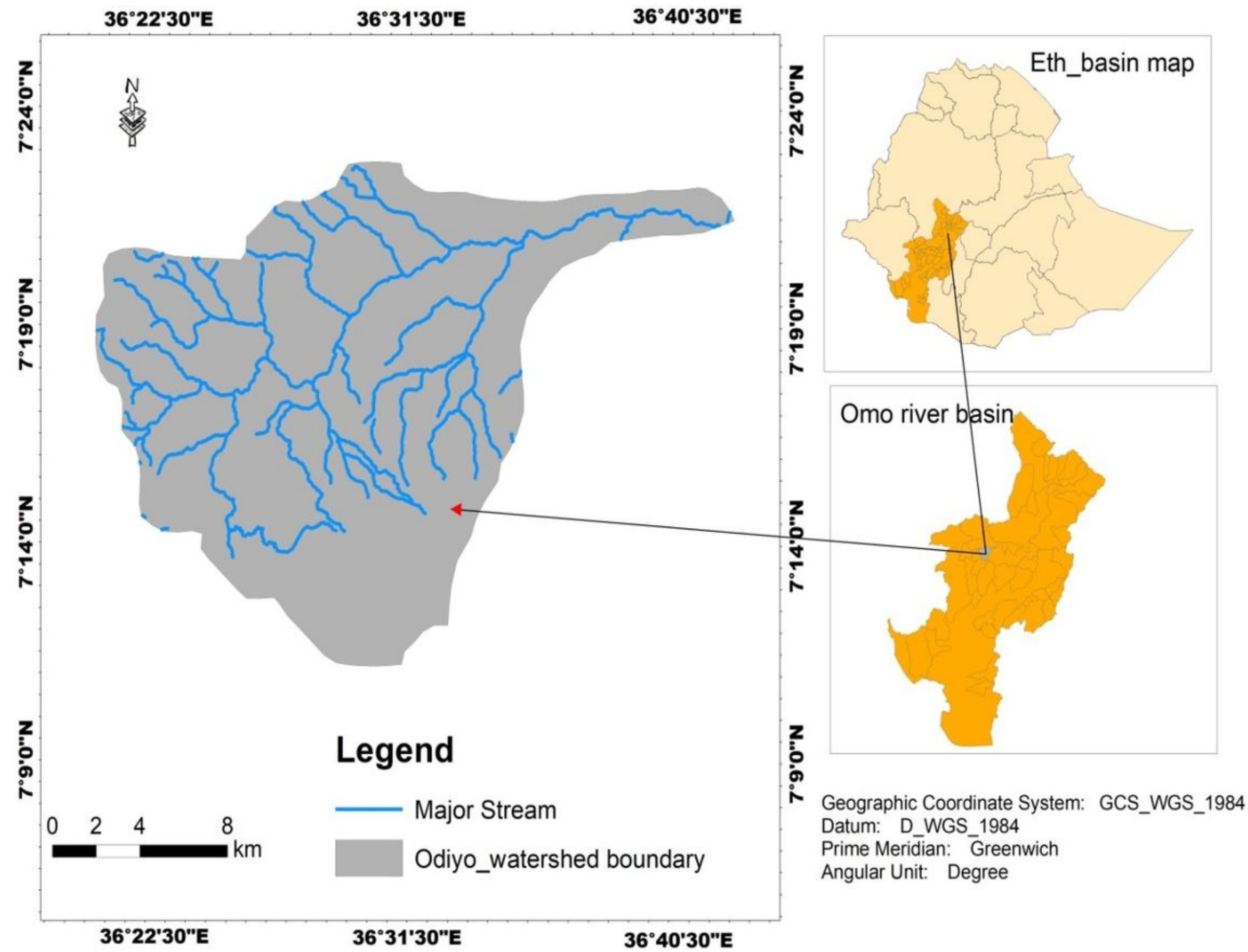

Figure 1

Locational map of odiyo watershed Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

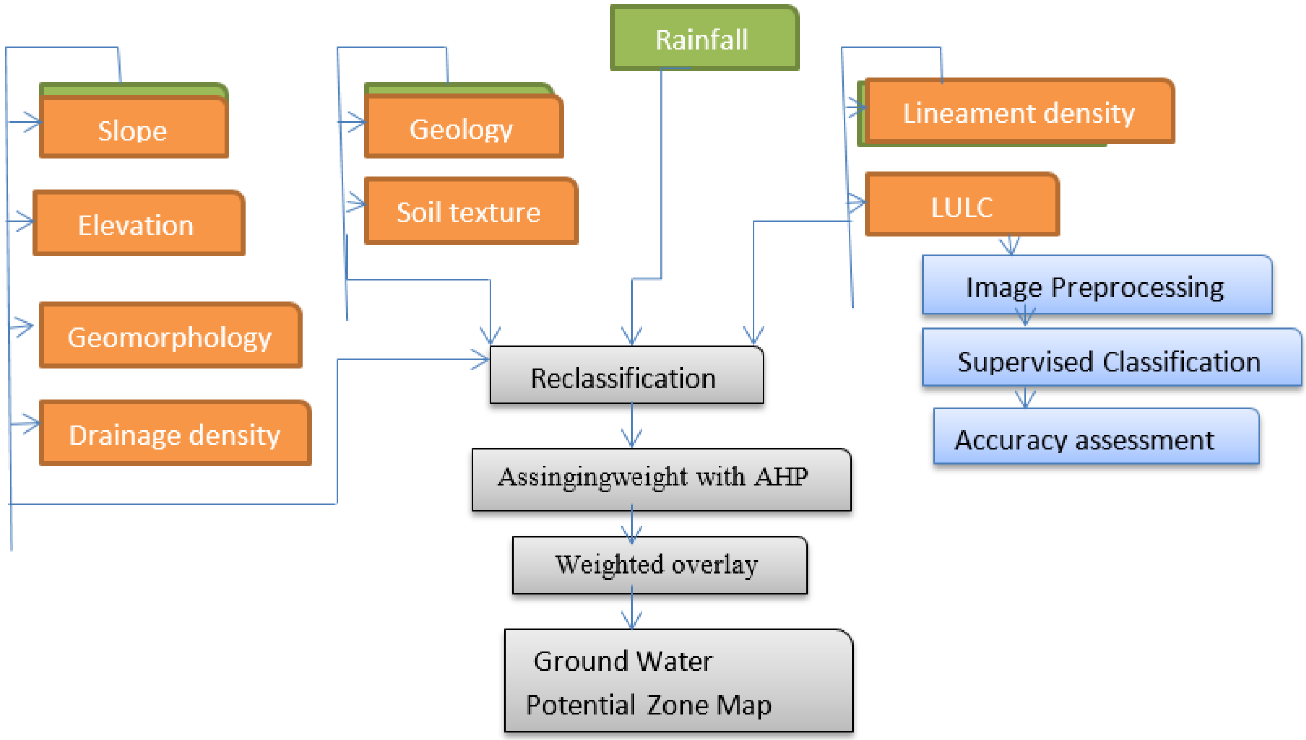

Figure 2

Methodological flowchart

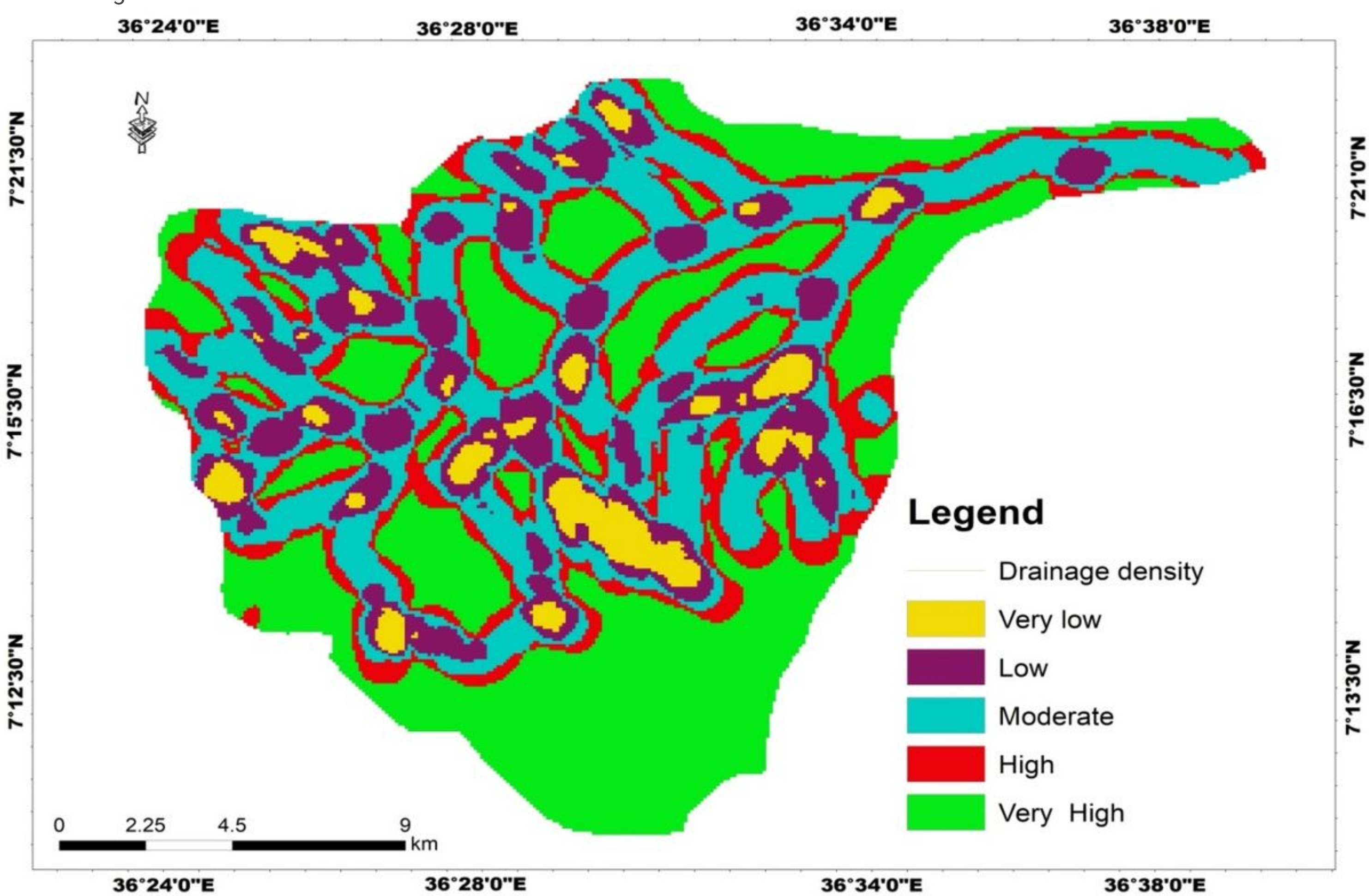

Figure 3

Reclassified Drainage density map. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

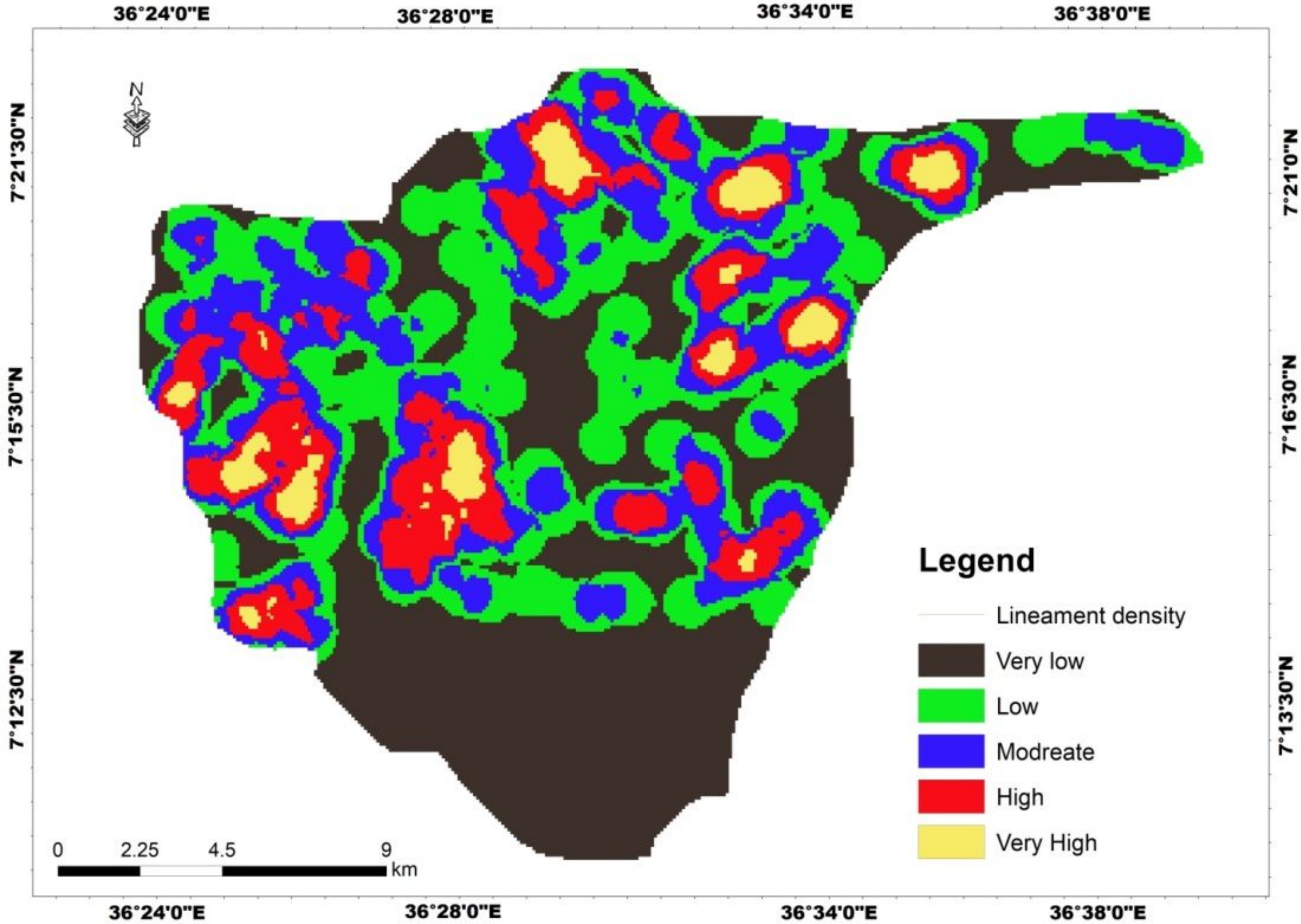

Figure 4

Reclassified Lineament density map. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

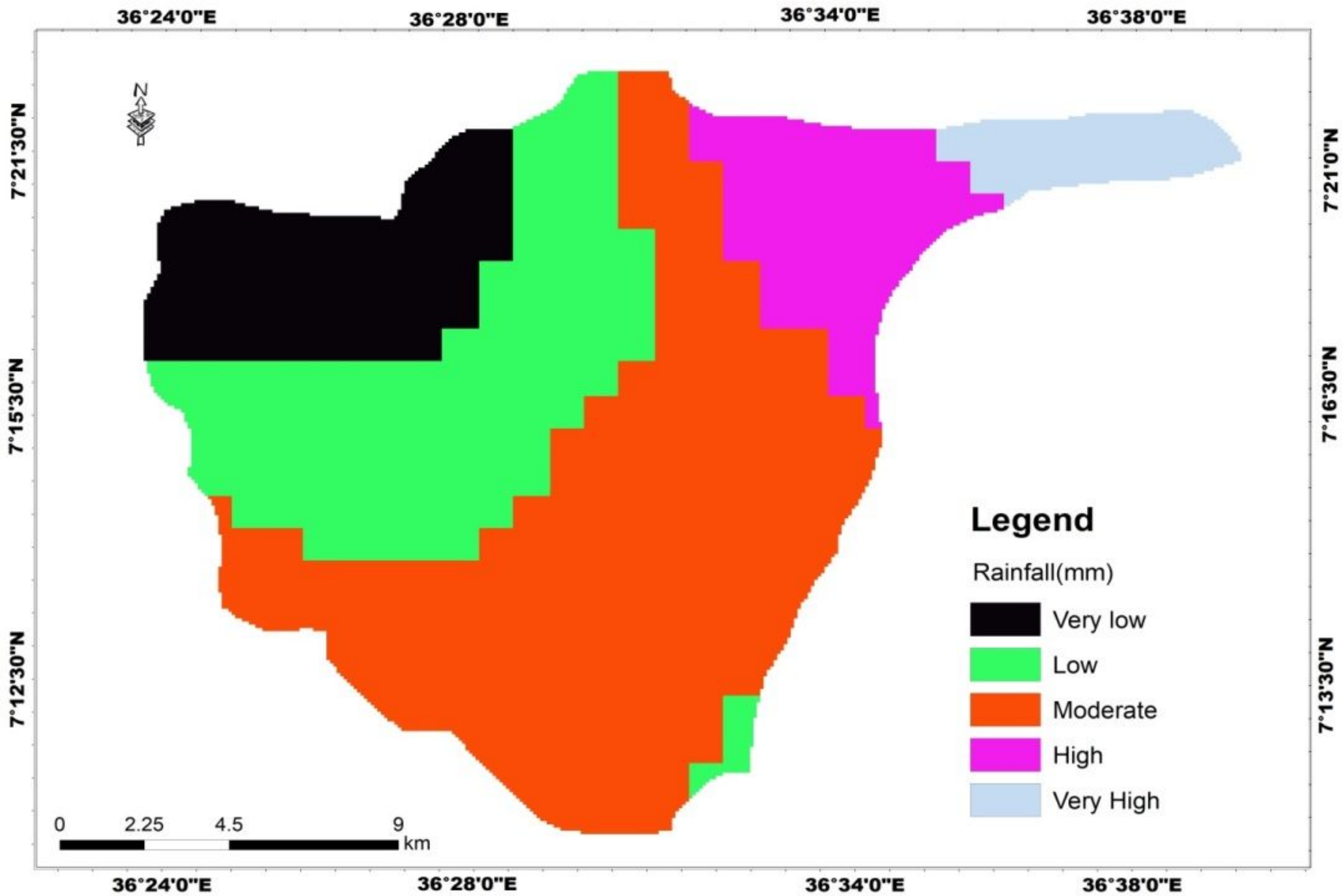

Figure 5

Reclassified Rainfall map. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

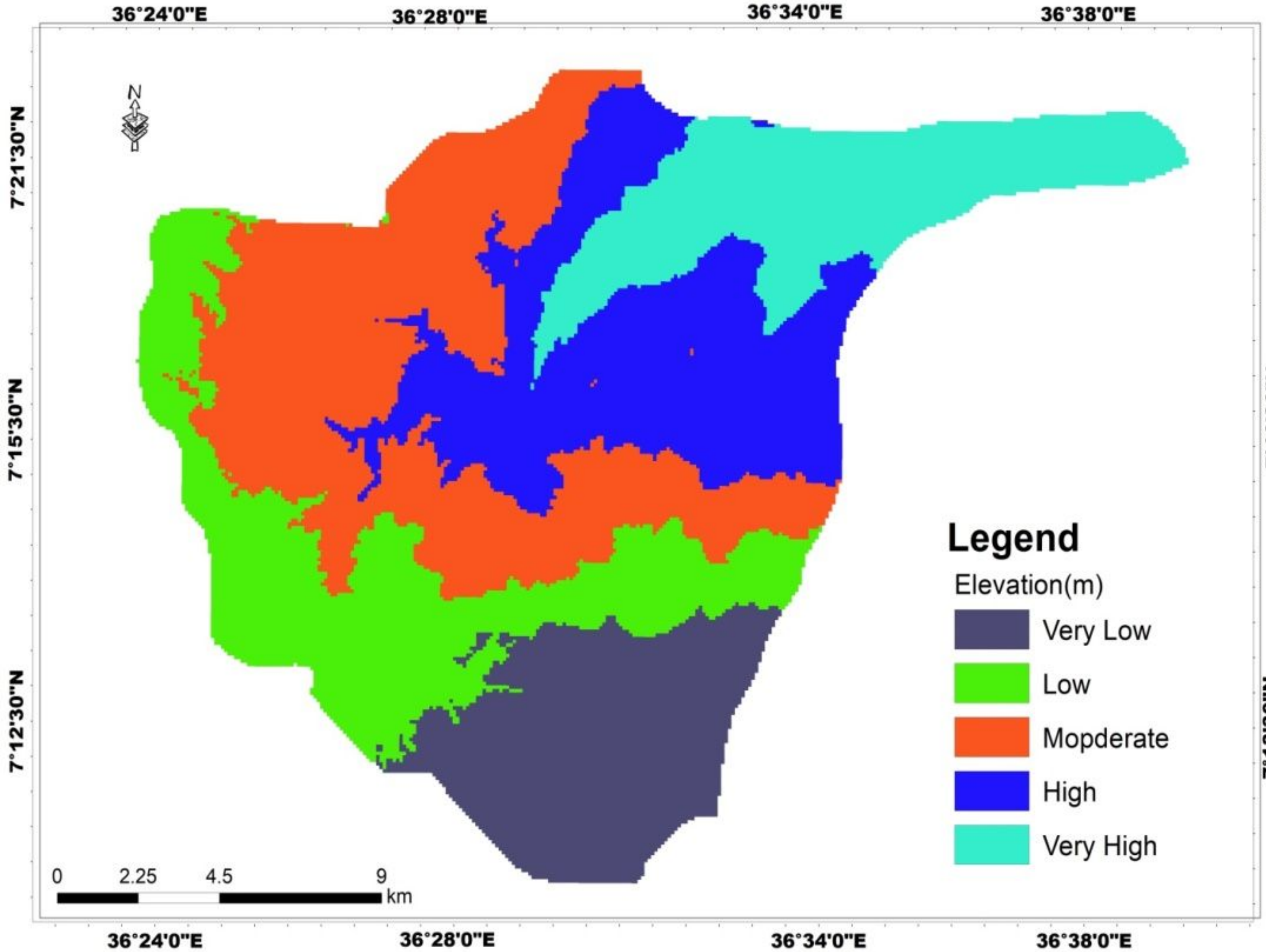

Figure 6

Reclassified Elevation map. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

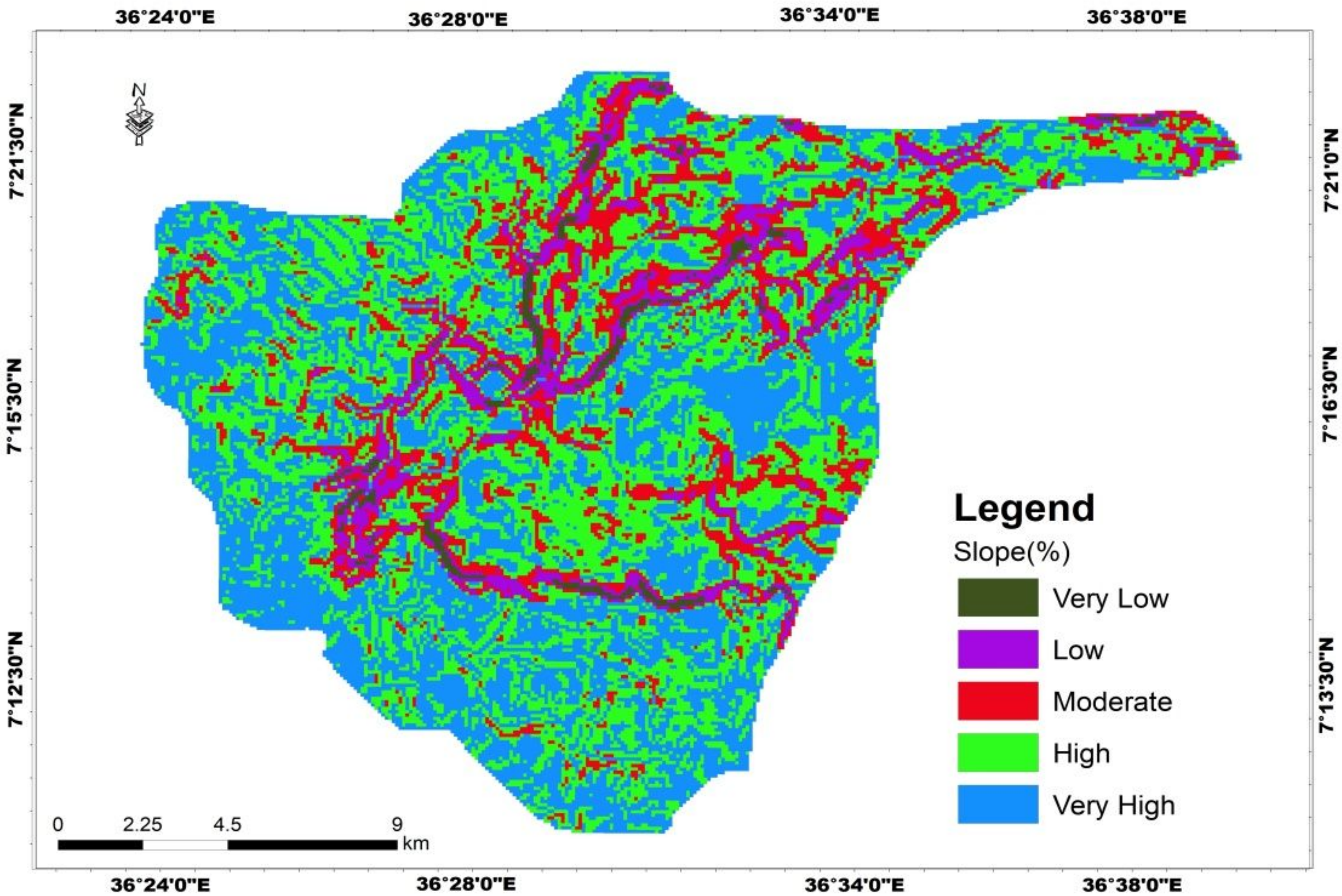

Figure 7

Reclassified Slope map. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

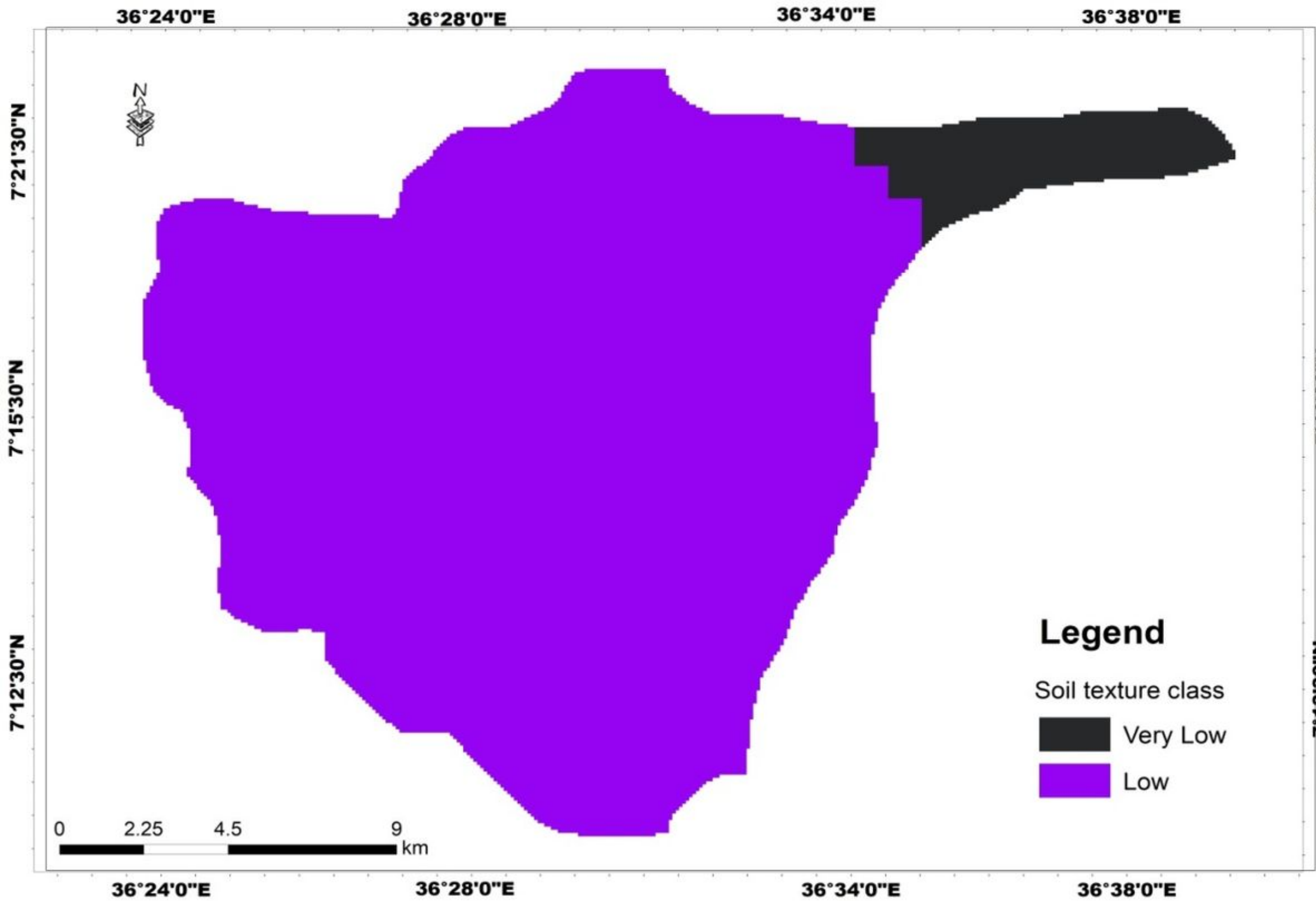

Figure 8

Reclassified Soil texture map. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

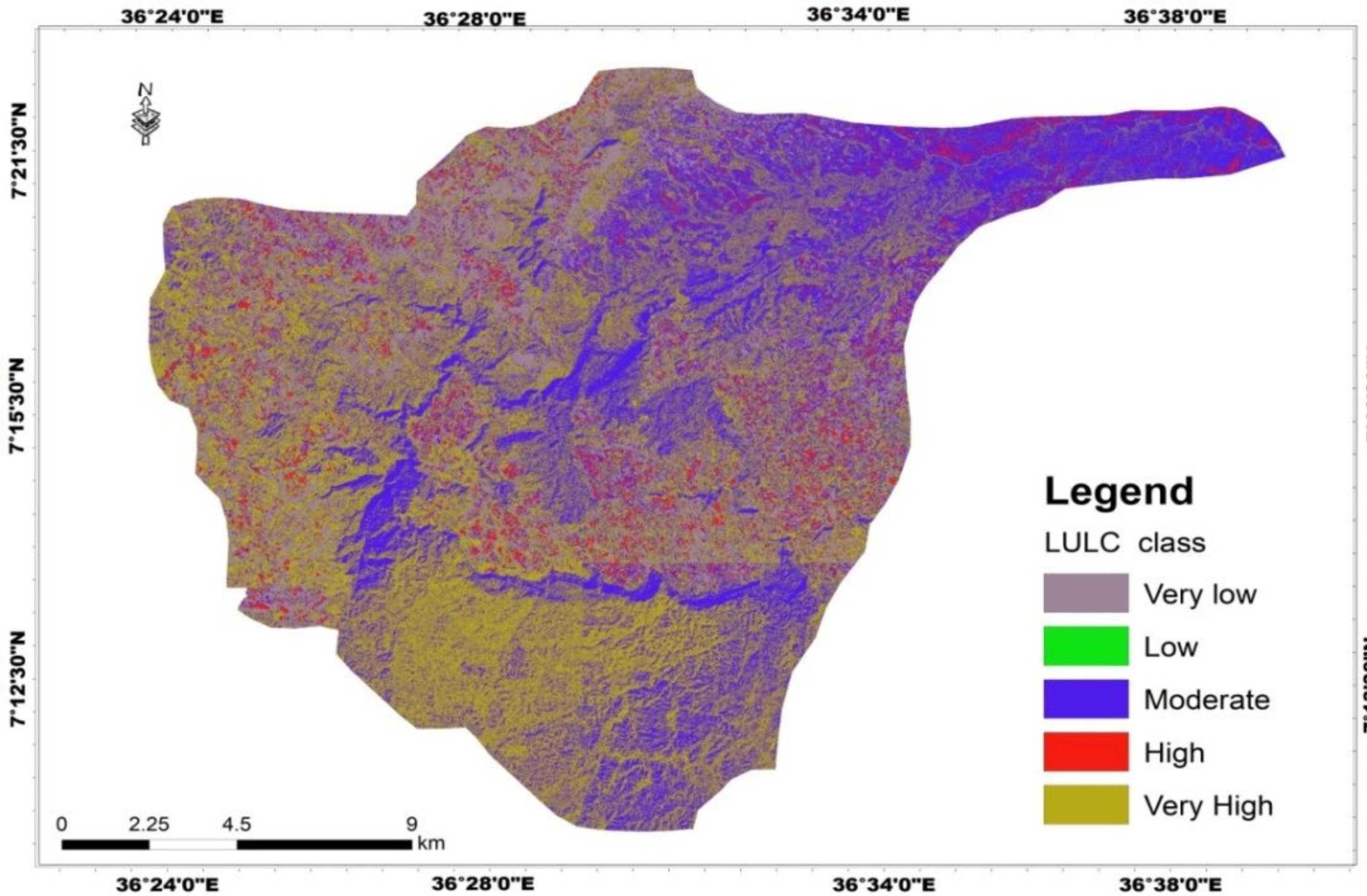

Figure 9

Reclassified LULC map. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

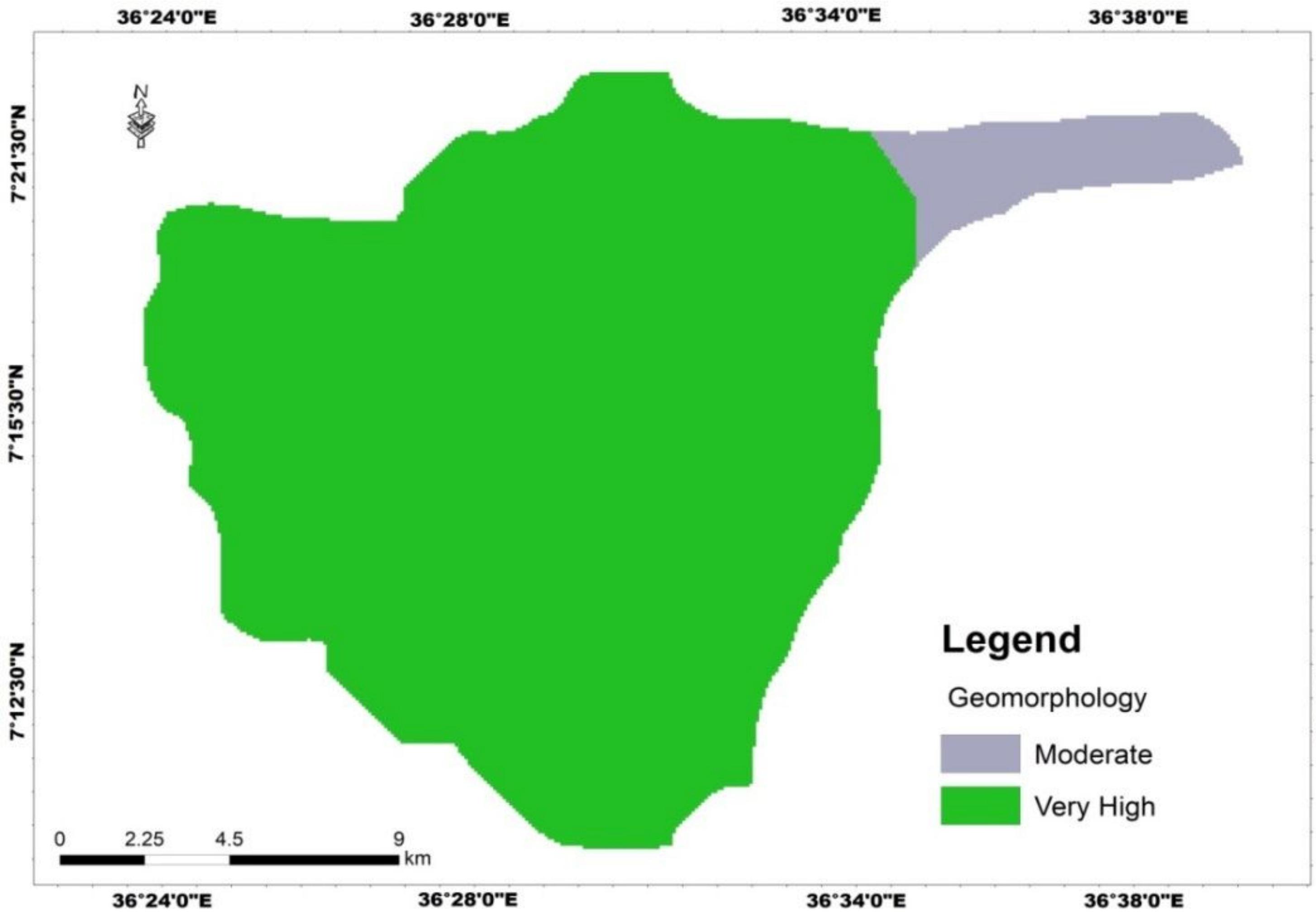

Figure 10

Reclassified Geomorphology map. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

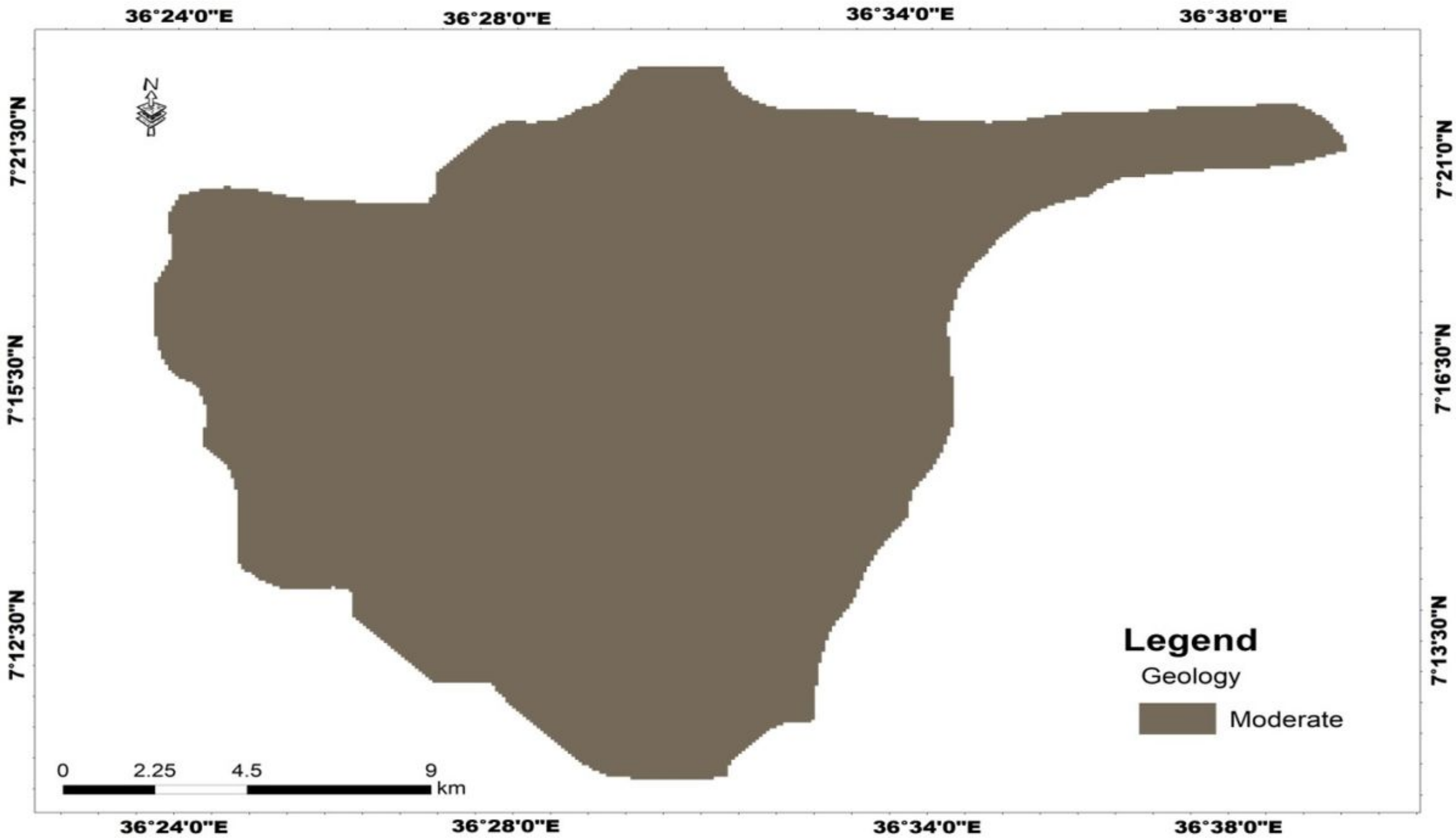

Figure 11

Reclassified Geology map. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

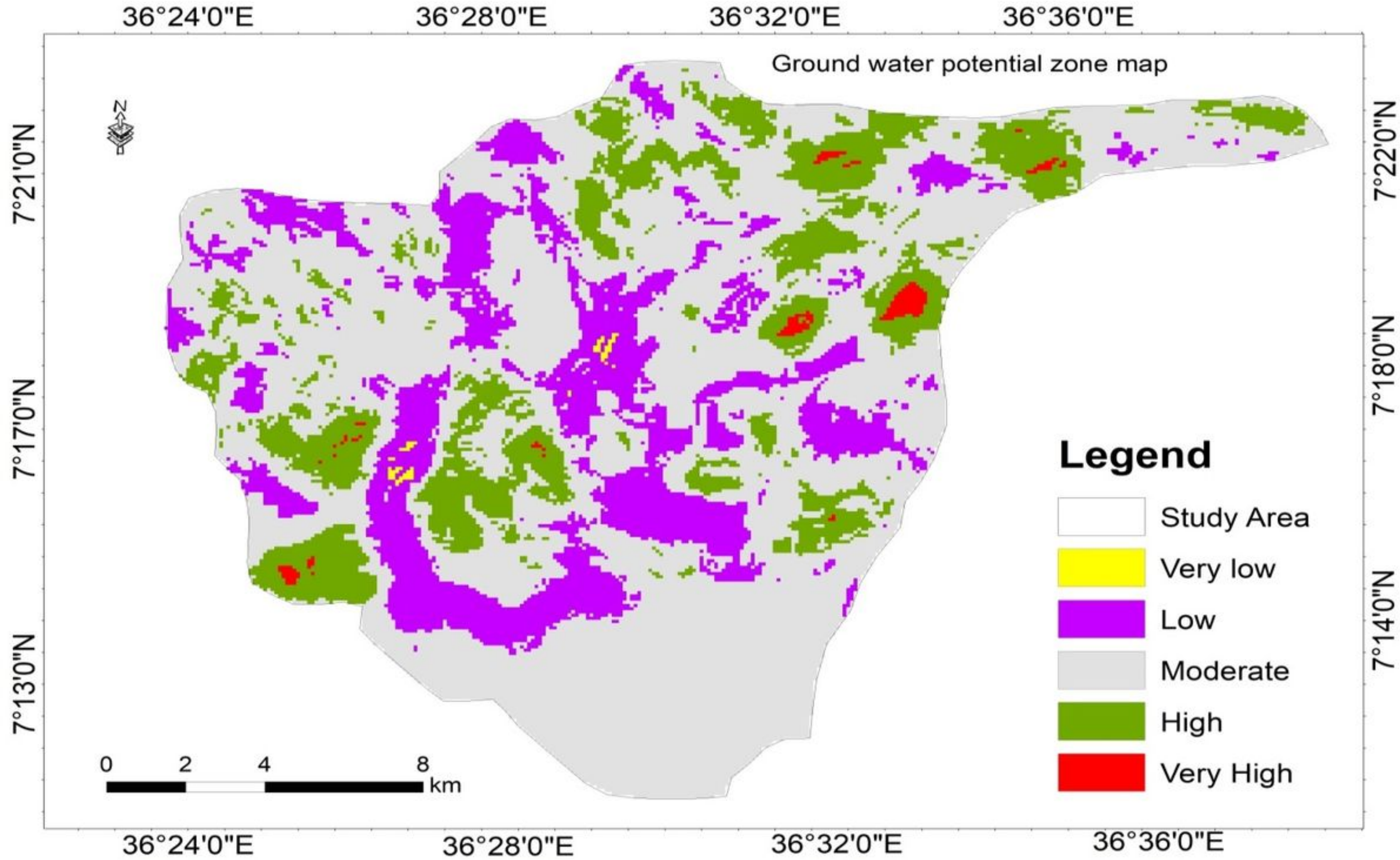

Figure 12

Groundwater Potential zones of map of odiyo watershed Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.