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India's Geo-wealth, Geomorphological Heritage and Geomorphodiversity: Assessment, Classification, and Promotion

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Abstract: *India is a country with rich geo-wealth and geoheritage. Geo-wealth refers to all the abiotic elements (geological, geomorphological, hydrological, and pedological) of the landscape. Geological and geomorphological features occurring in different parts of the country are part of the natural assets and are precious national heritage (geoheritage), worthy of conservation. Apart from rock monuments and fossil parks, geomorphological wonders or geomorphosites have great potential to attract tourists. Such sites are also significant from the point of view of geoscience education and research. Geotourism with a focus on landscape and geology is growing rapidly all over the world and India is no exception to this. To promote geotourism in India, comprehensive information (geoinfographics) about geomorphosites should be made available to the tourists by way of websites. For this, first a peer-reviewed national inventory of geomorphosites and their classification, mapping and assessment is required. In this paper, a simple 10-digit geocoding system for four dozen potential geomorphosites in India is suggested. This coding could be used to establish a classification and the priority of geomorphosites. It is obvious that serious efforts are needed to protect the national geomorphological wonders for posterity.*

Introduction

India is a country with outstanding, remarkable and rich geo-wealth. India has about 2.1% of the Earth's land surface area and about 8% of the world's biodiversity. The country is rich with unparalleled geo-wealth and geodiversity due to – (a) large variety of rocks representing almost the entire spectrum of the geological timescale (>3.0 Gyr to Holocene), (b) the Indian Shield, a repository of economically valuable minerals, made up of a number of Precambrian cratonic blocks, fold belts and rifts, and characterised by some of the oldest land surfaces in the world, (c) the Himalaya Mountains, the highest, youngest and tectonically most active mountain belt in a collisional setting, (d) the vast alluvial landscape of the Indus-Ganga-Brahmaputra Rivers occupying a large geological and sedimentary depression, (e) the Western Ghat (Sahyadri), the great escarpment of India associated with the western passive margin, (f) the Deccan Traps, a large igneous province, (g) nearly 7,500 km long coastline,

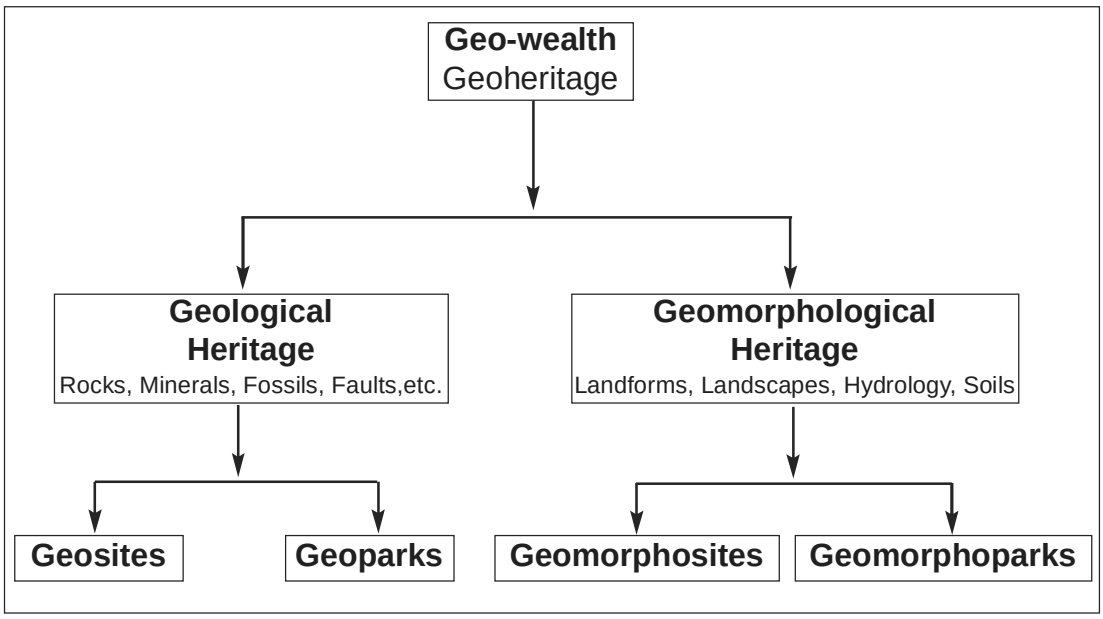

Figure 1. Classification of geo-wealth (geoheritage)

(h) the monsoon climate, (i) variety of geomorphic processes (e.g. hillslope, fluvial, coastal, aeolian, glacial, etc.), and (j) presence of all the major ecosystems of the world.

Geo-wealth is a descriptive term that refers to all the abiotic elements (geological, geomorphological, hydrological, and pedological) of the landscape. As this geo-wealth has been transmitted or inherited from the past, it is described as geoheritage (Brocx and Semeniuk, 2007). Geoheritage may be further classified as geological heritage and geomorphological heritage (Fig. 1). The former deals with the geological features (rocks, minerals, fossils, folds, faults, etc.), and the latter refers to the geomorphological features and elements (landforms, landscapes, drainage network and soils). Geomorphological heritage includes sites or a collection of sites, called geomorphological sites or geomorphosites, which are geomorphological landforms or landscapes "that have acquired a great scientific, cultural/ historical, aesthetic and/or social/economic value due to human perception or exploitation" (Panizza, 2001). Greater is the number of physical elements in an area, the greater is the geomorphic diversity or geomorphodiversity (Panizza, 2009; Pellitero, *et al.*, 2011)

India's World Heritage Sites and National Geological Monuments

Geotourism is defined as "a form of nature tourism that specifically focuses on landscape and geology" (Dowling, 2011). The subject of geotourism is growing rapidly all over the world, and India is no exception to this. While historical monuments, archaeological sites and ancient temples are major drivers of tourism in India, attracting millions of tourists every year, the number of tourists visiting national parks (Nanda Devi, Kaziranga, Sundarbans, Manas, Kanha, etc.), biosphere reserves (Nilgiri, Mannar, Similipal, Nokrek, Pachmarhi, Kanchanjanga, Dehang Debang, Dibru-Saikhowa, etc.), Ramsar sites (Wular, Lokta, Chilka, Sambhar, Vembanad), as well

Table 1. UNESCO's World Heritage Sites in India

Sr. No.	Natural Properties
1	Kaziranga National Park
2	Manas Wildlife Sanctuary
3	Keoladeo National Park
4	Sundarbans National Park
5	Nanda Devi & Valley of Flowers
6	Western Ghat
7	Great Himalayan National Park
Sr. No.	**Cultural Properties**
1	Agra Fort
2	Ajanta Caves
3	Ellora Caves
4	Taj Mahal
5	Group of Monuments Mahabalipuram
6	Konark - Sun Temple
7	Churches and Convents of Goa
8	Fatehpur Sikri
9	Group of Monuments at Hampi
10	Khajuraho Group of Monuments
11	Elephanta Caves
12	Great Living Chola Temples
13	Group of Monuments at Pattadakal
14	Buddhist Monuments at Sanchi
15	Humayun's Tomb
16	Qutub Minar and its Monuments, Delhi
17	Mountain Railways of India
18	Champaner-Pavagadh Archaeological Park
19	Mahabodhi Temple Complex at Bodh Gaya
20	Rock Shelters of Bhimbetka
21	Chhatrapati Shivaji Terminus
22	Red Fort Complex, Delhi
23	The Jantar Mantar, Jaipur
24	Hill Forts of Rajasthan
25	Rani-ki-Vav (The Queen's Stepwell)

as geoheritage sites (Ladakh, Lonar Crater, Jog Falls, Varkala Beach, Mawsmai Cave, Borra Cave, Mt. Abu, Araku Valley, Nilgiri, Mahabaleshwar, etc.) is steadily increasing.

Places that provide best examples of the world's cultural and natural heritage are inscribed on the UNESCO's World Heritage List. As of November 2014, India has 32 World Heritage Properties (Table 1). Of these, seven are listed solely for their outstanding natural value and the remaining 25 are cultural properties (Fig. 2). In addition, a large number of cultural and natural properties from different parts of India have been submitted between 1998 and 2014 to the World Heritage Committee for recognition. These 46 properties on the tentative (or waiting) list include – the river island of Majuli in midstream of Brahmaputra River in Assam, the Chilka Lake in Odisha, Desert National Park in Rajasthan, Kangchendzonga National Park in Sikkim, and Narcondam Island in Andaman.

The Archaeological Survey of India (ASI) has listed 3,683 ancient monuments and archaeological sites and remains as sites of national importance. Three-fourth of the ASI's national heritage sites are located in eight states of India, namely, Uttar Pradesh (742), Karnataka (506), Tamil Nadu (413), Madhya Pradesh (292), Maharashtra (285), Gujarat (202), Delhi (174), and Rajasthan (163).

To provide a unique spectrum of the national geoheritage and geodiversity, the Geological Survey of India (GSI) has declared some of the most fascinating and scientifically significant geological features as National Geological Monuments (Table 2). These rock monuments, geological marvels and fossil parks (Fig. 2) provide an insight into the past environments and formations as well as the palaeo-flora and fauna of the subcontinent (Anantharamu *et al.* 2001), and are important from the standpoint of tourism/recreation, public education, and sustainable economic development. Of the 26 National Geological Monuments in India, seven fossil sites have been declared as Geological Parks (Fig. 2).

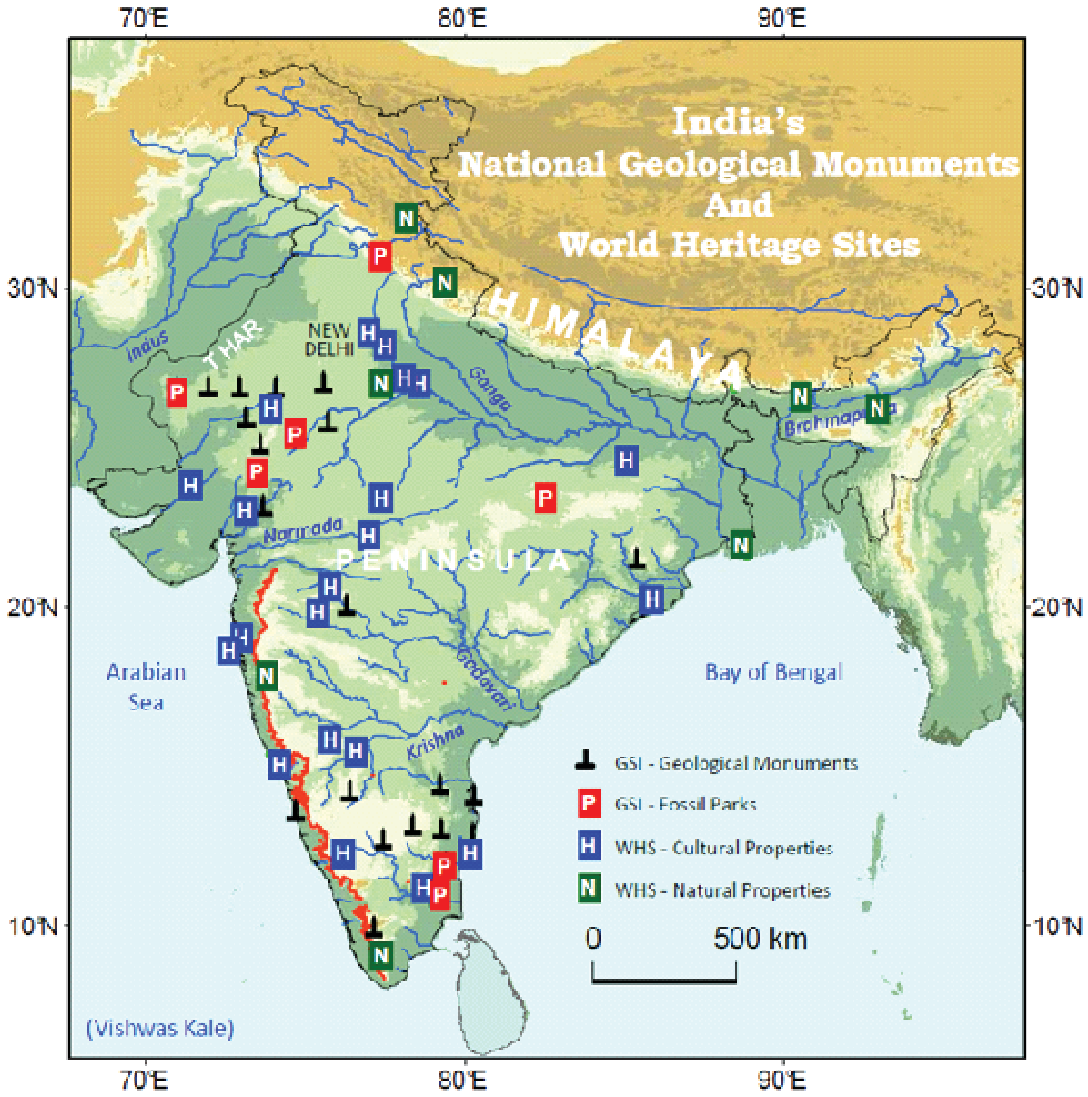

Figure 2. UNESCO's World Heritage Sites and GSI's National Geological Monuments in India

Majority of the GSI's monuments are concentrated in Rajasthan (10) and three southern states, viz. Karnataka (4), Andhra (3), and Tamil Nadu (3).

Geomorphological heritage sites in India

In addition to the geological monuments and fossil parks, general public is also attracted to natural or "geomorphological wonders". These geomorphological wonders are in fact distinctive or outstanding landforms, such as waterfalls, pothole-studded channels, gorges, canyons, beaches, natural arches, mesas, plateaux, escarpments, badlands, alluvial fans and cones, terraces, inselbergs/bornhardts, sand dunes, karst caves with stalactites and stalagmites, etc. Scientifically and educationally significant geomorphological heritage sites include those with text-book features and landscapes. A few

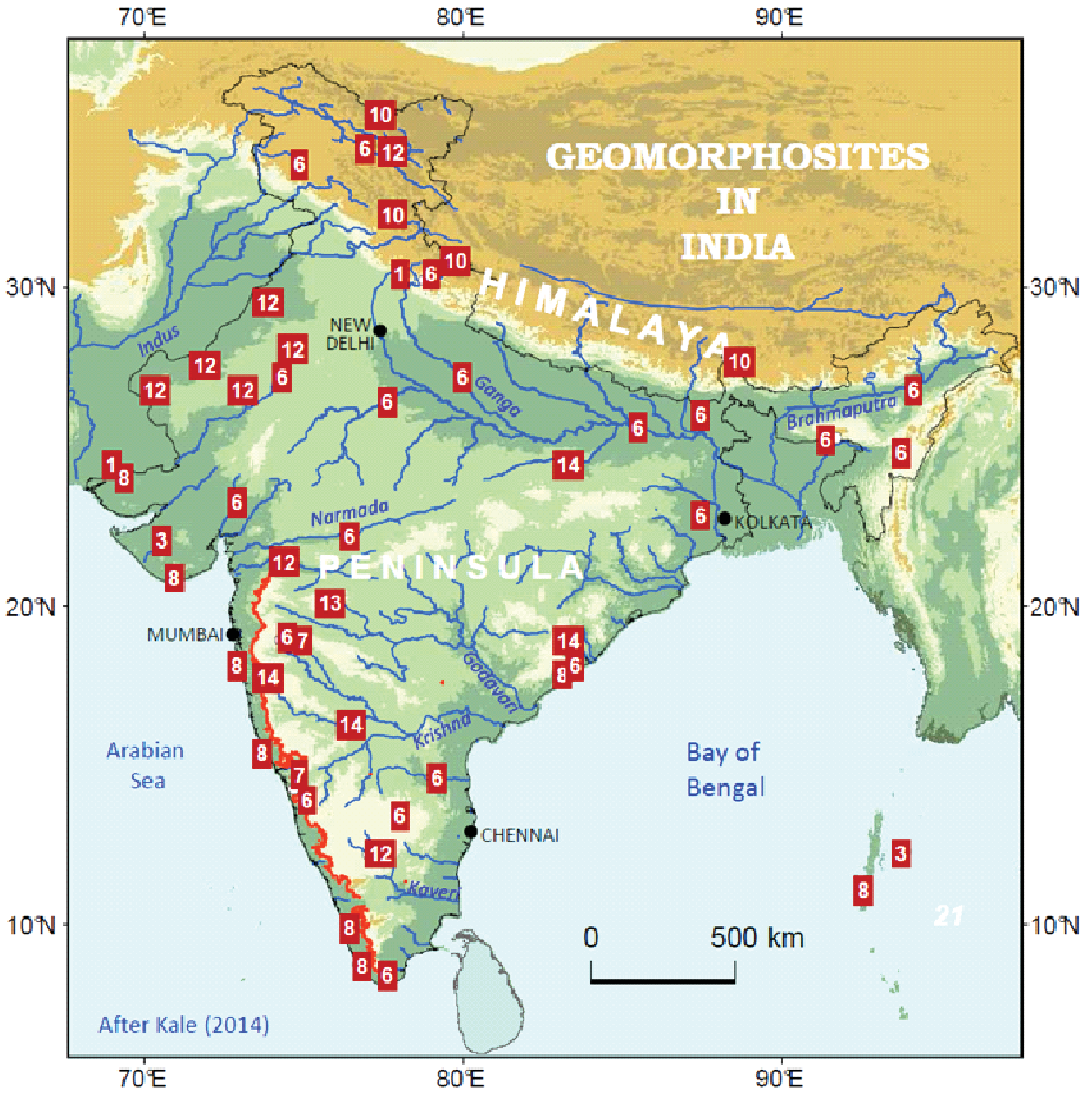

Figure 3. Geomorphosites in India (After Kale, 2014b). Numbers correspond with IUCN geo-theme numbers given in Table 4

attempts have already been made to identify and list some of the potential geomorphosites / geomorphoheritage sites in India (Ranganathan and Jayaram 2006; Raina and Srivastava 2008; Kale, 2009; Reddy 2013; Vaidyanadhan and Subbarao, 2014; Kale, 2014a). Potential geomorphosites listed by Kale (2014b) are shown in Fig. 3.

The three principal geomorphic provinces and several sub-provinces of India display a large variety and complexity of landforms and processes. The three main geomorphic provinces of India are (Kale, 2014c) – the Indian Peninsula (the Indian Shield), the Himalaya Mountains (the Orogenic Belt), and the Indus-Ganga-Brahmaputra Plains (the Foreland Basin). Each province consists of relief forms and associations of relief forms,

Table 2. GSI's National Geological Monuments

Sr. No.	Geosite	Location
1	Marine Gondwana Fossil Park	Manendragarh, Sarguja District, Chhattisgarh
2	Akal Fossil Wood Park,	Jaisalmer District, Rajasthan
3	National Fossil Wood Park	Tiruvakkarai, Villupuram District, Tamil Nadu
4	National Fossil Wood Park	Sattanur, Perambalur District, Tamil Nadu
5	Siwalik Fossil Park	Saketi, Sirmur District, Himachal Pradesh
6	Stromatolite Park	Bhojunda, Chittaurgarh District, Rajasthan
7	Stromatolite Park	Jhamarkotra, Udaipur District, Rajasthan
8	Peninsular Gneiss	Lalbagh, Bengaluru, Karnataka
9	Columnar Basaltic Lava	Coconut Island (St. Mary's Islands), Udupi District, Karnataka
10	Pillow Lava	Maradihalli, Chitradurga District, Karnataka
11	Pillow Lava, Iron ore belt	Nomira, Keonjhar District, Orissa
12	Pyroclastic Rocks	Peddapalli, Kolar district, Karnataka
13	Nepheline Syenite	Kishangarh, Ajmer District, Rajasthan
14	Mineralised zone	Gossan, Rajpura-Dariba, Rajsamand District, Rajasthan
15	Barr Conglomerate	Pali District, Rajasthan
16	Welded Tuff	Jodhpur District, Rajasthan
17	Charonockite	St. Thomas Mount, Chennai, Tamil Nadu
18	Bedded Barytes of Mangampeta	Cuddapah District, Andhra Pradesh
19	Eddy Current Markings	Panchmahal District, Gujarat
20	Eparchaean Unconformity	Tirumala hills, Andhra Pradesh
21	Jodhpur Group–Malani Igneous Suite Contact	Jodhpur District, Rajasthan
22	Great Boundary Fault at Satur	Bundi District, Rajasthan
23	Lonar Lake*	Buldhana District, Maharashtra
24	Laterite in Angadipuram*	Malappuram District, Kerala
25	Natural Arch in Tirumala hills*	Chittoor District, Andhra Pradesh
26	Forms in Sendra Granite*	Pali District, Rajasthan

* Geomorphosites; *Source:* Anantharamu *et al.* (2001)

which are scenic, spectacular as well as of special interest to geoscientists and the general public. It is, therefore, not surprising to note that earth scientists from all over the world are undertaking scientific studies in different parts of the country. Some of the noteworthy multi-national studies have dealt with the tectono-genic landforms, fluvio-glacial features, and lacustrine/speleothem records of the Himalaya and Ladakh, the

Table 3. Standard criteria used in geomorphosite assessment methods

Scientific value criteria	Additional value criteria	Management criteria
rarity	cultural	accessibility
representativeness	ecological	visibility
integrity	aesthetics	vulnerability
diversity		
scientific knowledge		

(after Bruschi and Cendrero, 2005; Pereira and Pereira, 2010)

lakes/playas and sand dunes of the Thar Desert, the Kosi megafan, the braided channel of the Brahmaputra River (India and Bangladesh), the granitic and the duricrusted landforms of the Peninsular India, the Western Ghat Escarpment, and the Ganga-Brahmaputra Delta.

(a) The Indian peninsula

The Indian Peninsula has high potential for geoscientific studies as well as geotourism. The triangular-shaped peninsula is the oldest and the largest geomorphic province of India, and is made up of Archaean rocks and Proterozoic fold belts. This fragment of the Gondwanaland largely displays an erosional landscape, which is not only visually appealing but also scientifically important. The Peninsular landscape displays many features inherited from the past (Cenozoic). By and large, bedrock landforms, rocky channels and partially to deeply weathered rocks dominate the scenery of this ancient landmass.

The Peninsula has both specific geomorphosites of local and regional significance and key geomorphosites or extensive areas with international recognition. Specific sites include waterfalls, gorges, inselbergs/bornhardts, laterite-capped mesas, cuestas, badlands, calc tufas, karst caves, etc. There are some landforms and landscapes that are very well recognised all over the world because of their special geomorphic significance, geologic history, or a combination of both, such as the Deccan Traps Region, the Western Ghat Escarpment, the Rann of Kachchh, the Lonar Crater, charnockitic/granitic landforms of the Indian cratons, etc. This ancient landscape provides good examples for understanding the mode of escarpment recession, deep weathering and denudation, laterite formation, river captures, badlands formation, inselberg and pediment formation, bedrock channel processes, etc.

Popular tourist destinations in the Peninsula, such as hill stations (hill resorts), hill forts, and ancient temples located in the Western Ghat zone (including Nilgiri Hills) or its offshoots, provide breathtaking views of the landscapes. Some of the top tourist destinations are Mount Abu, Mahabaleshwar-Panchgani, Coorg, Ooty, Kodaikanal, Munnar, Mainpat, Hazaribagh, Pachmarhi, Araku Valley, etc.

(b) The extra-peninsular region

The Himalaya Mountains have some incredible and extraordinary landforms and landform assemblages due to high elevation, steep and unstable slopes, steep rainfall gradient towards north and ongoing tectonic

movements. These tallest mountains in the world extend over a length of nearly 2500 km and consist of several parallel tectonic mountain chains, separated by thrust faults. The mountain building process, which started about 55 Myr as a result of the collision of the Indian and Eurasian Plates, has given rise to four, almost parallel, morpho-tectonic zones namely the Siwaliks, the Lesser Himalaya, the Greater Himalaya, and the Tethys Himalaya. Each belt displays a distinct set of landforms and scenery.

The spectacular rugged relief of the Himalayan landscape is the result of ongoing tectonic uplift, rapid valley incision, landslide erosion and glacial erosion (Kale, 2014c). Due to their location in the collisional setting and ongoing tectonic movements, these mountains are highly deformed and show multiple evidence of tectonic deformation. Distinctive tectono-genic, fluvial and glacial landforms include snow-covered jagged peaks, alpine mountains, long glaciers, cirques and glacial valleys, moraines, deep gorges across anticlines, intermountain basins (duns), strath and fill terraces, drainage network anomalies, knickpoints, palaeolakes, landslides, etc. All these forms and features are significant to geoscience education and research.

As a result of the enormous geomorphodiversity in this mountainous terrain, there are countless geomorphosites that are capable of providing opportunities for geotourism and, thus, sustaining local and state economies. Some of the most captivating landscapes in the Himalaya are observed in the Kashmir Valley, Ladakh, Lahul-Spiti Valley, Chamoli, Garhwal and Sikkim Himalaya. Some leading popular tourist destinations include Leh, Kullu-Manali, Shimla, Mussoorie, Nainital, Darjeeling, Gangtok, Kalimpong, Tawang, etc.

(c) The Indus-Ganga-Brahmaputra plains

This vast alluvial landscape created by the Indus, Ganga and the Brahmaputra (IGB) Rivers and their tributaries lies to the south of the Himalaya Mountains and provides classic examples of alluvial landforms on different scales. The IGB Plains are primarily composed of fan, floodplain, channel and deltaic deposits (Kale, 2014c).

Noteworthy landforms and features in this landscape include floodplains, alluvial fans (megafans), meandering and braided channels, river terraces, badlands, multiple palaeochannels, ox-bow lakes, etc. Even though some of these geomorphosites may not be very appealing to the general public and tourists, they undoubtedly have high potential for scientific studies as fascinating outdoor laboratories for fluvial geomorphologists interested in alluvial rivers. The mega-fans in particular have attracted greater attention from global geoscience community. Another noteworthy feature in this geomorphic province is the Chambal Badlands that inspires awe amongst visitors.

(d) The Indian coastline

India has a coastline of around 7500 km, with varying rock types, structure, tidal range and wave energy. Representative and eye-catching coastal landforms form a significant part of the Indian geomorphosites and geomorphoheritage sites. Rocky landforms (sea cliffs and wave-cut platforms), depositional features (beaches, sand dunes, bars, spits, mud flats, and mangrove swamps) and coral landforms (reefs and atolls) are both aesthetically significant and scientifically important. Famous beaches, such as Mandvi, Diu, Juhu, Diveagar, Ganpatipule, Calangute, Colva, Gokarna, Kollam, Varkala, Marina, Ennore, Rushikonda, Yarada, Konark, Puri, Digha, etc. attract thousands of tourists from

Table 4. Geo-coding of the parameters for classification of geomorphosites

Digit	Criteria	Geo-code	
First	Geomorphic Province - Principal (Area code)	1 = Himalaya Mountains (Orogenic Belt)	
		2 = Indus-Ganga-Brahmaputra Plains (Foreland Basin)	
		3 = Indian Peninsula (Indian Shield)	
Second	Rarity/Abundance (levels of significance)	1 = unique (having international appeal/significance)	
		2 = rare (having national appeal/significance)	
		3 = common (having regional or local appeal/significance)	
Third	Scientific or Intrinsic Value (Educational/pedagogical Value)	1 = High representativeness (textbook example); high pedagogical use	
		2 = Moderate representativeness and moderate pedagogical use	
		3 = Low representativeness and low pedagogical use	
Fourth	Additional Value (most dominant value)	1 = Touristic Value (Aesthetic/Scenic Value)	
		2 = Cultural Value (including Historical and Religious Value)	
		3 = Ecological Value	
		4 = Economic Value	
Fifth and Sixth	IUCN geothemes (International Union for Conservation of Nature)	01 = Tectonic and structural features	10 = Glaciers and ice caps
		02 = Volcanoes/volcanic system	11 = Ice Ages
		06 = Fluvial, lacustrine/deltaic systems	12 = Arid and semi-arid systems
		07 = Caves and karst system	13 = Meteorite impact
		08 = Coastal systems	14 = Other distinct landforms/features not included above*
		09 = Reefs, atolls and oceanic islands	15 = Weathering and mass movement features
Seventh	Accessibility	1 = Highly accessibility (approachable by mettle road)	
		2 = Moderate to low accessibility (< 10 km from nearest road)	
		3 = inaccessible (> 10 km from nearest road)	
Eighth	Integrity – State of Preservation	1 = In natural state	
		2 = Partially damaged due to natural or human factors	
		3 = Completely destroyed due to natural or human factors	
Ninth	Potential Threat and Management	1 = Legal protection, least threat and under a management agency (local to national)	
		2 = low to moderate risk/threat and informal management	
		3 = High threat. No legal protection and No management	
Tenth	Geomorphodiversity	1 = Geomorphospot (1 distinct landform/feature) – low diversity	
		2 = Geomorpholocality (up to 12 distinct landforms/features) – moderate diversity	
		3 = Geomorphopark (multiple and variety of landforms/features) – high diversity	

India and abroad every year.

Other outstanding landforms that are of interest to tourists and scientists alike include the large saline marshland of the Rann of Kachchh, cliffs and shore platforms in miliolite around Diu, chain of brackish lagoons and lakes (kayals) of the Malabar Coast, the coral islands of Lakshadweep, the Chilka Lake and the Pulicat Lagoon on the east coast, the Sundarbans tidal delta of West

Table 5. Some Indian examples of potential geomorphosites and their 10-digit geo-code and 2-digit postcode (Continued)

Sr. No.	Geomorphosites/ area	Special geomorphic features/characteristics	Geomorphic		Scientific Value	Additional Value	IUC geo-theme	Accessibility	Integrity	Threat and Management	Geomorpho-diversity	PIN code	Geo-code
			Province	Rarity/ Abundance									
1	Kashmir Valley, Jammu and Kashmir	Intermontane basin, flood plain, terraces, fluvial, glacial and karst features, Karewa lacustrine deposits	1	2	2	1	1	1	2	2	3	**19**	**1221 01 1223**
2*	Allah-Bund fault scarp, Kachchh, Gujarat	1.6-m fault scarp developed in Rann of Kachchh sediments following 1819 Earthquake	3	1	1	1	1	3	1	1	1	**37**	**3111 01 3111**
3+	Chhatarpur Cuestas, Madhya Pradesh	Cuestas dipping southeast	3	3	1	3	1	3	1	2	1	**47**	**3313 01 3121**
4	Ramgarh ring structure, Rajasthan	A crater-like feature, 110 km ENE of Kota	3	2	1	1	1	1	1	2	1	**32**	**3211 01 1121**
5*	Duricrusted landforms of Panchpatmali, Odisha	Laterite-capped mesas and plateaux	3	3	2	4	1	1	3	3	1	**76**	**3324 01 1331**
6	Duricrusted landforms of Mainpat, Chhattisgarh	Laterite-capped mesas and plateaux	3	3	2	4	1	1	1	2	1	**49**	**3324 01 1121**
7	Duricrusted landforms of *Netarhat*-Lupungpat, Jharkhand	Laterite-capped mesas and plateaux	3	3	2	4	1	2	1	2	1	**83**	**3324 01 2121**
8+	Kurnool Mesas, Andhra Pradesh	Mesas and escarpment in Erramala Range	3	3	1	1	1	1	2	2	1	**51**	**3311 01 1221**
9*	Girnar Complex, Gujarat	A volcanic plug	3	2	1	3	2	1	1	2	1	**36**	**3213 02 1121**
10*	Barren Island, Andaman and Nicobar Islands	Only active volcano in India	3	2	1	3	2	3	1	1	1	**744**	**3213 02 3111**
11*	Alaknanda River Terraces, Uttarakhand	Six river terraces along Alaknanda River, Srinagar	1	2	1	4	6	2	2	2	1	**24**	**1214 06 2221**
12*	Majuli River Island, Assam	Largest river island in the world in Brahmaputra River	2	2	2	3	6	2	3	2	1	**78**	**2223 06 2321**
13*	Kosi Megafan, Bihar	Most cited megafan in the world developed by Kosi River, multiple palaeochannels	2	2	1	3	6	1	2	2	2	**84**	**2213 06 1222**
14*	Badvel Alluvial Fan, Andhra Pradesh	Only large, symmetric alluvial fan in cratonic terrain. On a right-bank tributary of Sagileru River	3	2	2	3	6	2	2	2	1	**52**	**3223 06 2221**
15*	Bithur Meander, Uttar Pradesh	Large abandoned meander of Ganga River near Kanpur	2	2	1	3	6	1	2	3	1	**20**	**2213 06 1231**
16	Dhawan's Bedrock Meanders, Surgana, Maharashtra	Entrenched meanders of Dhawan River and many adjoining rivers	3	2	1	1	6	2	1	2	1	**42**	**3211 06 2121**
17*	Nighoj Knickpoint, Maharashtra	Spectacular isolated and coalesced potholes, inner channel, grooves, polished rocks, etc. on Kukdi River	3	1	1	1	6	1	1	2	1	**41**	**3111 06 1121**

Table 5. Some Indian examples of potential geomorphosites and their 10-digit geo-code and 2-digit postcode (Continued)

Sr. No.	Geomorphosites/ area	Special geomorphic features/characteristics	Geomorphic Province	Rarity/ Abundance	Scientific Value	Additional Value	IUCN geo-theme	Accessibility	Integrity	Threat and Management	Geomorpho-diversity	PIN code	Geo-code
18*	Gersoppa or Jog Falls, Karnataka	Highest waterfall (253 m) in India. On Sharavathi River. River capture and gorge	3	2	1	1	6	1	1	2	2	**58**	**3211 06 1122**
19*	Nohkalikai Falls, Meghalaya	198 m waterfall on the edge of Meghalaya Plateau	3	3	2	1	6	1	1	2	1	**79**	**3321 06 1122**
20*	Dhuandhar Falls, Jabalpur, Madhya Pradesh	Waterfall, canyon, abandoned channel of Narmada	3	2	2	1	6	1	1	1	2	**48**	**3221 06 1112**
21	Chain of waterfalls in Panna Hills area, Rewa Plateau Edge, Madhya Pradesh	Over 20 waterfalls (10-100 m), on Ken-Tons-Odda Rivers and their tributaries. Over the escarpment (except Raneh falls), with gorges and receding knickpoints,	3	2	1	3	6	2	1	1	2	**48**	**3213 06 2112**
22	Chambal Badlands, Madhya Pradesh	Largest badlands in India along Chambal River	2	2	2	3	6	2	2	3	1	**47**	**2223 06 2231**
23*	Erra Matti, Dibbalu Badlands Visakhapatnam, Andhra Pradesh	Badland topography, gullies within red coastal sand dunes	3	3	2	1	6	1	2	3	1	**53**	**3321 06 1231**
24*	Garhbeta, West Medinipur District, West Bengal	Bank gullies in red mudstones and sandstones along the right bank of Silai River	3	3	2	1	6	1	2	3	1	**72**	**3321 06 1231**
25!	Karai Badlands, Perambalur, Tamil Nadu	Badlands in early Cretaceous to Palaeogene age marine sediments consisting of gypseous clays and sandstones. Rich in fossils	3	3	2	1	6	1	2	1	1	**62**	**3321 06 1211**
26*	Loktak Lake, Imphal, Manipur	Lake in an intermontane valley	1	2	1	2	6	1	3	3	1	**79**	**1212 06 1331**
27	Mawsmai Cave, Meghalaya	Karst cave with stalactites and stalagmites	3	2	1	1	7	1	2	1	1	**79**	**3211 07 1211**
28	Bora Cave, Andhra Pradesh	Karst cave with stalactites and stalagmites	3	2	1	1	7	1	2	1	1	**53**	**3211 07 1211**
29	Sundarban Delta, West Bengal	Tidal mangrove system, delta, distributaries, islands, beaches, dunes	2	2	1	3	8	2	2	1	3	**74**	**2213 08 2213**
30+	Kakinada Spit, Andhra Pradesh	About 21 km long spit at the Godavari delta	3	2	1	4	8	2	2	2	1	**53**	**3214 08 2221**
31*	Rann of Kachchh, Gujarat	Huge saline marshland bordered by Allah Bandh scarp in the north	3	1	1	3	8	3	1	1	2	**37**	**3113 08 3112**
32	Karwar Tombolo, Karnataka	Tombolo connecting Baitkol Island to Karwar mainland	3	3	1	3	8	1	1	2	1	**58**	**3313 08 1121**
33!	Varkala Beach, Kerala	Cliff and beach at Varkala	3	2	2	1	8	1	2	1	2	**69**	**3221 08 1212**
34*	Diu rocky coast, Gujarat	Cliffs, shore platforms (modern and raised), notches, etc. in miliolite limestone	3	3	2	1	8	1	1	2	2	**36**	**3321 08 1122**

Table 5. Some Indian examples of potential geomorphosites and their 10-digit geo-code and 2-digit postcode (Continued)

Sr. No.	Geomorphosites/ area	Special geomorphic features/characteristics	Geomorphic Province	Rarity/ Abundance	Scientific Value	Additional Value	IUCN geo-theme	Accessibility	Integrity	Threat and Management	Geomorpho-diversity	**PIN code**	**Geo-code**
35*	Harihareshwar wave-cut platform Maharashtra	Shore platform, cliffs and honeycomb weathering in basalt	3	3	2	1	8	1	1	2	1	**41**	**3321 08 1121**
36*	Vembanad Backwaters, Kerala	Estuarine-lagoon (backwater) system, barrier islands/spits/ridges	3	3	1	3	8	1	2	2	2	**68**	**3313 08 1222**
37	Lakshadweep Archipelago	A group of atolls, reefs, submerged banks and islands	3	2	1	1	9	3	2	2	3	**682**	**3211 09 3223**
38	Siachen Glacier and Nubra Valley, Jammu and Kashmir	2nd Longest glacier outside polar regions in Nubra valley. U-shaped valleys, arête, hanging valleys, moraines, etc.	1	2	1	3	10	3	1	3	3	**19**	**1213 10 3133**
39+	Chamoli Glacial Landscape, Uttarakhand	U-shaped valleys, arête, hanging valleys, moraines, talus cone , Bhagirath and Satopanth Glaciers	1	3	2	3	10	2	2	2	3	**24**	**1323 10 2223**
40	Lahul-Spiti Landscape, Himachal Pradesh	Gorges, terraces, triangular facets, entrenched meander, glacial landforms	1	3	2	3	10	2	2	2	3	**17**	**1323 10 2223**
41	Ladakh Landscape, Jammu and Kashmir	Alluvial fans, bajada, moraines, alluvial and strath terraces, dunes	1	2	1	1	12	2	2	2	3	**19**	**1211 12 2223**
42*	Dechu Parabolic dunes, Rajasthan	Multiple compound Parabolic dunes, Jodhpur District	2	3	1	1	12	1	2	1	1	**34**	**2311 12 1211**
43*	Talakad Sand dunes, Karnataka	Aeolian sand dunes on the bank of Kaveri River	3	2	1	1	12	1	2	1	1	**57**	**3211 12 1211**
44*	Prakasha Sand dunes, Gujarat	Aeolian sand dunes on the bank of Tapi River	3	2	1	1	12	1	1	3	1	**42**	**3211 12 1131**
45*	Lonar Crater, Maharashtra	Impact crater in basaltic terrain	3	1	1	1	13	1	1	1	1	**44**	**3111 13 1111**
46!	Silathoranam Natural Arch, Andhra Pradesh	Natural rocky arch in Tirumala Hills	3	2	1	1	14	1	1	1	1	**51**	**3211 14 1111**
47#	Shivagange Inselberg, Karnataka	Bowler hat-shaped granite inselbergs seen from Bengaluru-Tumkur Road	3	2	1	1	14	2	1	2	1	**57**	**3211 14 2121**
48	Mahabaleshwar-Panchgani landscape, Maharashtra	Western Ghat Scarp, laterite-capped mesas, beheaded valley, box-shaped valley, waterfalls	3	2	1	1	14	1	2	2	3	**41**	**3211 14 1223**

Note: See Table 4 for explanation of geo-codes. * = after Kale (2014b); + = after Vaidyanadhan and Subbarao (2014); # = after Anantharamu *et al.* (2001); ! = after GSI (2012)

Bengal, and the Andaman-Nicobar Archipelago.

Scientifically and educationally significant geomorphosites include modern features, such as estuaries, deltas, mud flats, sand dunes, spits, bars, cliffs, shore platforms, stacks, beaches, beach cusps, etc. and relict features such as beach rocks, aeolianite and dead cliffs as well as raised beaches, wave-cut platforms, oyster beds, coral reefs and tidal deposits. All these features are significant from the point of view of absolute and relative changes in sea level.

(e) The Thar desert and Ladakh

The barren and desolate landscape of the arid regions generally inspires awe amongst tourists. India has a hot desert (the Thar Desert) as well as a cold desert (Ladakh). These two different types of dryland regions have outstanding geomorphoheritage value because of their aesthetically appealing as well as scientifically significant characteristics. In recent years some places, such as Jaisalmer and Leh, are becoming very popular tourist destinations.

The Thar Desert displays a landscape dominated by sand dunes of different types and sizes, as well as erosional features created by the fluvial and aeolian processes. Parabolic dunes, playas and ephemeral streams are the key features of the Indian desert.

The cold-desert landscape of Ladakh displays features created by cryogenic weathering, rivers, glaciers, and aeolian and mass movement processes. The area also provides number of opportunities to study tectono-genic and structural landforms. Other distinctive features include number of fans (alluvial and debris-flow dominated), talus cones, fan belts (bajada), strath and alluvial terraces, moraines, sand dunes and remnants of palaeolakes.

Gaps in geomorphodiversity information

The terms "geosite" and "geodiversity" are being used by geologists and geomorphologists since 1990s (Sharples, 2002; Gray 2004). Inventory covering key geological and geomorphological sites and landscapes has been prepared by many countries (European countries, USA and Australia, in particular). Although considerable work has been completed in understanding India's geodiversity in terms of rocks, minerals and fossils by the Geological Survey of India (GSI) since its inception in 1851, there is considerable gap in the knowledge of India's geomorphodiversity. In spite of the fact that a few attempts have been made to identify key geomorphosites/ geomorphoheritage sites in India (Kale, 2014a), there are strategic gaps in the information on India's landforms, landscapes, rivers and soils. Till date there is no official national inventory of geomorphosites in India. Further, no attempt has been made to evaluate the quality of geomorphological heritage from the point of view of geotourism, geoconservation and management.

Geomorphosite assessment and classification

The value of geomorphosites can be scientific/educational, intrinsic, cultural, aesthetic, economic and functional (Gray 2004) as well as ecological (Reynard, 2005). Several classification and assessment methods have been suggested and used since the term geomorphosites was introduced by Panizza (2001). The assessment methods are based on multiple criteria – three of which are common, namely, scientific value, additional value, and management criteria (Kubalíková, 2013) (Table 3).

Panizza (2001) suggested assessment of the geomorphosites on the basis of scientific

criterion (as a model of geomorphological process or as an ecological support), pertinence (world-wide to local), the degree of preservation (well-preserved to poorly-preserved), and the degree of damage (nil to destroyed). Coratza and Giusti (2005) proposed a methodology to assess the scientific quality of a geomorphosite in terms of weighted mean, on the basis of seven characteristics – value for the scientific research, educational value, areal extent, rareness, integrity, exposure and added value. Reynard *et al.* (2007) based their assessment on five criteria – scientific value (integrity, representativeness, paleogeographical value, and rareness), ecological value (ecological impact and protected species), aesthetic value (number of viewpoints, contrasts, vertical development), cultural value (religious, historical and artistic importance), and economic value (economic products).

Pereira and Pereira (2010) suggested an assessment methodology for potential geomorphosites based on three principal criteria – geomorphological intrinsic value (scientific and other geomorphological values), potential use (accessibility, visibility and use of other natural or cultural values), and need for protection (deterioration and vulnerability). Bruschi *et al.* (2011) proposed a parametric method based on three sets of criteria: intrinsic quality, potential for use and protection needs. Hassan *et al.* (2012) used the Analytic Hierarchy Process (AHP) to assess geosites using multiple attributes (climate, topography, geomorphic forms, infrastructure, safety, distance, etc.).

All the above methods, involving multiple criteria assessment and classification, are based on ranks, scores or weights assigned by the researcher or experts. Values (between 0 and 1, or from 1 to 5, etc.) are assigned to each of the criterion and attribute to reflect their relative importance or status. Finally, the sum of ranks/scores or weights or their mean value is taken into consideration to determine the overall importance, potential or value of the site (or sites) under review.

Ranking and scoring is a simple way to manage multivariate datasets, especially when requisite data are lacking or difficult to generate. However, the classification and assessment, based on scoring/ranking, involve varying degree of subjectivity (Bruschi *et al.* 2011). More often than not the results cannot be replicated. Further, the sum or mean value of the scores, ranks or weights of multiple sets of criteria for a geomorphosite do not provide any idea about the type of landform/ landscape, the associated geomorphic process (or processes), tentative location, scientific importance, additional value, integrity, accessibility, etc. This is the severe limitation of all the methods of geomorphosite assessment and classification proposed so far.

Therefore, a simple, 10-digit geo-coding system for the geomorphosites of India is proposed here (Table 4). This coding is used to establish a classification and priority of geomorphosites, both in terms of geotourism promotion and management. The first digit (1 to 3) represents the major geomorphic province of India. The second digit (1 to 3) stands for the rarity/abundance of the site. The third digit (1 to 3) represents the scientific or intrinsic value of the geomorphosite. The additional value (touristic, cultural, ecological or economic) is denoted by the fourth digit (1 to 4). The fifth and sixth digits (01 to 15) denote the geotheme number adopted by the International Union for Conservation of Nature (IUCN). The seventh digit (1 to 3) indicates the accessibility. The integrity or the state of preservation of the geomorphosite is represented by the eighth digit (1 to 3), and the potential threat and management is

denoted by the ninth digit (1 to 3). The tenth digit (1 to 3) represents the degree of geomorphodiversity (geomorphospot, geomorpholocality, and geomorphopark, respectively). Following the definition of 'geoparks' by Global Network of National Geoparks (GGN) (UNESCO, 2006), a geomorphopark has been defined here as "a sufficiently large area comprising of a number of geomorphological features of special scientific importance, rarity or beauty". Table 5 gives examples of four dozen potential geomorphosites in India and their 10-digit geo-codes. Their approximate location of the site/area is indicated by the 2-digit postcode.

Geo tourism promotion

In geotourism, geomorphological wonders (geomorphosites) are considered equivalent to famous historical monuments (Taj Mahal, Konark Sun Temple, Khajuraho Temples, Mahabalipuram Monuments, Hampi Monuments, etc.) and archaeological sites (Kalibangan, Lothal and Dholavira Harappan sites; Bhimbetka rock shelters; Ajanta, Ellora and Elephanta caves, etc.). Therefore, geotourism also places considerable emphasis on providing comprehensive information to the visitors, sightseers and local communities about the scientific aspects of a specific landform (its special characteristics, significance, age and genesis). Several approaches have been adopted to promote geotourism (Dowling, 2011). Scientific information about the landform/feature is shared with the tourists through colourful pamphlets, infographic brochures/posters and educational handbooks, or by erecting informative panels at the geomorphosites/ geomorphoheritage sites or through museums and thematic guided tours. The promotional material includes simple maps, colour photographs, sketches and diagrams, and explanation that are understood by the general public. These traditional methods, however, have certain limitations. The information regarding geomorphosites cannot be accessed in real time. Therefore, geotourism will be best promoted by using web-based Google Maps. Comprehensive information about the geomorphological wonders should be made available to the tourists by way of websites before their visit. Now-a-days tourism infographics are being used to promote tourism.

However, to promote geotourism in our country first a national inventory of geomorphosites / geomorphoheritage sites is required. It is obvious that in the development of a peer-reviewed national inventory, different academic and professional organizations, research institutions and university departments should be involved. There is also a need for a body to setup, maintain and regularly update the database. There is also a need to have simple and informative geomorphodiversity maps for different regions (national, state, site-specific). Systematic mapping of landforms is required to achieve a national assessment of India's landforms. Such maps will facilitate in determining the outstanding geoheritage sites/areas in India.

Concluding remarks

The Indian region is endowed with extraordinary and rich geo-wealth. There are countless fascinating and exquisite features, landforms and landscapes in the sub-continent that have immense scientific, cultural, and socio-economic value. However, geological and geomorphological heritage is not sufficiently recognised in India. This is evident from the fact that the GSI declared the list of National Geological Monuments only in 2001 (that is, 150 years after its inception)

and only seven natural properties from India are included in the list of World Heritage Sites in the last three decades (since 1983). Further, not a single geopark from India appears in the list of Global Geoparks Network (GGN), supported by UNESCO. Furthermore, till date there is no official national inventory of geomorphosites. It is obvious that not only geotourism has to be promoted in India but also that the geo-wealth and geodiversity of our country has to be conserved and preserved for posterity. Several institutions /organisations such as the Geological Survey of India (GSI), the Geological Society of India, the Indian Institute of Geomorphologists (IGI), etc. and the Ministry of Earth Sciences (MoES) as well as the university earth science departments have a key role to play in this overdue activity. A national geomorphosites inventory and a full understanding of the scientific, cultural, aesthetic, economic, and ecological value of the geomorphological wonders are vital from the standpoint of geotourism promotion and conservation of India's rich geoheritage.

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