

# Exploring landslide susceptible zones by analytic hierarchy process (AHP) for the Gish River Basin, West Bengal, India

Tirthankar Basu<sup>1</sup> · Swades Pal<sup>1</sup>

Received: 5 May 2017/Revised: 21 August 2017/Accepted: 24 August 2017/Published online: 30 August 2017  
© Korean Spatial Information Society 2017

**Abstract** Landslide is a major threat in the Darjeeling Himalaya within sub-humid climate. Hence proper identification of landslide susceptible zone (LSZ) is very much essential. In this case a multi criterion evaluation approach is applied using thirteen selected indicators. The parameters are categorized into five categories viz. anthropogenic factor, surface causal factor, lithological causal factor, triggering factor and protective factor. Weighted composite model is prepared adopting weighting base as Analytic Hierarchy Process. The obtained result shows that near about 19.92 sq. km (approximately 7.52%) area within the basin is highly susceptible for landslides. High drainage density (avg. 4.31 km/sq. km), relatively steeper slope ( $>10^\circ$ ) accelerate this process. Beside the main landslide susceptibility layers five separate models of five causal factor groups are prepared and correlated with final LSZ for understanding the priority cluster. Lithological factors cluster appears as a dominant factor group (correlation value 0.95). This LSZ model is also validated by frequency as well as areal density of historical landslides. Beside this, the validation by ROC curve shows 84.00% area under the curve. So, the model can be treated as relevant.

**Keywords** Landslide susceptibility · Gish River Basin · Analytic hierarchy process · Responsible factors cluster · Landslide inventory · Model validation

## 1 Introduction

Landslide susceptibility map depicts the areas which are potentially prone to landslides by analyzing some principle factors that contribute to landslides. But proper identification of landslide susceptibility zones depends on the knowledge of slope movement and their controlling factors. For example, lithological and structural variations such as difference in strength and permeability of rocks and soil, presence and pattern of fractures and joints, slope modification through roads, terrace for tea etc. Considering these factors a proper landslide susceptibility map is very much essential to reduce the risk of such geomorphic hazard. The methodologies for the assessment of landslide susceptibility broadly fall under three categories i.e. qualitative, semi quantitative and quantitative. Estimation of weightage value through quantitative way involves several sophisticated methods like Analytic hierarchy process [1], bivariate [2], multivariate [3], logistic regression [4], fuzzy logic [5], artificial neural network [6] etc. Analytic Hierarchy Process (AHP) by Saaty [7] allows direct participation of decision makers in finding out the final outcome. Decomposition, comparative judgment and synthesis of priorities are the three principles on which AHP is based on. It involves building a hierarchy of decision elements then comparison between possible pairs to give a weight in case of each parameter. It also provides a consistency ratio to check the consistency level. This procedure has gained wide application in different fields such as in site selection, suitability analysis and landslide susceptibility [8]. Hence

---

**Electronic supplementary material** The online version of this article (doi:10.1007/s41324-017-0134-2) contains supplementary material, which is available to authorized users.

---

✉ Tirthankar Basu  
basu.tirthankar89@gmail.com  
  
Swades Pal  
swadeshpal82@gmail.com

<sup>1</sup> Department of Geography, University of Gour Banga, Malda, West Bengal 732103, India

now importance is given to estimate the proper weightage value of different landslide causing factors using Analytical hierarchy process (AHP).

Darjeeling Himalaya is highly susceptible for landslide. Every year a variety of reasons such as heavy rainfall, reduction in natural vegetation cover, urban development, soil saturation have caused landslides of varied magnitudes on the steep slopes [9]. For this reason accurate landslide susceptibility map is essential to identify such hazard prone areas.

The aim of this paper is the identification and delineation of proper landslide susceptible zones for the Gish River basin by taking into consideration of 13 parameters. The AHP method is taken into consideration to find out the weightage value of different parameters. To prepare the final output map integration process has been applied on the basis of the weightage value of each indicator. An attempt is also taken to validate the final output in reference to landslide inventory map.

## 2 Study area

Gish River Basin of Darjeeling Himalaya (264.94 km<sup>2</sup>), a tributary of Tista River, possesses high range of height (2355 m at source and 115 m at confluence (Fig. 1). Ramthi Khola, Lethi Nadi, Nimbong Khola, Pokhribong Khola, Reyon Khola, etc. are its important tributaries. The average annual rainfall in the study area is 3094.4 mm and 80% rainfall happens during monsoon season (July to October). Maximum landslides take place in this season. Darjeeling Himalaya is one of the most vulnerable belts of Himalayan range and it recorded more than 20,000 landslides in 1 day [10]. The upper part of the basin is composed with darjeeling gneiss (Fig. 2a). Mainly loamy type of soil dominates here (Fig. 2b). The middle part is mainly dominated by daling phylite and schist, lower gondwana, biotite daling phylite and Older Alluvium.

## 3 Materials and methodology

### 3.1 Parameter selection, scaling and weighting of the indicators

In this case 13 parameters are taken into consideration and these parameters are further classified into five categories e.g. triggering factor (rainfall and seismicity); lithological causal factors (geology, soil, lineament and Gravity anomaly); surface causal factor (slope, drainage density and relative relief); anthropogenic causal factor (road,

agriculture and settlement); protective factor (natural vegetation). Methods for preparing the data layers are shown briefly in Table 1.

For making all the data layers unidirectional 10-point scale, a semi-quantitative method is selected [11]. For this the spatial data layers are classified into 10 equal classes in ArcGIS (9.3). It is supposed that greater rating will have maximum potentiality to influence landslide susceptibility. One can also consider it in reverse order. The scaling process and the logic behind scaling are shown in Table 2.

Analytic Hierarchy Approach [1] is used for weighting the parameters. Ranking of the selected parameters for making comparison matrix is done based on the previous literatures [12] and field experience. Consistency check in this case is 0.02. For example, slope is given maximum priority because most of the existing landslide sites are located within the steeper slope. In case of some qualitative data layers e.g. geology and soil, before assigning 10-point rating to the individual class frequency ratio (number of existing landslide to the concerned zone) is calculated.

After deriving the weightage of different layers, integration of different layers using weighted linear combination (WLC) Eq. (1) of Eastman [13] is performed. This methodology is implied in the ArcGIS(9.3).

Simple equation of WLC is as follows:

$$WLC = \sum_{j=1}^n a_{ij} w_j \quad (1)$$

where,  $a_{ij}$  =  $i$ th rank of  $j$ th attribute;  $w_j$  = weightage of  $j$ th attribute.

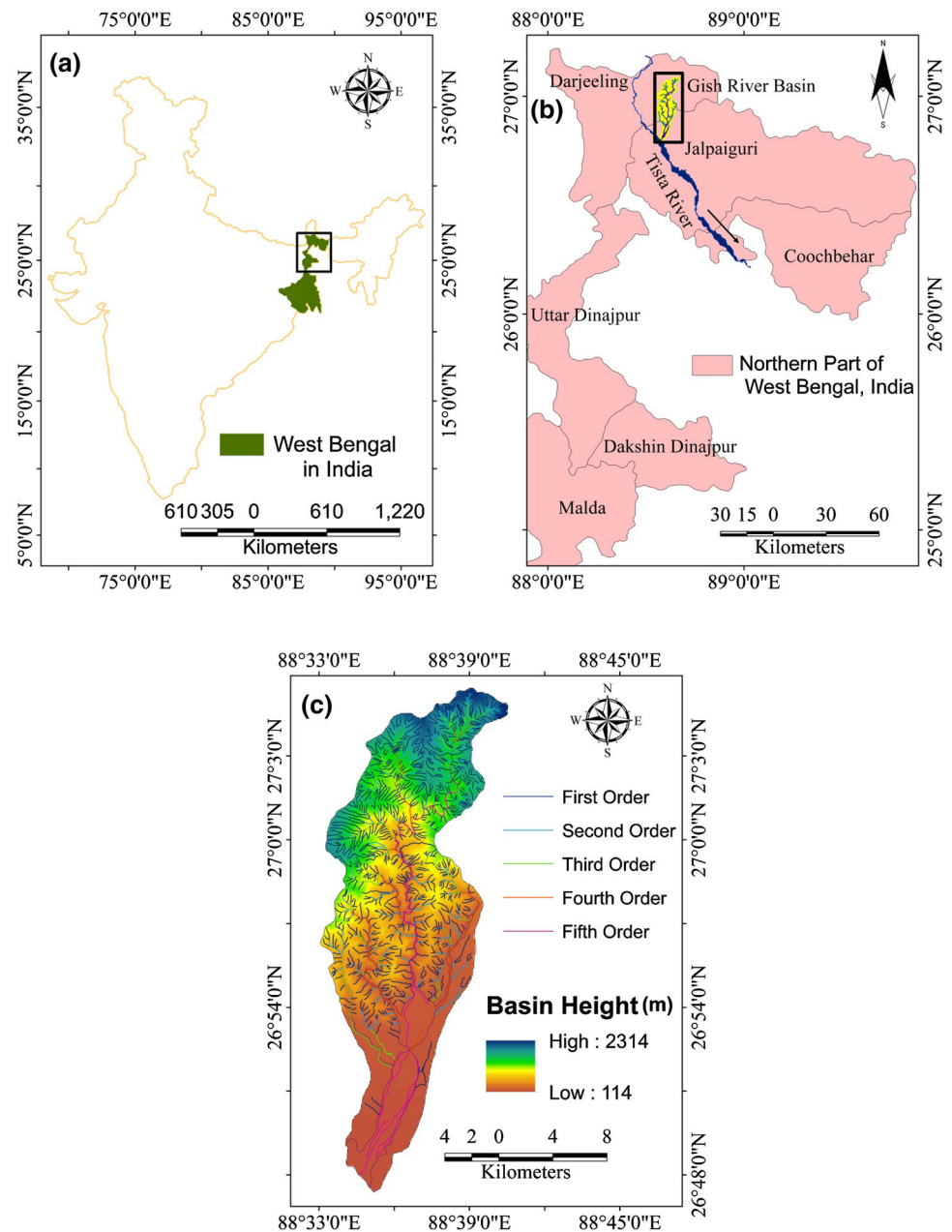
### 3.2 Preparation of different factors cluster

Beside the main landslide susceptible model, five separate WLC models of landslide affecting homogenous factor cluster [triggering factor model (TFM), anthropogenic factor model (AFM), lithological factor model (LFM), surface causal factor model (SCFM) and protective factor model (PFM)] are prepared to find out the role of individual factors cluster to landslide susceptibility. Correlation matrix based weighting of the parameters has been done following Pal [13]. To get the standardized weighted value of different parameters the Eq. 2 is used.

$$W_{ij} = \frac{W_i}{W_{i\_total}} \times 1 \quad (2)$$

where,  $W_{ij}$  = Weighted value,  $W_i$  = Summation of standardized correlation value  $W_{i\_total}$  = Sum of all  $W_i$  Again,  $W_i = W_{11} + W_{12} + \dots + W_{1n}$   $W_{11}$ ,  $W_{12}$ ,  $W_{1n}$  = Standardized correlation value of 1st, 2nd and last indicators of 1st row.

**Fig. 1** Location of the study area **a** Location of West Bengal in India, **b** Location of Gish River Basin in northern part of West Bengal, **c** Gish River Basin

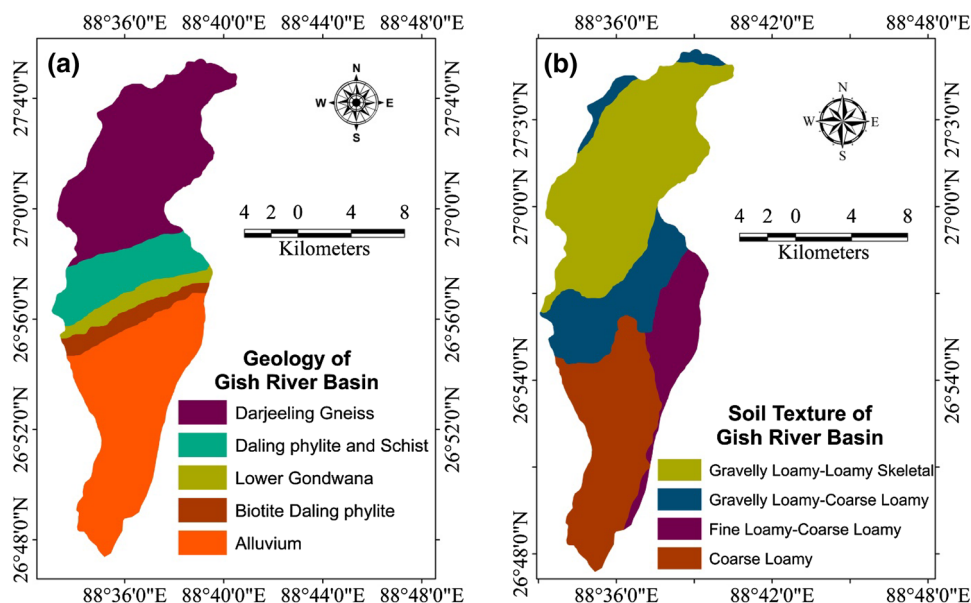


### 3.3 Validation of the landslide susceptible model

For determining the level of accuracy of the final output, validation process is followed with the help of landslide inventory. Elmahdy et al. [14] rightly documented that this approach of validation is directly linked with direct incidences. The imprints of the past landslides are obtained from secondary sources like previous literatures [15], toposheets (78 B/9 & 78 A/12) of Survey of India, Google earth and from on field observations. Total 45 locations are

identified and after assigning the latitude and longitude these are updated on the landslide susceptible map (Fig. 3b). The validation process is performed through three steps. The first step aims to establish the relationship between different LSZ and occurrence of landslide frequency density. Areal density (areal extent of landslide/area of the concerned zone) under different LSZ is shown in case of second step. In the last step Receiver Operating Characteristic (ROC) curve is prepared to find out the

**Fig. 2** Geology and soil map  
**a** Geology, **b** Soil



predicted rate of the model, prepared using Analytic Hierarchy Approach (AHP) (Fig. 5b).

## 4 Results and analysis

### 4.1 Landslide susceptibility mapping

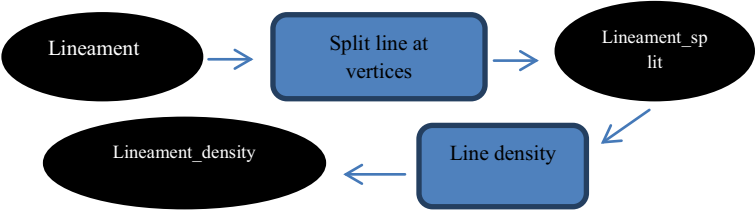
From integration of parameters, landslide susceptibility model is prepared. Equation 3 represents the expression of statistical model of landslide susceptibility model and Fig. 3a, b show the spatial model for the same in continuous and classified modes.

$$\begin{aligned}
 \text{Landslide Susceptibility Model} &= \text{slope} \times 0.195 \\
 &+ \text{geology} \times 0.188 + \text{drainage density} \times 0.165 \\
 &+ \text{lineament} \times 0.126 + \text{relative relief} \times 0.085 \\
 &+ \text{soil} \times 0.054 + \text{rain fall} \times 0.039 + \text{road} \times 0.028 \\
 &+ \text{agricultural land} \times 0.024 + \text{settlement} \times 0.021 \\
 &+ \text{vegetation} \times 0.019 + \text{seismic frequency} \times 0.031 \\
 &+ \text{gravity anomaly} \times 0.024
 \end{aligned}
 \tag{3}$$

In order to find out the landslide susceptibility zones (LSZ) with greater precision the composite raster layer of landslide susceptibility (Fig. 3a) is further subdivided into five equal interval zones (Fig. 3b) viz. very high (WLC = 6.18–7.22), high (5.14–6.18), moderate (4.10–5.14), low (3.06–4.10), very low (3.04–3.08). Very high landslide susceptible zone is located in a scattered manner at the

upper part of the basin. Nearly 19.92 km<sup>2</sup> (7.52%) of the total basin area falls under the very high LSZ zone. In this zone, degree of slope ranges from 42.13° to 10.44° (average 26.285°) and steeper slope triggers this incidents [16]. By eroding the slopes or by saturating the regolith streams may adversely affect stability of the slope [17]. Drainage density ranges from 5.48 to 3.14 km/km<sup>2</sup> (average 4.285 km/km<sup>2</sup>), it also helps for soil saturation in the contiguous area and helps to trigger landslide. Higher relative relief indicates greater intensity of erosion hence greater chance for landslide susceptibility [10]. In this zone, relative relief is higher and it ranges from 873 to 301 m (average 587 m). High landslide susceptible zone covers nearly 90 km<sup>2</sup> (33.97%) area of the basin (Table 4). This zone is also located in the upper part of the basin and some patches in the middle part of the basin. In this zone also drainage density (average 3.9 km/km<sup>2</sup>), slope (average 27.075°) and relative relief (average 422 m) are high. 52.25 km<sup>2</sup> (19.72%) area lies under the moderate landslide susceptible zone. In this zone range of the degree of slope is higher (from 50.13° to 4.28°), drainage density (average 1.965 km/km<sup>2</sup>) and relative relief (average 279.5 m) are also quite less than high and very high susceptible zones. Lower catchment is majorly characterized by low landslide susceptibility. Mandal and Maiti [18] also proved this in their work over Darjeeling Himalaya. Loamy skeletal type of soil covers nearly 99% of very high LSZ. Lineament density (5.66 km/km<sup>2</sup>) is also high in this region and average value of gravity anomaly is also highest in this region. Hence, higher value of lithological causal factors makes this region most vulnerable for landslide.

**Table 1** Procedure to prepare raster layer of different parameters

Category	Parameters	Measures taken to prepare the raster layer
Triggering factor	1. Rainfall 2. Seismicity	Point based raster layers is prepared in ERDAS Imagine environment
Lithological factors	1. Geology 2. Soil 3. Lineament density map	Geological vector polygon is converted into raster layer Vector polygon of soil layer is converted into raster layer Lineament density map has been prepared from the lineament map in ArcGis 9.3 by using the following model
 <pre> graph LR     A([Lineament]) --&gt; B[Split line at vertices]     B --&gt; C([Lineament_sp lit])     C --&gt; D[Line density]     D --&gt; E([Lineament_density])             </pre>		
	4. Gravity Anomaly	Gravity anomaly map of the study area has been extracted from Ansari et al. (2014) [25]
Surface causal factor	1. Slope 2. Drainage density and 3. Relative Relief	Slope layer is derived from SRTM DEM (30 m) The Grid wise drainage density (Dd) and relative relief (R) have been used considering respective formulas [26] $R = H - h$ [27] where, H = highest elevation h = lowest elevation $Dd = L\mu/A$ [28] where, $L\mu$ = total length of drainage A = total area
Anthropogenic causal factor	1. Settlement 2. Agriculture 3. Roads	All settlement and agriculture land layers separately digitized from Google earth image manually and grid based binary number is assigned for spatial data layer preparation. The grid possesses e.g. settlement is assigned 1 and otherwise assigned 0. In case of road layer road density map is generated
Protective factor	1. Natural Vegetation	Normalized Differences Vegetation Index (NDVI) calculation is performed for obtaining the vegetative cover over the study area

In case of high LSZ nearly 88% of this is situated on the granite formation. In this zone lineament density (4.14 km/km<sup>2</sup>) is also quite high. On the other hand, low and very low zones are situated mainly on the alluvium geological formation (99.06%) with greater cohesiveness and soaking power. Density of lineament (3.63 km/km<sup>2</sup>) is also low in this region. All these things are responsible for less frequent and low magnitude of landslide. In case of anthropogenic factors settlement and agricultural land do not play major role here in determining the landslide susceptibility because very low sparse presence (nearly 12%) of the settlement in the very high or high landslide susceptible zones. While on the other hand settlement and agricultural land covers greater percentage of area (67.79%) in case of very low landslide susceptible zone. Road density

(0.988 km/km<sup>2</sup>) shows high value in respect to very high and high LSZ but the value is low (0.479 km/km<sup>2</sup>) in case of low and very low LSZ.

**4.2 Responsible factors cluster**

Figure 4a–e represents the factors cluster models depicting landslide susceptibility in terms of the individual factor groups. This, in fact, helps to understand which factor cluster carries responsibility for influencing historical landslides based on their physical location. Frequency analysis of the historical landslides (LS) in different factors cluster models (only within high and very high LS susceptible zones) states that out of total 45 sites, 25, 01, 24, 18 and 11 number of LS sites are located in lithological,

**Table 2** Scaling process and logic behind scaling

Parameters	Scaling process	Logic behind scaling	Weight
Slope (sl)	10 rank at the steepest class slope class	High degree of slope indicates more probability for the occurrence of landslide [16]	0.195
Geology (Gg)	Highest rank of 10 is given to gneiss and lowest rank of 1 is given to phyllite	Value in case of each rock is given on the basis of their hardness value as per Moh's scale. In harder rock, chance of forming lineament is high; frequency ratio is also considered here for weighting. Mandal and Maiti [24] also considered gneiss as more susceptible for landslide in their work	0.188
Drainage density (Dd)	10 rank highest drainage density class	Low value of drainage density indicates highly resistant permeable sub surface material with low relief and dense vegetation [29]	0.165
Lineament (Lt)	10 rank at highest lineament density class	It is established from the previous literatures that high lineament density indicates high land slide susceptibility [30]	0.126
Relative relief (Rr)	10 rank at highest relative relief	Low value of relative relief indicates flat to gentle slope [10] and hence intensity of sliding is less	0.085
Soil (Si)	10 rank is given to loamy skeletal soil and lowest rank of 1 is given to fine loamy soil	Coarser soil with high saturation level increases land slide Different soil types have different influence on landslide occurrence [31]; basis of weighting: frequency ratio	0.054
Rainfall (Rf)	10 rank at highest rainfall intensity zone	Rainfall is considered as a major triggering factor of landslide occurrence	0.039
Road (Rd)	10 rank at highest density	Roads are one of the reason for the occurrence of landslide	0.028
Agricultural land (Ag)	Rank 10 indicates presence of agricultural land and rank 0 indicates absence of agricultural land	Several researchers have stretched the link of human impacts like construction of settlement and extension of agriculture land in sloppy area etc. with landslide occurrences [32]	0.024
Settlement (St)	Rank 10 indicates presence of settlement and rank 0 indicates absence of settlement		0.021
Vegetation (Vg)	10 rank at lowest vegetation cover	Greater vegetation cover reduces the probability of landslide [33]	0.019
Seismic frequency (Sf)	10 rank at highest frequency class	Earthquake triggers disturbance equilibrium in slope and exerts landslides; moreover some earth quakes do not trigger earth quake explicitly but making the mass fragile and prepare that area for susceptibility in future days [34]	0.031
Gravity anomaly (Ga)	10 rank at highly anomalous area	Gravity anomaly reflects the density of the rocks [35]. Higher density of rocks has greater chances for the formation of lineaments	0.024

anthropogenic, surface, triggering and protective models respectively. Only one is counted within very high and high zones of AFM; maximum number of LS sites is the cumulative consequences of lithological and surface factors followed by triggering factors.

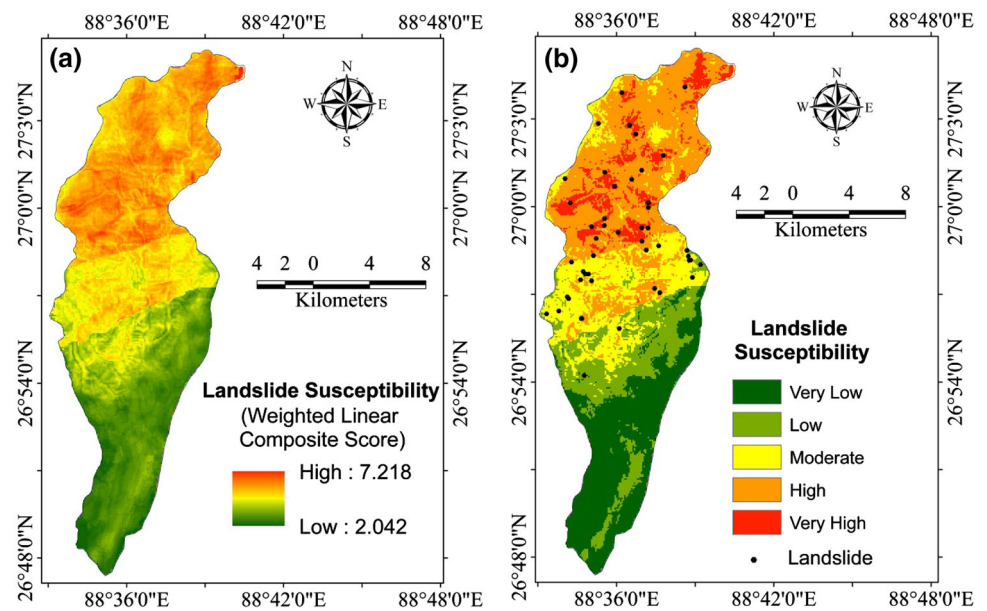
Highest relationship with landslide susceptibility can be observed in case of lithological clusters (Table 3). So influence of lithological factors (Geology, Soil, Lineament and Gravity anomaly) is greater to determine the vulnerability. Beside this, correlation value of 0.89 in case of surface causal factors (drainage density, relative relief and slope) also shows significant impact for the occurrence of landslide. In case of this basin anthropogenic factors play minimum role as its correlation value is only 0.00452. Among the anthropogenic factors, only road to some extent exerts significant influence. Most of the landslide in the

study area occurs during the monsoon season. Though the rainfall is significantly high throughout the region but highest landslide susceptibility zone is not located in the highest rainfall area. That is why the relationship is slightly low. Lastly the protective factor model shows positive relation which suggests that high and very high landslide susceptible zones are covered with less vegetation.

## 5 Discussion

In last 100 years earth quake incidents within 500 km buffer distance from the basin boundary was 82 with a magnitude varies from 5.0 to 8.0  $M_w$  (USGS Earthquake Hazards Program). Landslide of 2015 (April, 25) is considered as a cumulative result of Nepal earthquake

**Fig. 3** Landslide susceptible zones **a** Continuous susceptibility grades **b** Classified susceptibility zones



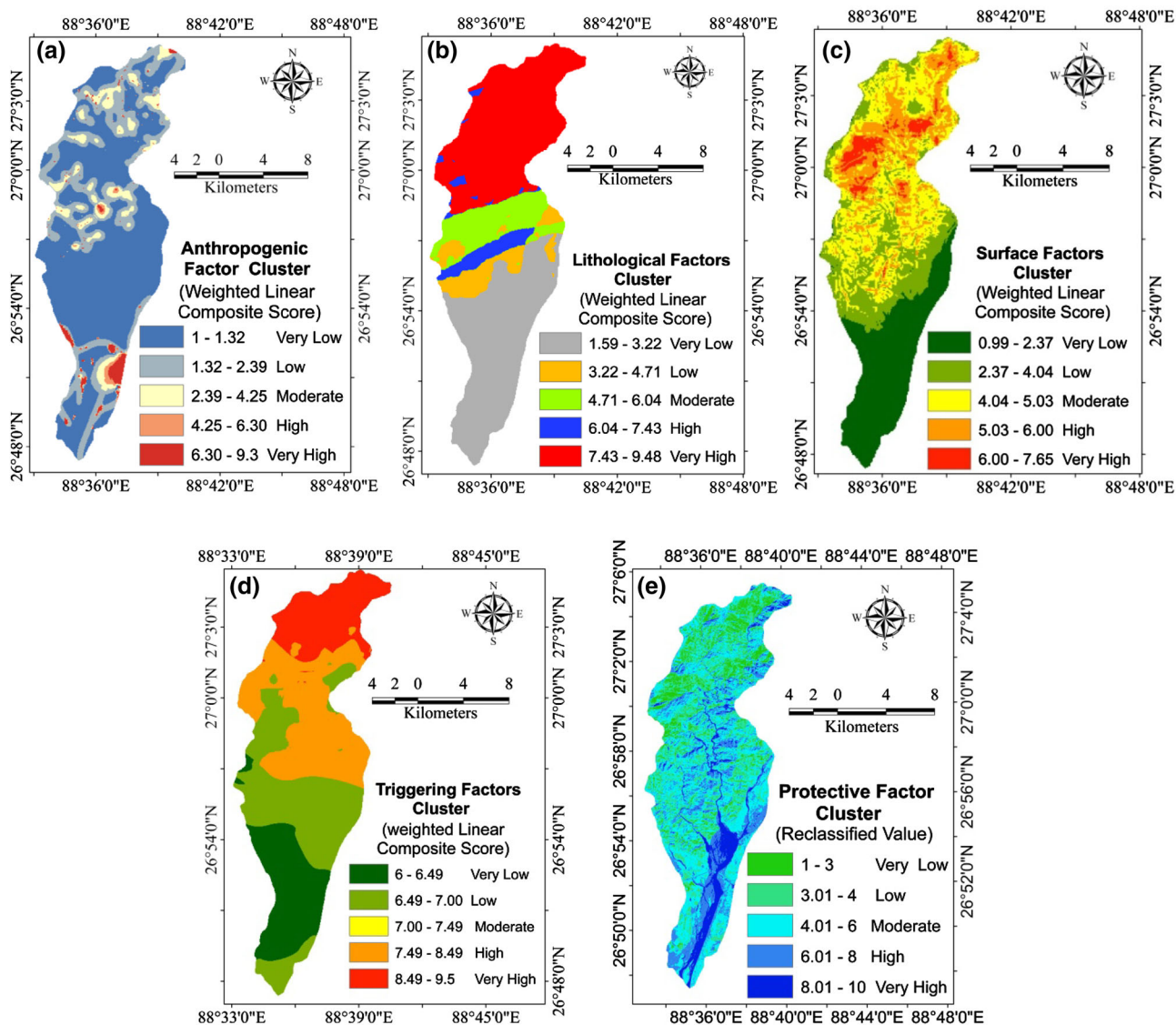
(intensity: 7.8  $M_w$ ) and excessive torrential rain (about 200 mm). Earthquake exerts significant stress on crystalline rocks. Formation and deformation of joints, fractures, lineaments in rocks are very regular phenomena. Excessive infiltration of water through these joints during monsoon season slides the rock fragments. More than 90% landslide incidents happen during monsoon season due to excess rainfall. In this area average monsoon rainfall is about 600–800 mm [19]. Intensive rainfall within few hours often simulates landslide incidents. Out of total rainfall, 10–50% rainfall happens within 1–10 days [20]. It is quite difficult to calculate threshold rainfall whistling landslide because other existing conditioning factors work integrated manner. Most of the previous works in Himalayan Mountain condemned earthquake and rainfall as prime factors of landslide incidents [19–21]. Unconsolidated loose materials is sensitive to move and speed of movement depends on degree of slope and presence of water. But it doesn't indicate that frequency of earthquake will always be high in the high rainfall zone. In the region where high rainfall takes place is composed with fine to coarse loamy soil and this sort of soil has greater elasticity and not highly sensitive to earthquake; slope of this region is very low because in this region river already fall into the plain. The high landslide susceptible zone is prone to steeper slope, crystalline rocks and therefore sensitive to slope instability. According to the local people degenerated forest species may be one of the causes behind accelerated landslide in this zone. Heavy pressure of human activities like heavy traffics, slope modification for constructing roads and houses etc. are also very crucial for boosting landslide incidents [22]. Presence of road just at the edge of the steeper slope is susceptible for landslide. Every year,

these vital roads become blocked with heap of landslide about 10–15 times. In the surrounding regions (like Lish, river basin) also built up area is condemned as dominant one [23]. Direct suffering of people from this incident in every monsoon highlights this as major factor.

The landslide susceptibility model is validated with the help of historical landslide locations. From Table 4 it can be observed that there are 14, 21, 08, 02 and 00 landslide sites are associated with very high, high, moderate, low and very low zones respectively (Fig. 3b). Simple frequency analyses in different zones sometimes may not carry any particular interpretation because areas under different susceptible zones are not identical. For this reason, frequency density of the occurrences of landslide is calculated. From this frequency density it is observed that very high landslide density ( $0.70/\text{km}^2$ ) is associated with very high landslide susceptible zone. The next high frequency density of landslide occurrence is observed over the high landslide susceptible zone. Moderate landslide susceptible zone is associated with moderate landslide frequency density. The low landslide susceptible zone indicates low value for landslides frequency density ( $0.04/\text{km}^2$ ). From this it can be stated that the prepared spatial model can be accepted.

After determining the relationship between frequency of landslides and LSZ, second attempt (Fig. 5a) is taken to find out the areal coverage of landslides under different LSZs in order to validate this model more effectively.

The size of landslides in the study area are categorized into three categories viz.  $>0.15$ ,  $0.15\text{--}0.05$  and  $<0.05$   $\text{km}^2$ . Table 5 presents the areal coverage of different categories of landslides under different LSZ. From Table 5 it can be observed that larger size landslides are associated with high and very high LSZ having greater cumulative areal



**Fig. 4** Responsible factors cluster model **a** Anthropogenic factors cluster **b** Lithological factors cluster **c** Surface factors cluster **d** Triggering factors cluster **e** Protective factor cluster

**Table 3** Relationships between landslide susceptibility layer and other factor clusters

Layer	Triggering factor	Anthropogenic factor	Lithological causal factor	Surface causal factor	Protective factor
Landslide susceptibility layer	0.67609	0.00452	0.9461	0.88931	0.33469

coverage. On the other hand, moderate and low LSZ are associated with mainly minor size of landslide having relatively lesser areal coverage under landslide. While considering the total areal coverage under landslide, it is also observed that highest areal density (0.068) is associated with very high landslide susceptible zone and lowest areal density (0.00) is associated with very low landslide

susceptible zone. The second validation technique also shows that this model is valid.

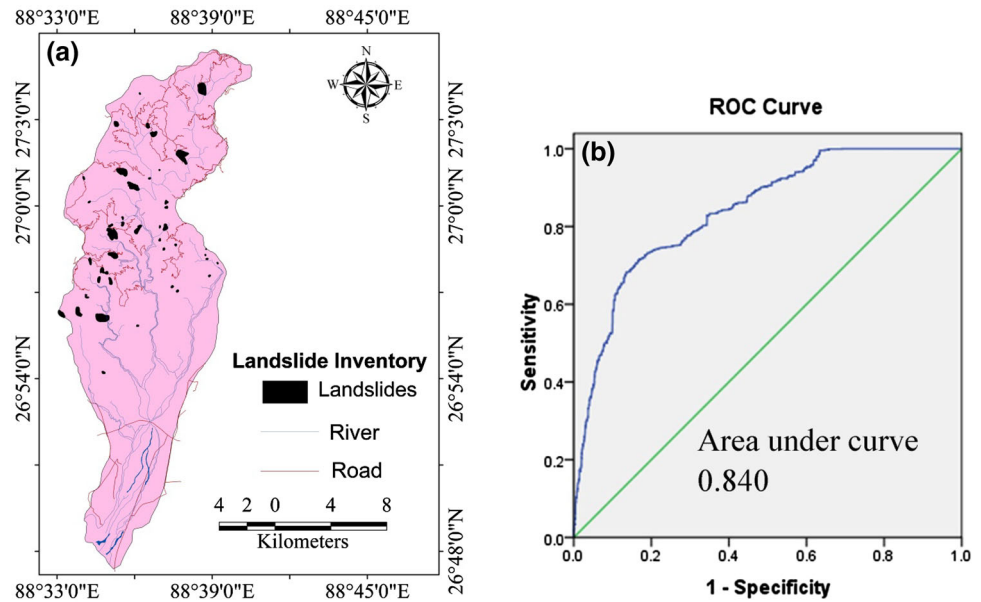
Receiver Operating Characteristic (ROC) curve (Fig. 5b) is prepared to validate the landslide susceptible model in a quantitative way. To prepare the ROC curve a total number of 2156 landslide and 2156 non landslide points are taken into consideration. The ROC curve is generated with the help of SPSS statistical software. The



**Table 4** Density of Occurrence of Landslide in Different LSZs

Land slide susceptibility zone	Area (km <sup>2</sup> )	Number of landslide	Number of landslide per km <sup>2</sup>
Very high	19.92	14	0.70
High	90.00	21	0.23
Moderate	52.25	08	0.15
Low	41.28	02	0.04
Very low	61.49	00	0.00
Total	264.94	45	0.17

**Fig. 5** Location of historical landslides and receiver operating characteristics (ROC) curve **a** Landslide inventory map, **b** ROC curve



**Table 5** Areal density of landslide under different LSZs

Landslide susceptible zones (LSZ)	Number of landslide with different sizes (km <sup>2</sup> )						Total area under different LSZ (km <sup>2</sup> )	Areal density	
	>0.15	Area covered	0.15–0.05	Area covered	<0.05	Area covered			
Very high	5	0.998	3	0.231	9	0.129	1.359	19.92	0.068
High	6	1.013	4	0.151	16	0.136	1.300	90	0.014
Moderate	1	0.035	4	0.188	12	0.084	0.306	52.25	0.006
Low	0	0.000	1	0.049	3	0.014	0.063	41.28	0.002
Very low	0	0.000	0	0.000	0	0.000	0.000	61.49	0.000

Area of some landslides overlaps in two different LSZ. In that case area under different LSZ is calculated but the frequency is assigned under both the LSZ

area under curve >0.80 (80%) is suggested as good accuracy rate by Rasyid et al. [24]. In case of this study, the ROC curve shows 84.00% (0.84) area under the curve. This shows good prediction rate of the model as the value is greater than 80%. Thus all the validation procedure suggests that the landslide susceptible model, prepared using Analytic Hierarchy Approach, is accurate to determine the landslide susceptible zones.

### 6 Conclusion

This study has been carried out by taking into consideration of thirteen landslide decisive parameters. These parameters are further subdivided for common scaling. All the parameters are intimately related with landslide and able to depict the vulnerability of a place in respect to the occurrence of a landslide. Based on this all the parameters are

integrated to prepare the landslide susceptibility zone. After validation this methodology is proven useful to predict the landslide susceptible area.

The final outcome of the study demonstrates the following facts: (1) Very high landslide susceptibility zone is mainly situated around the upper part of the basin. On the other hand, very low landslide susceptible zone is situated mainly towards the downward portion of the basin. (2) Very high LSZ is associated with high runoff and steeper rock surface as the drainage density and relative relief is high in this zone. (3) Among the causal factors lithological condition exerts greater influence to determine the susceptibility in respect to the occurrence of landslide. Slope modification for construction of roads, expansion of settlements is apparently appeared as less important factor. But impact of slope modification has far flung effects. Even it does not mean that landslide alongside the roads is the sole expression slope modification. Its effect may be away from the road side. Scientific routing and light weight buildings are essential for partially escaping from landslide incidents. Present trend of heavy weight traffic, high traffic density, multi-storied buildings and expanding clustered towns are not ecological to reduce landslide frequency.

## References

- Moradi, M., Bazyar, M. H., & Mohammadi, Z. (2012). GIS-based landslide susceptibility mapping by AHP method, a case study, Dena City, Iran. *Journal of Basic and Applied Scientific Research*, 2(7), 6715–6723.
- Yilmaz, C., Topal, T., & Suzen, M. L. (2011). GIS-based landslide susceptibility mapping using bivariate statistical analysis in Devrek (Zonguldak-Turkey). *Environmental Earth Sciences*, 2012(65), 2161–2178.
- Eshghabad, S. M., Solaimani, K., & Omidvar, E. (2012). Landslide susceptibility mapping using multiple regression and GIS tools in Tajan Basin, North of Iran. *Environment and Natural Resources Research*, 2(3), 43–51.
- Kumar, R., & Anbalagan, R. (2015). Landslide susceptibility zonation of Tehri reservoir rim region using binary logistic regression model. *Current Science*, 108(9), 1662–1672.
- Pradhan, B., Sezer, E. A., Gokceoglu, C., & Buchroithner, M. F. (2010). Landslide susceptibility mapping by neuro-fuzzy approach in a landslide-prone area (Cameron Highlands, Malaysia). *IEEE Transactions on Geoscience and Remote Sensing*, 48(12), 4164–4177.
- Pascale, S., Parisi, S., Mancini, A., & Schiattarella, M. (2013). Landslide susceptibility mapping using artificial neural network in the urban area of Senise and San Costantino Albanese (Basilicata, Southern Italy). In: *ICCSA, part IV*, LNCS 7974, pp. 473–488.
- Saaty, T. L. (1980). *The analytical hierarchy process*. New York: McGraw Hill.
- Ayalew, L., Yamagishi, H., Marui, H., & Kanno, T. (2005). Landslides in Sado Island of Japan: Part II. GIS-based susceptibility mapping with comparisons of results from two methods and verifications. *Engineering Geology*, 81, 432–445.
- Official Website of Government of Darjeeling. [www.darjeeling.gov.in/geography.html](http://www.darjeeling.gov.in/geography.html).
- Rai, P. K., Mohan, K., & Kumra, V. K. (2014). Landslide hazard and its mapping using remote sensing and GIS. *Journal of Scientific Research*, Banaras Hindu University, Varanasi, 58: 1.
- Pal, S. (2016). Identification of soil erosion vulnerable areas in Chandrabhaga river basin: A multi-criteria decision approach. *Modeling Earth Systems and Environment*, 2(5), 1–11.
- Achour, Y., Boumezbeur, A., Hadji, R., Chouabbi, A., Cavaleiro, V., & Bendaoud, E. A. (2017). Landslide susceptibility mapping using analytic hierarchy process and information value methods along a highway road section in Constantine, Algeria. *Arabian Journal of Geosciences*, 10, 1–16. doi:10.1007/s12517-017-2980-6.
- Eastman, J. R. (2006). *Idrisiandes: tutorial, clark labs*. Worcester: Clark University.
- Elmahdy, S. I., Marghany, M. M., & Mohamed, M. M. (2014). Application of a weighted spatial probability model in GIS to analyse landslides in Penang Island, Malaysia. *Geomatics, Natural Hazards and Risk*, 7:1, Taylor and Francis Group. pp. 353–356. doi: 10.1080/19475705.2014.904825.
- Paul, P. K., & Das, S. (2014). Landslide susceptibility evaluation of GIT watershed of Kalimpong subdivision, India using information value method. *International Journal of Economic and Environment Geology*, 5(2), 18–24.
- Chauhan, S., Sharma, M., Arora, M. K., & Gupta, N. K. (2010). Landslide susceptibility zonation through ratings derived from artificial neural network. *International Journal of Applied Earth Observation and Geoinformation*, 12, 340–350.
- Gokceoglu, C., & Aksoy, H. (1996). Landslide susceptibility mapping of the slopes in the residual soils of the Mengen region (Turkey) by deterministic stability analyses and image processing techniques. *EngGeol*, 44, 147–161.
- Mandal, S., & Maiti, R. (2014). Role of lithological composition and lineaments in landsliding: A case study of Shivkhola watershed, Darjeeling Himalaya. *International Journal of Geology, Earth and Environmental Sciences*, 4(1), 126–132.
- Biswas, S. S., & Pal, R. (2016). Causes of landslides in Darjeeling Himalayas during June–July, 2015. *Journal of Geography and Natural Disasters*, 6, 173. doi:10.4172/2167-0587.1000173.
- Dahal, R. K., & Hasegawa, S. (2008). Representative rainfall thresholds for landslides in the Nepal Himalaya. *Geomorphology*, 100, 429–443. doi:10.1016/j.geomorph.2008.01.014.
- Basu, T. & Pal, S. (2017). Identification of landslide susceptibility zones in Gish River basin, West Bengal, India. *Georisk*, Taylor & Francis. pp. 1–16. DOI: 10.1080/17499518.2017.1343482.
- Arbanas, Z., & Dugonjić, S. (2010). Landslide risk increasing caused by highway construction. *Researchgate*, pp. 333–342.
- Mandal, B., & Mandal, S. (2016). Assessment of mountain slope instability in the Lish River basin of Eastern Darjeeling Himalaya using frequency ratio model (FRM). *Modeling Earth Systems and Environment*, 2, 1–14.
- Rasyid, A. R., Bhandary, N. P., & Ryuichi, Y. (2016). Performance of frequency ratio and logistic regression model in creating GIS based landslides susceptibility map at Lompobattang Mountain, Indonesia. *Geoenvironmental Disasters*, 3(19), 12.
- Ansari, Md A, Khan, P. K., Tiwari, V. M., & Banerjee, J. (2014). Gravity anomalies, flexure, and deformation of the converging Indian lithosphere in Nepal and Sikkim-Darjeeling Himalayas. *International Journal of Earth Sciences (GeolRundsch)*, 103, 1681–1697.
- Ghosh, K. G., & Saha, S. (2015). Identification of soil erosion susceptible areas in Hinglo River Basin, Eastern India based on geo-statistics. *Universal Journal of Environmental Research and Technology*, 5(3), 4–5.

27. Hadley, R. F., & Schumm, S. A. (1961). *Sediment sources and drainage basin characteristics in upper Cheyenne River Basin*. US geol survey water supply paper 1531-B:198.
28. Strahler, A. N. (1964). Quantitative geomorphology of drainage basins and channel networks. In V. T. Chow (Ed.), *Handbook of applied hydrology* (pp. 411–476). New York: McGraw-Hill.
29. Nag, S. K. (1998). Morphometric analysis using remote sensing techniques in the Chaka sub-basin, Purulia district, West Bengal. *Journal of the Indian Society of Remote Sensing*, 26(1), 69–76.
30. Simon, N., Roslee, R., Marto, N. L., Akhir, J. M., Rafek, A. G., & Lai, G. T. (2014). Lineaments and their association with landslide occurrences along the Ranau-Tambunan Road, Sabah. *EJGE*, 19, 645–655.
31. Kitutu, M. G., Muwanga, A., Poesen, J., & Deckers, J. A. (2009). Influence of soil properties on landslide occurrences in Bududa district, Eastern Uganda. *African Journal of Agricultural Research*, 4(7), 611–620.
32. Reichenbach, P., Busca, C., Mondini, A. C., & Rossi, M. (2014). The influence of land use change on landslide susceptibility zonation: The Briga catchment test site (Messina, Italy). *Environmental Management*, 54, 1372–1384.
33. Iwahashi, J., Okatani, T., Nakano, T., Koarai, M., & Otoi, K. (2014). *Landslide susceptibility analysis by terrain and vegetation attributes derived from pre-event LiDAR data: A case study of granitic mountain slopes in Hofu, Japan*. INTER-PRAEVENT2014 in the Pacific Rim November 25–28, 2014, in Nara, Japan.
34. Kamp, U., Growley, B. J., Khattak, G. A., & Owen, L. A. (2008). GIS-based landslide susceptibility mapping for the 2005 Kashmir earthquake region. *Geomorphology*, 101, 631–642.
35. Omosanya, K. O., Mosuro, G. O., Laniyan, T. A., & Ogunleye, D. (2012). Prediction of gravity anomaly from calculated densities of rocks. *Advances in Applied Science Research*, 3(4), 2059–2068.