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DOES PATTERNS OF SOIL ERODIBLE FRACTION IN ARID REGION RELATE WITH LANDFORM TYPES?

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Abstract – Understanding and quantifying the large, unexplained variability in soil erosion data are critical for advancing erosion science, evaluating soil erosion models, and designing erosion experiments. Soil erodible factor has been quantified around the globe with regard to soil properties, land use types and their management methods, but more empirical research is needed to connect the soil erodible fraction (EF) factor and landform types. In this research, we investigated the likely interactions between EF and landform types (Older Alluvial Plain: OAP, Younger Alluvial Plain; YAP and Hilly Undulating Terrain; HUT) and with their biotic (plant community dynamics) and abiotic (soil) components in hot arid region of the India. EF's behaviors on 36 lands related to specific landform and their interactions with predictor (plant species richness, diversity, evenness, soil nitrogen, phosphorus, moisture, gravel proportion and bare patch index, pH and electric conductivity) were evaluated using non-parametric Kolmogorov-Smirnov test and through partial least square regression. This research proposed that EF was not primarily governed by landform type. At the landform level we found significant negative relationships of species richness and diversity with EF at OAP and YAP. Bare patch size was positively related with EF at OAP only. After sequential use of Variable Importance for the Projection (VIPs), we found that with cumulative data set, richness, species diversity, soil moisture, gravel content and phosphorus were the significant predictors for EF.

INTRODUCTION

Landform is geomorphic feature on earth surface, having explicit territory and significantly affected with interaction of biotic, soil and weathering components (Pelfini and Bollati, 2014). Based on their structural features they may be under construction or in a distractive stage. The relationships between landform features and community attributes are well demonstrated in published literature (Swanson *et al.,* 1988; Larkin *et al.,* 2006; Solon *et al.,* 2007; Ott and van Aarde, 2014). Within India hot arid and semi arid region, Bawa *et al.* (1988); Kolarkar *et al.* (1992) and Mohharan *et al.* (2016) have identified 14 different types of landforms that includes: Hills, Piedmonts plains, Rocky or gravelly pediments, Flat buried pediments, Sandy undulating buried pediments, Flat aggraded older alluvial plains, Saline flat aggraded older alluvial plains, Sandy undulating aggraded older alluvial plains, Sand dunes, Flat inter-dunal, Sandy undulating inter-dunal plains, Shallow saline depressions, Graded river beds and Younger alluvial plains.

Soil erodibility (SE) is a measure of a specified soil's susceptibility to erosion and varies from soil texture differences, soil structure, shear strength, infiltration capacity, permeability, organic matter and soil chemical content. Most soil erodibility studies were carried out with respect to land use (Singh and Khera, 2008; TaherNezami, 2013; Ajibolo *et al.,* 2018; Jeloudar *et al.,* 2018) and few were conducted with reference to landform (Satisha and Ulaganathan, 2009; Amini, 2017). Present study was conducted to address (a) do different landforms have a distinctive soil erodible fraction (EF) factor?, (b) to identify the biotic and abiotic factors that are influencing the EF at landform level and (c) to prepare a model equation for EF with significant predictors applicable for all landforms.

MATERIAL AND METHODS

Study was conducted at thirty six different wastelands located within 16 km radius of the Jodhpur district of Rajasthan, India. These lands were lying between $26^0\,11'\,33.4''$ to $26^0\,18'\,47'$ Latitude and $72^0\,56'\,5.9''$ to $73^0\,60'\,35.1''$ Longitude. Among these, eighteen, twelve and six lands were located on Older Alluvial Plains (OA), Younger Alluvial Plain (YAP) and Hilly Undulating Terrain (HUT), respectively. In general, OAP are covered with the alluvium of different thickness and within the alluvial deposits, a thick layer of $CaCO_3$ has developed in the form of nodules which is locally known as *Kankar* pan while YAP are narrow strips associated with the bank of river or water channel (Mathur and Pandey, 2016).

Soil samples were collected up-to 30 cm depth at all lands. All the soil parameters were quantified in triplicate. Soil moisture (%) was estimated in non-dried soil through gravimetric method (Black, 1965). While other physical and chemical parameters were estimated in well air-dried and sieved (2 mm) soil samples (Pandeya *et al.*, 1968). Electrical conductivity (mS/m) and soil pH were measured in water-soil suspension (5:1) by respective digital meters. Soil organic carbon, total nitrogen, available phosphorus and calcium carbonate were quantified by standard methodologies of Jackson (1973) and Allen *et al.* (1976). Soil texture analyses (proportion of sand, clay, sand and silt) were carried out by the sieve method (Jackson, 1973). Erodible Fraction (EF) Factor at each land was quantified according to Santra *et al.* (2014) and Mandakh *et al.* (2016) with using following formula:

$$EF = \frac{20.09 + 0.31S_A + 0.17S_i + 0.33\frac{S_A}{CL} - 2.59OM - 0.95CaCO_3}{100} \quad .. (1)$$

Where S_A is the sand content (%), S_i is the silt content (%), CL is the clay content (%), OM is the organic matter content (%), $CaCO_3$ is the percentage of calcium carbonate in the soil sample. Organic matter was calculated from estimated organic carbon by using conventional conversion i.e. OM = 1.7 x OC (Chaudhari *et al.*, 2013). The value of EF ranges from zero (no soil erodibility) to one (maximum erodibility, Santra *et al.*, 2014).

At each land nested quadrat technique was applied wherein 10 quadrats of 10m x 10m (for woody perennial and annuals) abutting each other in a raw were laid across the field (Kent and Coker, 1992). Diversity indices were calculated as per standard methodology (Ludwig and Reynold, 1999). The species richness is defined as the total number of species per sampling unit (Bhattarai *et al.*, 2004). Shannon-Weaver is a diversity index and generally ranges from 1.5 to 3.5 and rarely up to 4.5. Its higher valued indicates the high diversity while the lower value represents the dominance of few species (Mathur, 2005). Evenness index standardize abundance and range from near zero when most individuals belong to a few species, to close to 1, when species are nearly equally abundant.

Bare Patch Index $_{Modified}$ was quantified by using the mean size of bare patches at land (B_{Mean} in centimeter). This index having a multiplication factor of connectivity of bare patch where 1 was used for inter-connected bare patches and 0.5 for their non- connectivity (Mathur and Sundarmoorthy, 2018). Thus, this equation can be equated as:

$$BPI_{Modif} = B_{Mean}\ x \left(\frac{\sum B}{\sum L}\right) x\ Connectivity\ of\ Bare\ Patch$$

{i.e. 1 for yes and 0.5 for no} .. (2)

′B the percent bare surface area of a land and total transect length (ΣL 100m).

Within a landform the distribution behavior of EF at different studied lands were assessed through one sample non-parametric Kolmogorov-Smirnov (K-S) test. Results of K-S test were interpreted through 'D' statistic which actually denotes the difference between observed and theoretical frequency distributions. If calculated value of test statistic D is less than critical value one should accept null hypothesis, and reject the null hypothesis in alternative case. In this study, our null hypotheses (H_0) pertain to no difference among the soil erodibility of different lands located at specific landform. However, behavior of EF among different landforms was assessed with student t- test (unequal variance).

Partial Least Square (PLS) regression analysis was carried out to examine the relationship of environmental variables/predictors (plant species richness, diversity, evenness, soil nitrogen, phosphorus, moisture, gravel proportion and bare patch index, pH and electric conductivity) with SE and its integral soil properties (silt, sand, clay, sand/clay, soil organic matter and $CaCO_3$) at different landforms. This multivariate technique was interpreted with model qualities (Q^2 cumulated index), bi-plot relationships between exploratory (X) and dependent factors (Y) and through Variable Importance in Projection (VIPs). Q^2 referred goodness of prediction or prediction variation which is the proportion of predictive residual error sum of squares and total sum of square. In context of the VIPs, the PLS was conducted at three different time, i.e. to identify the significant and non significant VIPs at each landform type, in combined data set to identify the non significant variables and again carried out after elimination of non significant VIPs in combined data set so that a model equation for EF can be formulated with significant predictors. Use of this multivariate approach for modeling the soil properties was advocated by Ongsomwang and Rattanakom (2013) and Shi *et al.* (2013). These multivariate analyses was carried out by using PAST (Hammar *et al.*, 2001) and XLSTAT (2017) software's

RESULTS

Ranges of different studied parameters (soil physical, chemical and plant community) are provided in Table 1. Data were analyzed and interpreted for within and among landforms. Lands at OAP and YAP had the higher species richness (14) while it was ranged from 3 to 10 at the lands belongs to HUT. Lands under the OAP were more diversified compared to YAP and HUT. Within a landform, large variations were observed for bare patch size which was 2.48 to 31.49 at OAP, 3.01-37.31 at YAP and 5.22-30.87 at HUT (Table 1). Among the landforms higher amount of soil organic matter was recorded at HUT followed by OAP and YAP. Within each landform the values of EF at different lands are presented in Table 2. At OAP it ranged from 0.22 to 0.44, followed by YAP (0.22-0.43) and HUT (0.34-0.41). Among the landforms, both minimum (0.22) and maximum (0.44) were recorded at OAP while, with reference to EF, HUT was found more homogenous compared to OAP and YAP.

Table 2. EF Values at each studied land at different landforms

Land	OAP	YAP	HUT
1	0.33	0.37	0.34
2	0.35	0.33	0.37
3	0.44	0.40	0.41
4	0.29	0.28	0.35
5	0.31	0.38	0.38
6	0.38	0.41	0.37
7	0.33	0.32	
8	0.36	0.36	
9	0.40	0.34	
10	0.30	0.32	
11	0.35	0.36	
12	0.38	0.43	
13	0.39		
14	0.40		
15	0.41		
16	0.22		
17	0.33		
18	0.38		

Table 1. Range of Various Studied Parameters at three types of Landforms

Parameters	Landform Types		
	OAP	YAP	HUT
Total Study Sites	18	12	6
Available P %	0.004-0.05	0.01-0.05	0.01-0.05
Soil Nitrogen (%)	0.01-0.25	0.02-0.11	0.04-0.11
Soil pH	6.40-9.09	7.64-8.96	6.23-9.11
Soil Electric Conductivity (mS/m)	0.10-0.54	0.11-0.41	0.11-0.24
Moisture	0.59-12.42	0.37-5.85	0.48-8.20
Gravel (%)	0.40-39.95	2.04-39.95	0.11-24.33
Bare Patch	2.48-31.49	3.01-37.31	5.22-30.87
Species Richness	4.0-14.0	3-14	3-10
Species Diversity	1.08-2.38	0.69-2.20	0.56-1.98
Species Evenness	0.77-1.20	0.85-1.0	0.80-1.04
Soil Organic Matter (%)	0.04-0.34	0.03-0.28	0.11-0.35
$CaCO_3$ (%)	0.010-0.089	0.006-0.01	0.005-0.044
Clay (%)	8.97-35.72	8.97-36.56	23.30-39.60
Silt (%)	1.60-32.83	3.72-32.83	1.10-19.07
Sand (%)	18.26-73.0	18.26-60.0	37.61-64.57
Sand : Clay	0.91-3.26	0.91-2.04	1.36-1.89
EF	0.22-0.44	0.28-0.43	0.34-0.41

Behavior of EF

Within landforms the value of K-S test for OAP (0.14), YAP (0.10) and HUT (0.17) were recorded with alpha level 0.05 (Table 3). In present study, the D values of K-S test were recorded lesser than the critical values (Table 3) at all the landform types and hence we accept the null hypothesis and concluded that there is no difference in erodibility of lands belongs to a specific landform. Among landforms, result of student –t test is presented in Table 4. We found non-significant t-stats with comparison to one-tail critical t value which also suggested that EF is independent to landform factor type.

Table 3. Kolmogorov Smirnov one sample test conduct at various landforms for EF behavior

Parameters	OAP	YAP	HUT
Degree of Freedom	16	10	4
D critical value (0.05)	0.21	0.26	0.37
D-computed value	0.14	0.10	0.17

Table 4. Student t test with unequal variance conduct for among the landforms

t-test statistics	Landforms	OAP	YAP
t- stats	HUT	1.08^{NS}	0.73^{NS}
t Critical one-tail		1.71	1.74
t- stats	YAP	0.30^{NS}	
t Critical one-tail		1.70	

NS= Non-significant.

Model Qualities

The Q^2 cumulated index measures the global goodness of fit and we found that for all the landforms and in combined the Q^2 remain low even with fourth components (ideally it should be close to 1), suggested that quality of model fit varies a lot and depends on the EF itself as well as with its integral parameters i.e., depended variables. The cumulated R^2Y and R^2X corresponds to the correlation between the exploratory (X) and dependent (Y) variables with the component close to 1 with 4th component generated by PLS summarize well both by X_S and the Y_S for the studied landforms (Table 5 to 7).

Bi-plot relationships between X and Y

At OAP, the EF was located in opposite direction of diversity (r^2 = - 0.80, P<0.01) and species richness (r^2 = - 0.84, <0.01) and also showed a negative relationship with soil moisture (r^2 = -0.48, P<0.05) while EF showed close proximity with bare patch size (r^2 = 0.71, P<0.01; Figure 1). At YAP, the richness

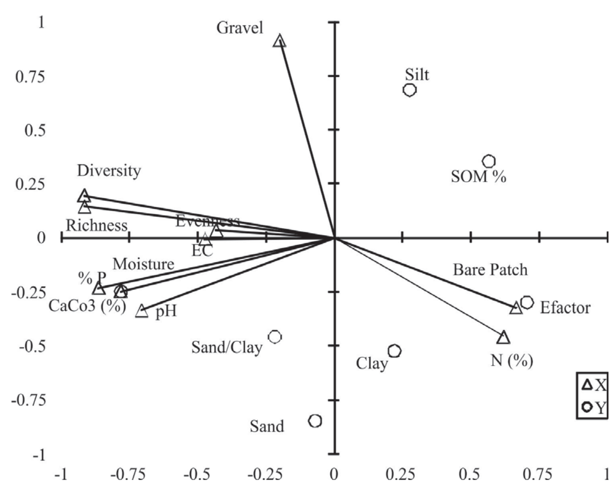

Fig. 1. PLS Bi-plot at OAP landform

Table 5. PLS model quality indexes and Variable Importance in the Projection (VIP) of exploratory variables at OAP

Indexes and VIP	Com1	Com 2	Com 3	Com 4
Q^2 cumulative	0.11	0.27	0.23	0.16
R^2 Y cumulative	0.23	0.51	0.56	0.62
R^2 X cumulative	0.48	0.62	0.74	0.81
Gravel	0.03	1.85	1.77	1.72
% P	1.39	1.03	1.11	1.08
Richness	1.30	0.93	0.93	0.94
pH	1.05	0.93	0.90	1.00
Moisture	1.30	1.03	0.99	1.02
N (%)	0.74	0.82	0.80	0.83
Diversity	1.26	0.90	0.88	0.85
Bare Patch	0.74	0.85	0.90	0.88
Evenness	0.60	0.50	0.47	0.50
EC	0.75	0.51	0.76	0.73

(r^2 = - 0.76, P<0.01) and species diversity (r^2 = - 0.57, P<0.01) also showed negative relationships with SE (Figure 2). At HUT, EF located opposite to diversity, richness and soil moisture but their relationships were statistically non-significant (Figure 3). We also found several other relationships between exploratory (X) and integral dependent variables of EF (Y) like sand, silt, sand with gravel. Up- to this point we can say that richness, diversity and to some extent bare patch size and moisture content significantly affects the SE at OAP and at YAP. The significance of such exploratory variable for model quality was assessed with Variable Importance for the Projection (VIPs).

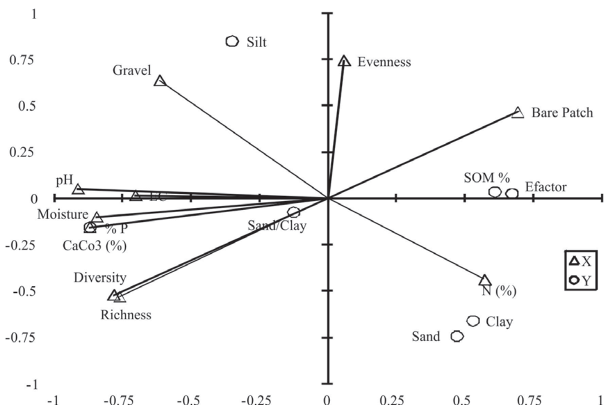

Fig. 2 PLS Bi-plot at YAP landform

Variable Importance for the Projection (VIPs)

VIPs for each exploratory variable for each landform are provided in Tables 5 to 7. This method allows us to identify which exploratory variable that contributes most to the model. Any independent variable with a VIP value greater than 1 was considered as highly important predictor (Onderka *et al.*, 2012). We found that at OAP and YAP, the bare patch size and soil electric conductivity were non-significant while soil nitrogen was non- significant at OAP and at HUT. Other soil parameters like soil

Table 6. PLS model quality indexes and Variable Importance in the Projection (VIP) of exploratory variables at YAP

Indexes and VIP	Com1	Com 2	Com 3	Com 4
Q^2 cumulative	0.11	0.26	0.27	0.30
R^2Y cumulative	0.32	0.57	0.69	0.79
R^2X cumulative	0.52	0.71	0.80	0.87
Gravel	1.25	1.49	1.42	1.36
Evenness	0.14	0.91	1.19	1.12
N (%)	1.13	1.00	1.08	1.02
Richness	0.77	1.14	1.16	1.09
% P	1.20	0.92	0.94	1.04
Bare Patch	0.72	0.79	0.72	0.82
EC	0.84	0.63	0.57	0.86
pH	1.36	1.02	0.93	0.93
Diversity	0.81	0.96	0.91	0.86
Moisture	1.17	0.89	0.81	0.77

Table 7. PLS model quality indexes and Variable Importance in the Projection (VIP) of exploratory variables at HUT

Indexes and VIP	Comp1	Comp2	Comp3	Comp4
Q^2 cumulative	0.00	0.48	0.52	0.85
R^2Y cumulative	0.54	0.83	0.91	0.98
R^2X cumulative	0.37	0.80	0.95	0.99
pH	1.60	1.29	1.25	1.21
Gravel	1.52	1.22	1.19	1.18
% P	1.11	1.16	1.11	1.12
Evenness	1.07	0.97	1.04	1.12
EC	1.04	1.05	1.02	1.05
Bare Patch	1.05	0.97	0.97	0.95
Richness	0.55	0.95	0.91	0.88
Diversity	0.20	0.91	0.87	0.86
Moisture	0.45	0.86	0.83	0.81
N (%)	0.15	0.22	0.66	0.71

moisture and pH were also non-significant at HUT.

Among the community parameters, richness and diversity were non-significant at HUT and evenness at OAP. With considering the significant and non-significant contribution of the predictor, the R^2 value of PLS for each dependent variable were calculated and are depicted in Table 8. We found that for EF, R^2 were significant at OAP and, YAP but not substantial for HUT. Based on PLS R^2 values, clay (%) was the only significant dependent variable at HUT. In the combined data set soil nitrogen, pH, EC, bare patch size and evenness were identified as non significant predictors (Table 9). After eliminating these non significant predictors from combined data set, our model equation for EF are as follows "EF = 0.43-0.12 x % P + 0.001 x Soil Moisture-0.003 x Gravel - 0.015 x Species Richness + 0.031 x Species Diversity" (PLS $R^2 = 0.65^{**}$). After this exercise and with selected significant predictors, PLS bi-plot with combined data set revealed the heterogeneity of the selected study land at different landforms (Figure 4). Thus, with reference to predictor and dependent variables we have selected heterogeneous land for this study.

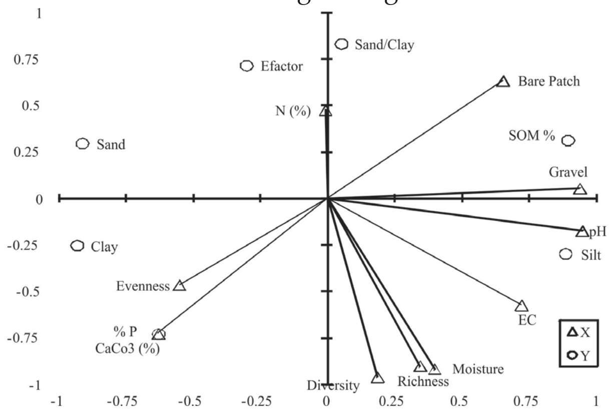

Fig. 3. PLS Bi-plot at HUT landform

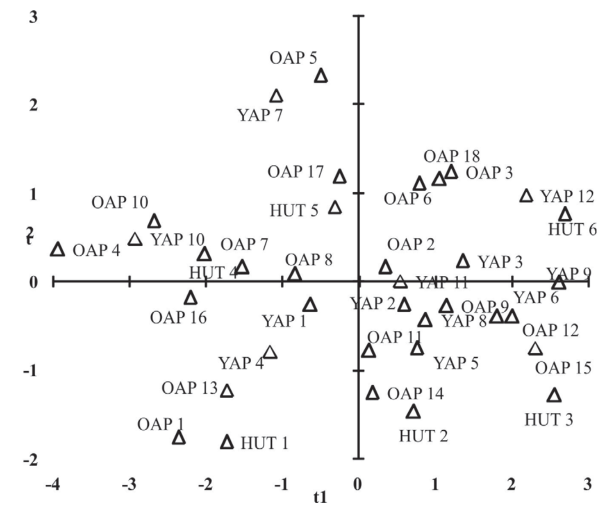

Fig. 4. PLS Combined data set after removing the non-significant VIPs

Table 8. Partial Least Square R^2 Values for E-factor and its different associated parameters.

Parameters	Landform Types		
	OAP	YAP	HUT
Clay %	0.51*	0.99**	0.99*
Silt %	0.59*	0.98**	0.95 NS
Sand %	0.79**	0.99**	0.96 NS
Sand/Clay	0.41*	0.98**	0.97 NS
$CaCo_3$ %	0.93**	1.0**	0.98 NS
EF	0.85**	0.99**	0.98 NS
SOM %	0.62**	0.95**	0.98 NS

Degree for Freedom in PLS for OAP = 14 (0.62** and 0.49*), YAP =9 (0.73** and 0.60*), HUT = 1 (1.0** and 0.99*) and for Combined = 32 (0.43** and 0.33*).
** = 99% and * = 95% level, NS= Non-significant)

Table 9. PLS model quality indexes and Variable Importance in the Projection (VIP) of exploratory variables in combined data set

Indexes and VIP	Comp1	Comp2	Comp3
Q^2 cumulative	0.14	0.37	0.38
R^2Y cumulative	0.20	0.47	0.52
R^2X cumulative	0.45	0.57	0.67
Gravel	0.72	2.05	1.97
% P	1.29	1.17	1.27
Moisture	1.08	0.94	0.91
Richness	1.30	0.88	0.90
N (%)	0.98	0.81	0.78
Diversity	1.23	0.80	0.78
pH	0.76	0.71	0.76
EC	0.87	0.60	0.72
Bare Patch	0.93	0.69	0.69
Evenness	0.51	0.34	0.32

DISCUSSION

Existing studies at the arid and semiarid places in Anatolia (Yakupoglu *et al.*, 2017), Argentina (La Manna *et al.*, 2016), Australia (Thomas *et al.*, 2018), China (Fu *et al.*, 2011 and Ouallali *et al.*, 2016), Morocco (Ouallali *et al.*, 2016), Iran (Vaezi *et al.*, 2017; Jeloudar *et al.*, 2018 and Nabiollahi *et al.*, 2018), Spain (Prosdocimi *et al.*, 2016) and United states (Nzeyimana *et al.*, 2017) have shown that soil erodibility is influenced by global climate change (Sanchis *et al.*, 2008) and land-use change (Adhikary *et al.*, 2014). From Indian arid and semi arid regions the soil erosion processes have been reviewed by Moharana *et al.* (2016) however, a general pattern to link the EF with landform is still need to explore.

Present study suggested normal distribution of EF within landform and among landforms. Thus, with our analysis we can say that within Indian hot arid region, the EF is not primarily governed by landform factor.

Soil erodibility is an estimate of the ability of soils to oppose disintegration, in the light of the physical attributes of each soil. Texture is the principal characteristic influencing erodibility however, structure, organic matter and permeability also contribute. Generally, soils with faster infiltration rates, higher levels of organic matter and improved soil structure have a greater resistance to erosion. Sand, sandy loam and loam-textured soils tend to be less erodible than silt, very fine sand and certain clay-textured soils. Vegetation effectively prevents soil erosion. However, the relationship between plant diversity and soil erosion remains ambiguous under various environmental conditions. Boix-Fayos *et al.* (2007) suggested that different vegetation patterns may combine with different soil erosion processes, even with similar vegetation coverage. Land-use type and its intensity also affecting the soil erodibility and in undisturbed forests, erosion losses are 70–2000 times lower than those from arable land and 20–100 times lower than losses from fertilized pastures (Berendse *et al.*, (2013) and Zhang *et al.*, 2018). Contrary to previous study by Santra *et al*. (2014) we recorded slight lower EF range (0.22-0.43) at all landform types.

At the landform level we found that species diversity and richness negatively related with soil erodibility at OAP and YAP. However, soil moisture and soil nitrogen were negatively and positively related with EF at OAP and YAP, respectively. Interestingly we found that bare patch size was significantly and positively linked with erodibility at OAP only. While soil moisture negatively related with SOM both at OAP and YAP. Gravel content was found uniformly and negatively related with clay and sand at all types of studied landform. Based on our analysis although we found that EF of different lands were non-significant to their landform type, however, species diversity, richness, soil moisture, nitrogen and bare patch size had have landform specific influence on EF.

After eliminating the non-significant predictor in combined data-set, our PLS bi-plot reveled that studied lands were heterogeneous in nature and they were showed their proximity or dissimilarity more with reference to species richness and diversity. For example, land 5 and 7 at OAP and YAP respectively, were identical in respect of gravel, richness, and diversity and in soil texture. However, lands in the left side of the bi-plot were more diversify (1.89-2.38) (richness 9-14) and less eroded (0.22-0.35) compared to lands (diversity 0.56-1.05 with richness 3-5, EF 0.38-0.43) located at right side.

Zhenhong (2004) studied the relationships between plant species diversity and soil erosion at semi-humid evergreen broad leaved forest and suggested that soil erosion magnitude is depends on the improvement of canopy interception. The inhibiting effect of species diversity on EF can be explained with fact that due to various plant species with different resource requirements occupying different niches, different plant species tend to distribute closely, while the same plant species with similar niches tend to distribute far away from one another because of competition (Hou *et al.*, 2016).

Our approach and results are in agreement of the study of Shi *et al.* (2013) in which partial least squares regression was utilized for linking land cover patterns to soil erosion and sediment yield. They confirmed that at landscape level, Shannon's diversity index, patch size were the primary landscape metrics controlling watershed soil erosion and sediment yield. According to them The PLSR approach provides a simple means to determine the relationships between land-cover patterns and watershed soil erosion and sediment yield, providing quantitative information that enables decision makers to make better choices regarding landscape planning.

CONCLUSION

Attempt was made to link the EF of different arid lands with their landform and found the non dependency between each other. Community composition and some soil predictor are worked at specific landform level. Model equation was developed with combined data set after eliminating the non-significant predictor. However, the cumulative impacts of landform type and land uses at the studied region need further exploration.

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