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Soil Quality Index (SQI) as Influenced by Paddy Land Use among Different Districts of Hilly Zone of Karnataka

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Abstract The hilly zone of Karnataka is characterized by heavy rainfall, loss of nutrients through leaching, top soil erosion, high soil acidity, which leads to acute soil degradation. With the intensification of agricultural practices to get enhanced returns, there is a new emphasis on using the concept of soil quality. Quantitative assessment of soil quality is done to determine the sustainability of land uses in terms of environmental quality and plant productivity. Thus, a study was conducted to address the selection of most appropriate soil quality indicator and to quantify the soil quality index (SQI) under paddy land use system among Shivamogga, Chikkamagaluru and Kodagu districts which majorly represents the hilly zone of Karnataka. About 160 surface samples at 0-15 cm depth were collected from different locations among 3 districts and analyzed for 24 physical, chemical and biological soil attributes. Principal component analysis (PCA) approach was employed to get the minimum data set on the measured attributes. The data obtained which was subjected to PCA provided 8 principal components (PC) with eigen values >1 and explaining at least 5% of variance in the data set. The 8 PCs together explained 84.36% of total variance. Based on the rotated factor loadings of soil attributes, the selected minimum data set were sand from PC-1, exchangeable Mg (Mg) from PC-2, soil organic carbon (SOC) from PC-3, available nitrogen (N) from PC-4, clay from PC-5, zinc (Zn) from PC-6, earthworm population density (EWPD) from PC-7 and boron (B) from PC-8. Indicators were transformed into scores (linear scoring method) to calculate the SQI. It ranged from the least of 0.39 in Shivamogga, 0.40 in Chikkamagaluru and the highest of 0.47 in Kodagu districts within paddy land use system of hilly zone of Karnataka. The overall contribution (in percent) in the determination of SQI was in the order of sand (41.22), Mg (15.62), SOC (13.31), N (7.33), clay (7.09), zinc (6.16), EWPD (5.43) and B (3.82).

Keywords Soil quality, Hilly zone, Paddy land use, Principal component, Minimum data set.

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Introduction

In appropriate land use and soil management practices has led to severe degradation of agricultural lands in recent times. Soil degradation is a major issue which is posing tremendous threat to agriculture sustainability and environment quality (Mandal et al. 2011). For this reason, recent interest in evaluating the quality of soil resources has been adopted by many researchers. Soil quality is defined as the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation (Karlen et al. 1998). Thus, assessing the soil quality index of a paticular land use and to identify the different soil quality indicators has become an important issue.

The hilly zone of Karnataka is characterized by heavy rainfall, acidic soils, highslope lands, loss of nutrients through leaching, regarding severe top soil erosion (Nirmalaya and Sahu 1993). Majority of areas of Shivamogga, Chikkamagaluru and Kodagu districts falls under hilly zone. Since only a few types of cropping systems are restricted in this region, paddy is the major land use of this region. Paddy area accounts for 1.04 lakh hectares and 3.94 lakh tonsproduction in Shivamogga, 0.25 lakh hectares with a production of 1.06 lakh tons in Chikkamagaluru, and 0.28 lakh hectares and production of 1.24 lakh tons in Kodagu district (Anonymous 2017). It is evident from the above data that the average productivity of these areas are very less, which lags behind the average productivity of other regions. Though farmers adopt some acidity amelioration practices such as liming and use of external nutrient inputs to improve the fertility, still there is decline in the crop productivity. Thus, it is necessary to identify the soil quality indicators and to integrate them to assess the soil quality index. Hence, a study was conducted to assess the soil quality index (SQI) through minimum data set under paddy land use system of Shivamogga, Chikkamagaluru and Kodagu districts which represents hilly zone of Karnataka.

Materials and Methods

The study area comprises of Thirthahalli, Hosanagara and Sagaratalukas of Shivamogga district, Sringeri, Koppa, N.R.Pura and Mudigeretalukas of Chikkamagaluru district ; Virajpete, Madikeri and Somavarpetetalukas of Kodagu district. About 160 surface samples (0-15 cm depth) from 32 different locations from paddy fallow fields of the area were selected for the study. The soil samples collected were analyzed for 24 different physical, chemical and biological properties by following standard procedures. Mechanical analysis to determine the percent sand, silt and clay content was done by following international pipette method (Piper 1966). The bulk density (BD), maximum water holding capacity (MWHC) and percent porosity were estimated by following Keen's cup method (Bernard and Raczkowshi 1921).

The soil pH was measured by using pH meter, electrical conductivity (EC) by conductivity bridge. The soil organic carbon (SOC) was determined by Walkley and Black wet oxidation method. The available nitrogen (N) was estimated by alkaline permanganate method, Bray's available phosphorus (P_2O_5) by Spectrophotometric method, the available potassium (K_2O) by flame photometry, exchangeable calcium (Ca) and exchangeable magnesium (Mg) by versanate titration method and available sulfur (S) by turbidometric method (Jackson 1973). The DTPA extractable iron (Fe) , Manganese (Mn), Copper (Cu) and Zinc (Zn) were estimated using atomic adsorption Spectrophotometric method as outlined by Lindsay and Norwell (1978). The hot water soluble boron was estimated by Azomethane-H method.

Earthworms were sampled by digging soil to a calculated area and the population density (EWPD) was determined by dividing the total no. of earthworms collected in the sampling area by the sampling area (Anderson and Ingram 1993). The soil microbial biomass carbon (SMBC) was estimated by chloroform fumigation method (Jenkinson and Powlson 1987). The soil dehydrogenase enzyme activity (DHEA) was estimated by the reduction of TTC (triphenyltetrazolium chloride) to TPF (triphenylformazan) (Page et al. 1982).

Statistical analysis

The data were subjected for normality of distribution

Table 1. Physical, chemical and biological properties as influenced by paddy land use.

Sl. No.	Districts / Soil attribute	Shivamogga Mean	Shivamogga SD	Chikkamagaluru Mean	Chikkamagaluru SD	Kodagu Mean	Kodagu SD
1	pH (1 : 2.5)	4.70	± 0.20	4.79	± 0.18	5.08	± 0.35
2	EC (DS m^{-1})	0.07	± 0.02	0.07	± 0.01	0.07	± 0.01
3	SOC (g kg^{-1})	9.40	± 2.10	11.91	± 2.70	13.44	± 3.10
4	CEC (cmol (p^+) kg^{-1})	10.96	± 0.90	10.18	± 0.61	10.60	± 0.71
5	Avl N (kg ha^{-1})	233.13	± 40.28	261.62	± 44.20	228.95	± 36.93
6	Avl P_2O_5 (kg ha^{-1})	22.24	± 2.31	24.02	± 5.16	25.74	± 5.37
7	Avl K_2O (kg ha^{-1})	256.44	± 31.80	235.07	± 42.63	214.59	± 31.45
8	Ex Ca (c mol (p^+) kg^{-1})	2.94	± 0.52	2.80	± 0.31	3.47	± 0.48
9	Ex Mg (c mol (p^+) kg^{-1})	1.43	± 0.25	1.20	± 0.37	1.58	± 0.61
10	Avl S (mg kg^{-1})	15.66	± 3.51	13.36	± 1.62	13.65	± 1.09
11	DTPA Fe (mg kg^{-1})	173.03	± 23.08	164.14	± 25.68	227.66	± 27.49
12	DTPA Mn (mg kg^{-1})	11.41	± 5.10	15.13	± 6.17	22.84	± 11.49
13	DTPA Cu (mg kg^{-1})	3.82	± 1.12	6.41	± 2.12	5.81	± 2.37
14	DTPA Zn (mg kg^{-1})	0.77	± 0.17	1.10	± 0.23	2.03	± 0.38
15	Avl B (mg kg^{-1})	0.37	± 0.06	0.37	± 0.06	0.39	± 0.06
16	Sand (%)	68.07	± 3.11	68.39	± 0.95	58.12	± 3.46
17	Silt (%)	7.99	± 2.30	6.96	± 1.80	16.35	± 3.02
18	Clay (%)	23.79	± 1.52	24.64	± 1.55	25.53	± 1.09
19	Bulk Density (Mg m^{-3})	1.44	± 0.01	1.44	± 0.01	1.41	± 0.02
20	MWHC (%)	29.83	± 0.53	30.05	± 0.38	30.79	± 0.62
21	Porosity (%)	43.05	± 0.60	43.39	± 0.26	43.25	± 0.39
22	EWPD (individuals m^{-2})	54.15	± 13.92	60.80	± 14.70	55.11	± 8.43
23	SMBC (ug g^{-1} soil)	273.65	± 43.14	316.93	± 43.73	319.76	± 61.88
24	DHEA (ug TPFg^{-1} soil day^{-1})	7.10	± 1.23	7.14	± 1.01	7.09	± 1.11

and ANOVA was performed using SPSS (version 16) to assess the effect of different soil attributes among different districts. Strength of different soil parameters were determined by Pearson's correlation coefficient. For determination of SQI, 3 steps were followed as developed by Andrews et al. (2002) as follows : (1) Selection of most critical soil quality indicators, i.e. minimum data set (MDS) of indicators that best represents the soil function, (2) scoring of MDS indicators into scores based on their performance of soil functions,, (3) integrating of indicator scores into a comparative index of soil quality. For selection of MDS, principal component analysis (PCA) was performed using SPSS (version 16) (Andrews et al. 2002). Principal components (PCs) are defined as linear combinations of variables that account for maximum variance within the entire dataset. It was assumed that PCS with eigen values >1 (Brejda et al. 2000) and those that explained at last 5% of the variation in the data (Sharma et al. 2005) were selected and subjected to varimax rotation to maximize correlation between PCs and the measured attributes (Shukla et al. 2006). Within each PC, the attribute with highest factor loading (positive or negative) or the attribute with highest correlation sum, were selected for further scoring.

Every observation of selected indicators was transformed into scores of 0 to 1 using linear scoring method. The equations proposed by Karlen and Stott (2001) were used to convert the soil data into scores as follows : y =(x-s) / (1.1*t-s) for more is better, y = 1-{(x-s) / (1.1*t-s)} for less is better, where y is the score of the soil data, x is value of the soil property, s is the lowest value and t is the highest value.

The third step was to calculate the soil quality index (SQI). After transforming the observed values into scores, the indicators were weighted using PCA results. The percentage of variation in the total data set was divided by total percentage of variation explained by all the selected PC's gives the weighted factor (W) for attributes selected under a given PC. The SQI was calculated using the formula $SQI = \sum_{i=1}^{n} W_i S_i$, where W is the weighting factor derived from PCA, S is the indicator score. Higher scores of SQI indicates better soil quality and vice versa.

Table 2. Correlation among soil attributes in different districts under paddy land use.

	pH	EC	SOC	CEC	N	P_2O_5	K_2O	Ca	Mg	S	Fe	Mn
EC	**0.501****											
SOC	-0.199	-0.271										
CEC	0.178	0.184	**0.357***									
Avl N	0.184	**.382***	-0.207	0.032								
Avl P_2O_5	0.243	0.037	-0.138	0.018	0.332							
Avl K_2O	-0.109	**.352***	-0.066	0.222	0.265	-0.141						
Exch Ca	**0.716****	**.605****	-0.155	0.039	0.041	0.168	-0.003					
Exch Mg	**0.646****	**.624****	**-.366***	0.106	0.111	-0.039	0.268	**.740****				
Avl S	-0.218	0.249	0.096	0.074	-0.327	-0.206	**.501****	0.138	0.234			
Exch Fe	**0.529****	0.139	0.138	-0.004	-0.133	**.359***	-0.186	**.577****	**.395***	0.083		
Exch. Mn	**0.624****	0.21	0.073	-0.26	-0.078	-0.063	-0.131	**.568****	**.599****	0.053	**.530****	
Exch Cu	0.127	0.027	.596**	**.436***	-0.058	-0.113	0.016	0.065	0.019	0.021	0.208	**.425***
Exch. Zn	**0.366***	-0.235	0.279	-0.125	-0.224	0.33	**-.572****	**.430***	0.065	-0.238	**.619****	0.348
Avl B	0.296	0.273	0.215	-0.17	0.105	-0.072	0.008	0.183	0.15	-0.142	0.221	0.173
Sand	**-.372***	0.115	-0.115	-0.146	0.259	-0.274	**.494****	**-.470****	-0.139	0.058	-.644**	-0.226
Silt	**.359***	-0.072	-0.073	0.256	-0.28	0.333	**-.434***	**.424***	0.211	0.11	.628**	0.325
Clay	0.162	-0.091	**.406***	-0.184	-0.055	-0.007	-0.162	0.212	-0.054	-0.297	0.264	-0.025
BD	-0.246	0.119	-0.079	-0.075	0.255	**-.374***	**.509****	**-.402***	0.08	0.237	**-.455****	-0.022
MWHC	0.343	0.118	0.195	0.03	-0.029	0.273	**-.359***	**.509****	0.023	-0.226	**.455****	0.117
Porosity	0.142	0.09	-0.005	-0.029	**.359***	0.26	-0.258	0.136	-0.18	**-.443***	-0.033	-0.134
EWPD	-0.027	-0.201	0.245	-0.009	0.011	-0.115	0.346	-0.153	-0.044	0.087	0.069	0.203
SMBC	0.038	-0.1	**0.478***	0.171	-0.096	0.251	0.236	0.013	-0.115	0.294	0.113	0.034
DHEA	0.097	0	-0.009	0.086	0	0.116	0.162	-0.027	0.166	0.239	-0.059	0.193

Table 2. Continued.

	Cu	Zn	B	Sand	Silt	Clay	BD	MWHC	Porosity	EWPD	SMBC
EC											
SOC											
CEC											
Avl N											
Avl P_2O_5											
Avl K_2O											
Exch Ca											
Exch Mg											
Avl S											
Exch Fe											
Exch Mn											
Exch Cu											
Exch Zn	0.19										
Avl B	0.154	-0.035									
Sand	0.062	**-.752****	-0.045								
Silt	-0.223	**.579****	0.076	**-.837****							
Clay	0.312	**.517****	0.043	**-.453****	-0.069						
BD	0.021	**-.747****	0.137	**.711****	**-.462****	**-.526****					
MWHC	0.126	**.648****	0.001	**-.619****	0.267	**.650****	**-.878****				
Porosity	-0.021	0.123	-0.042	-0.069	-0.162	0.284	**-.490****	**.610****			
EWPD	0.232	0.071	-0.142	0.058	-0.109	0.131	0.148	-0.161	-0.243		
SMBC	0.003	0.023	-0.135	-0.094	0.196	-0.088	-0.002	-0.069	-0.226	**.391***	
DHEA	0.182	-0.133	-0.088	0.01	0.129	-0.203	0.3	-0.313	-0.248	-0.054	0.213

Results and Discussion

The data on the mean values of different soil attributes across 3 different districts were presented Table 1. Soil attributes showed significant differences across 3 districts within paddy land use system. The correla-

Table 3. The results of principal component analysis and communalities to evaluate the soil quality index.

Soil attributes	PC-1	PC-2	PC-3	PC-4	PC-5	PC-6	PC-7	PC-8	Commu-nalities
pH	0.343	0.757	-0.104	0.192	0.070	-0.189	0.064	-0.229	0.835
EC	-0.243	0.779	-0.092	0.298	-0.110	0.192	-0.162	0.028	0.868
SOC	0.124	-0.221	**0.888**	-0.055	-0.070	0.094	0.144	-0.018	0.916
CEC	0.083	0.056	-0.588	0.118	0.054	0.402	0.205	0.202	0.644
Avl N	-0.230	0.130	-0.084	**0.846**	0.009	-0.017	0.067	-0.202	0.902
Avl P_2O_5	0.482	-0.007	-0.138	0.599	0.373	-0.134	0.008	0.111	0.760
Avl K_2O	-0.643	0.249	0.006	0.196	0.045	0.389	0.408	0.252	0.830
Exch Ca	0.350	0.862	0.018	0.025	-0.086	0.082	-0.117	0.078	0.886
Exch Mg	-0.036	**0.898**	-0.195	-0.105	0.127	0.028	0.047	-0.048	0.904
Avl S	-0.291	0.266	0.151	-0.388	0.221	0.427	0.084	0.504	0.873
Exch Fe	0.661	0.487	0.131	-0.065	0.114	0.039	0.233	-0.087	0.758
Exch Mn	0.184	0.681	0.275	-0.243	0.171	-0.410	0.169	-0.151	0.895
Exch Cu	0.009	0.179	0.779	-0.013	0.064	-0.170	0.106	-0.057	0.771
Exch Zn	0.881	0.097	0.222	-0.097	-0.015	**0.789**	0.089	-0.029	0.881
Avl B	-0.044	0.264	0.237	0.068	-0.085	0.228	-0.093	**0.775**	0.907
Sand	**-0.951**	-0.062	-0.045	-0.047	0.066	-0.057	0.033	0.073	0.949
Silt	0.940	0.076	-0.071	0.001	0.041	0.021	-0.052	-0.097	0.894
Clay	-0.080	0.042	0.039	0.135	**0.858**	0.049	0.102	0.175	0.721
BD	-0.868	-0.022	-0.011	-0.062	0.305	-0.037	0.162	-0.253	0.934
MWHC	0.715	0.212	0.189	0.238	-0.432	0.046	-0.192	0.230	0.943
Porosity	0.251	-0.031	0.049	0.599	-0.455	-0.152	-0.377	0.150	0.784
EWPD	-0.080	-0.050	0.184	-0.031	-0.082	-0.104	**0.911**	0.084	0.902
SMBC	0.167	-0.135	0.882	-0.023	0.144	0.153	0.066	0.020	0.877
DHEA	-0.159	0.096	0.137	0.037	0.019	0.033	-0.114	0.137	0.732
Eigen values	6.11	3.73	3.16	1.96	1.50	1.37	1.22	1.07	
Variance (%)	25.45	15.54	13.16	8.16	6.25	5.71	5.07	5.02	
Cum. Variance (%)	25.45	40.99	54.15	62.31	68.56	74.27	79.34	84.36	

tion matrix of 24 soil attributes across 3 districts were presented in Table 2. Table 2 clearly indicates that the soil attributes has tendency to respond in groups among the 3 different districts. Therefore, to reduce the redundancy of the data, PCA was performed on the measured soil attributes. The results of PCA showing PCs with their eigen values and proportion of variance (in percent) explained along with the rotated factor loadings and communalities are presented in Table 3. The PCA provided 8 PCS with eigen value >1 and explaining at least 5% of variance in the data set. The 8 PCS together explained 84.36% of total variance. Under PC-1, sand and silt were the 2 attributes with highest factor loadings. Since these 2 were highly correlated, only sand with the highest factor loading of -0.951 was retained in the PC-1. Thus, sand had a negative impact on soil quality. It has accounted for 25.45% of variation with an eigen value of 6.11. In PC-2, magnesium, calcium, pH and electrical conductivity were the for soil properties with highest factor loadings. In this PC-2, Mg with a factor loading of 0.898 with an eigen value of 3.73 which accounted for 15.54% variation was selected. Since these soils were acidic, the magnesium plays an important role in maintaining soil quality. In PC-3, SOC and SMBC were the soil attributes with highest factor loadings. Since, these were highly correlated, only SOC was selected. It accounted for 13.16% of the variance with an eigen value of 3.16. The importance of SOC as the strongest indicator of soil quality, as observed in this study, is frequently reported by Brejda et al. (2000), Liu et al. (2006), Shukla et al. (2006). Available N was selected from PC-4 with a factor loading of 0.846. It had accounted for 8.16% variation with an eigen value of 1.96. Clay was the selected attribute from PC-5 (0.858 factor loading) which accounted for 6.25% variation with 1.50 eigen value. In many studies , soil texture (proportion of sand, silt and clay) reported as a component of MDS indicators (Brejda et al. 2000, Cho et al. 2004). Similarly, zinc with factor loadings of 0.789 was selected from PC-6. Zn with an eigen value of 1.37 accounted for 5.71% of total

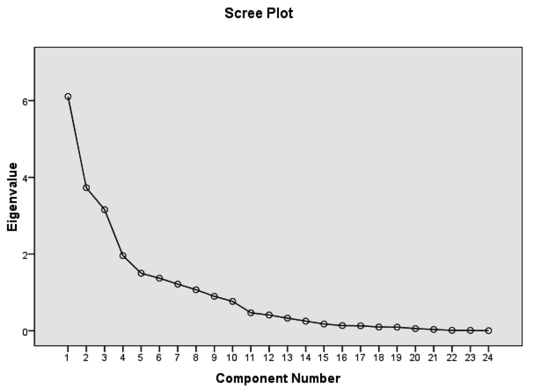

Fig. 1. Screw plot showing the relationship between eigen values and the principal components.

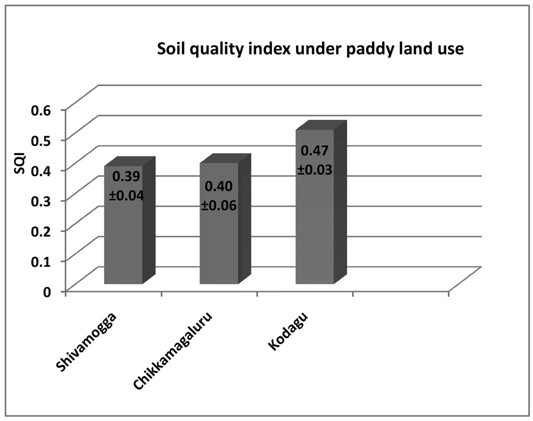

Fig. 2. Soil quality index of different districts under paddy land use.

variance. EWPD was the selected soil attribute from PC-7 with a highest factor loading of 0.911. PC-7 accounted for 5.07% of variance with an eigen value of 1.22. From PC-8, boron was the major attribute (0.775 factor loading) contributing 5.02% of total variance with an eigen value of 1.07. Since zinc and boron are the 2 important micro nutrients in mineral nutrition of plants, thus have a major role in ascertaining the soil fertility of a given area. Altogether, the 8 PCs accounted for 84.36 cumulative percent of total variance. The relationship between eigen value and principal component was depicted through screw plot (Fig. 1).

From the above PCs more is better approach was followed for all soil attributes except for sand where less is better approach was followed to compute the scores using the formula which was explained earlier. The individual scores from each PCs from all observations were multiplied by the weighting factor derived from PCA to obtain the soil quality index under paddy land use among 3 different districts. The weighting factor for the selected MDS varied from 0.304 for PC-1, 0.185 for PC-2, 0.157 for PC-3, 0.097 for PC-4, 0.075 for PC-5, 0.068 for PC-6, 0.060 for PC-7 and 0.053 for PC-8. The SQI assessed by linear scoring method under paddy land use ranged from 0.39 in Shivamogga 0.40 in Chikkamagalur and 0.47 in Kodagu district (Fig.2).

The SQI of Shivamogga, Chikkamagaluru and Kodagu districts fell under low category (Low=SQI<0.50) as per classification given by Xu et al. (2006). The order of contribution of the selected indicators to SQI was in the order of sand (41.22%), Mg (15.62%), SOC (13.31%), N (7.33%), clay (7.09%), Zn (6.16%), EWPD (5.43%) and B (3.82%). The results of SQI clearly indicated that the values for paddy of Shivamogga and Chikkamagaluru were onpar with each other and significantly differed with that of Kodagu district. The soil textural components -sand and clay played a major role in determining the SQI. Similar interpretations had also been done by Cho et al. (2004), Singh et al. (2013), Tesfahunegn (2014). SOC, N, Mg, Zn and B are the chemical attributes which greatly influenced the SQI. Similar results were reported by Brejda et al. (2002). EWPD was the biological attribute which contributed for SQI. The significant difference in SQI of Kodagu with that of other 2 districts may be attributed to the significant of difference in the soil contents and decreased content of sand.

Conclusion

From the present study, it can be concluded that 8 different soil attributes (indicators), viz : sand and clay from physiol attributes; SOC, N, Mg, Zn and B from chemical attributes ; and EWPD from biological attributes were identified, which reliably explain the soil quality of the study area. The SQI of all the 3 districts : Shivamogga, Chikkamagaluru and Kodagu fell under low category and SQI of Kodagu differed significantly with others. Since, there is a limited scope for improving the quality of the texture, the SQI can undoubbted be improved considerably by managing the other identified attributes and introducing more appropriate management techniques. To address the declining or low category of the SQI, the management practices should be examined and more of soil and nutrient conservation practices should be implemented in the study area which represents major parts of hilly zone of Karnataka.

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