Distribution of Soil Iron Oxides along Catena at Two Different Locations, in Erbil Province, Northern Iraq

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Abstract. Two locations selected in Erbil province, Northern Iraq. Three pedons were dug in each location on catena and twenty-three soil samples were collected for determine physical and chemical property. Increasing iron oxide causes coating of clay particles and decreasing the specific surface area in turn decreasing the ability of soils for adsorbing cations on it surfaces that causes decrease of cations concentration and cation exchange capacity. Conversely, high percentage of iron oxides that is act as cementing agent of soil particles and changing their sizes expectedly, in this way increase sand particles more than silt and clay particles. Total free iron oxides irregularly distributed and vibrated between increasing and decreasing. Generally, total iron oxides percent was relatively increased towards down of catena and highly related with parent material, topography, climate and vegetation cover additionally, related with the following soil forming processes, leaching, weathering, erosion, eluviations and illuviation. Increase iron oxides in study soils indicated to, increase soil development. Results of active ratio indicated to, soil development was increased towards down slope of catena. The objectives of this paper are study the soil characteristics and development of the pedons on catena and study the pathway of iron oxides distribution in pedons on catena.

Keywords: Iron oxides, Catena, Soil development, Active ratio, Clay

1. Introduction

Catena is the sequence of soils that developed from similar parent material under similar climatic conditions along a slope, and soil variability in a catena mostly depends on relief and relief-related environmental features such as relative height, slope angle, and water circulation, which influence soil-forming processes [1]. The red colors of the soils is due to hematite has greater pigment effect than other iron oxides and the pigment effect of iron oxides is particularly high when it occurs in a finely dispersed form [2]. Weak weathering or pedogenetic processes causes weakly developed soil horizon, with traces of gleying, is stratified, disturbed by cryoturbation, and contains up to 18% carbonates and about 1.8% iron oxides [3]. The clay illuviation process shown as Bt horizon mainly in the summit positions. The higher stability and consequently higher infiltration in this position have provided favorable conditions for the downward leaching of clay [4]. Total iron content (Fet) was greater in B horizon than in A and C horizons. Iron oxides contents were far greater in the B horizon than in the other two soil horizons. Iron oxides content increased with soil profile depth [5]. In line with this, Parisa Alamdari et. al., [6] indicated the concentration of iron oxides and their vertical distribution of some differences between soils northwest Iran that might be related to precipitation, moisture content, degree of weathering, seasonal flocculation of water table, Pedogenic accumulation and organic matter.
The vertical distribution of iron oxides indicates an increasing trend towards the lower B horizons and the largest amount of iron oxides can be related to argillic and cambic horizons. The accumulation of iron oxides in some of subsurface horizons can be attributed to migration of iron oxide-coated clay from upper to lower horizons. The determination of association of iron oxides with translocation of clay fraction was calculated by iron oxides/clay ratio, this ratio decreased from soil surface to lower part and the maximum iron oxides occurred at B horizons, following the same pattern as clay. The co-migration of clay and iron oxides is confirmed by the significant correlation of iron oxides and clay. Most of iron oxides content is a product of in situ Pedogenic processes. Sometimes iron oxides/clay ratio remains approximately constant, that indicates the weak horizonation of soils, due to low precipitation that limits the intensity of weathering of the parent material. The active ratio (iron oxides/clay) values have been used to estimate the degree of soil development; the ratio was lower in mollisols and inceptisols than in aridisols. In mollisols there is co-migration of free iron oxides with clay which also appears in the profile distribution of iron oxides/clay ratio [6]. Slope position has significant effect on the majority of soil properties; there were a number of soil properties which have also been found to be strongly correlated with the steepness of slope. Significant differences among slope positions were observed for most soil properties there were a number of soil properties which have also been found to be strongly correlated with the steepness of slope and on different slope positions were significantly affected by the degree of soil development and the leaching processes [7]. The objectives of this paper are study the soil characteristics and development of the pedons on catena, trend appraisal, pathway of iron oxides distribution in pedons on catena and explain the relationships between iron oxides and other soil properties on catena.
2. Methods and Materials

2.1. Description of Study Area and Soil Sampling

Two locations selected in Erbil province, Northern Iraq the first situated at Ashty area near Koyia city, second situated at Shaqlawa area (Table, 1) and (Fig. 1) with taking in consideration, the selected areas, represent Catena and contain considerable amount of iron oxides. Three pedons were dug in each location on catena at summit; back slope and Foot slope with specify soil horizons as mentioned by Schoeneberger et al., (2002) [8]. Twenty three soil samples collected concurrently from soil horizons in study pedons, then air-dried, crushed and passed through (2) mm sieve and storage in plastic bags in order to conducting laboratory analysis. Topography is characterized by Toposequence, show great variations and hilly and rolling physiographic units. The climate is Mediterranean-continental consisting of hot, dry in summer and cold, rainy in winter with average annual rainfall (464.35) and (791.25) mm in both study locations respectively. The formation of Ashty location is of Middle Miocene age. Shaqlawa formation represents a limestone unit, which is yellowish white to light brown in color, well-bedded and highly fractured. Avanah Formation is found as a tongue with in Gercus Formation [9].

| Study locations | Pedons No. | North latitude   | East latitude   | Elevation (m) | Slope (%) |
|-----------------|------------|------------------|-----------------|---------------|-----------|
| Ashty           | 1          | 36°51'39.6''     | 0°42'51''557'' | 397           | 5         |
|                 | 2          | 35°54'24.2''     | 0°44'46''57.5''| 482           | 10        |
|                 | 3          | 35°54'54.9''     | 0°44'46''54.9''| 489           | 2         |
| Shaqlawa        | 4          | 36°25'39.9''     | 0°44'17''38.2''| 951           | 5         |
|                 | 5          | 36°25'40.6''     | 0°44'17''37.1''| 978           | 13        |
|                 | 6          | 36°25'40.5''     | 0°44'17''37.2''| 971           | 2         |

Table 1. Locations of Studied Pedons

Figure 1. Map of Erbil Area Showing Study Locations
2.2 Laboratory Analyses

Particle size distribution was determined by hydrometer method [10]. Bulk density was determined by paraffin coated clod method as described by Black (1965) [11]. Soil pH and EC measured in (1:1) soil water suspension after an hour of intermittent shaking and overnight stand by using pH-meter and EC-meter according to Rowell (1996) [12]. Soluble sodium and potassium were determined by flame photometer model corning 400 as described by Hesse (1972) [13]. Soluble calcium and magnesium were determined by titration method with using (0.01N) EDTA, as described by Rowell (1996) [12]. Total calcium carbonate was determined by dissolution HCl using the method by FAO (1974) [14]. Soil organic matter was determined by wet oxidation [15]. Cation exchange capacity was determined with using flame photometer [16]. Total free iron oxides measured by Na-DCB (Sodium Dithionite-Citrate-Bicarbonate) method with using Atomic absorption spectrophotometer [17].

3 Results and Discussions

3.1 Effect of Total Free Iron Oxides on Soil Properties

Iron oxides consider an important constituent of the soil and responsible of many physical, chemical and morphological properties. Evidently the results indicated to decrease the concentration of cations and CEC in most study soils particularly at Shaqlawa location as a result of increasing iron oxides percentage.
(Table 3) that causes coating of clay particles and decreasing the specific surface area of these particles in turn decreasing the ability of study soils for adsorbing cations on it surfaces in addition to the effect of carbonate that causes decrease of cations concentration and cation exchange capacity. Conversely, iron oxides affects the soil pH that is slightly alkaline (Table 3) in spite of interpolation of carbonate but iron oxides consider as amphoteric substance and its behavior depending on the charge, that led to increasing positive charges in line with this alkalinity of study soils was decreased. The effect of iron oxides on electrical conductivity (EC) was unclear, none the less, iron oxides may be affects the electrical conductivity indirectly through its affecting on decrease of ions concentration which are play a role in electrical conductivity. Iron oxides can bonded with organic matter and consisting complex compound, that reduce the ability of organic matter as colloid in adsorbed cations on it surfaces therefore this is consider as another factor for decrease cation exchange capacity values of study soils.

Regarding the relationship of iron oxides with total carbonate, it may be reinforce the role of carbonate or retard it, hence can conclude sometimes there is a directly relationship between iron oxides and total carbonate for example both of them act as cementing agents and decrease specific surface area of soil particles and increase the particles size in turn both of them together affecting properties of study soils in contradiction with this, iron oxides reduce the effect of carbonate in an increasing the pH values of study soils. The results indicated to increase sand percentage when compare it with silt and clay percentage (Table 2), this belongs to the high percentage of iron oxides in soils at both study locations, that is coated clay particles and act as cementing agent of soil particles and changing their sizes expectedly, in this way increase sand particles more than silt and clay particles therefore, prove the iron oxides contribution in an increment of coarse soil particles, and convert the study soil texture to coarse soil texture as a final resultant for the affecting iron oxides on the particles size distribution. There is unclear relationship of iron oxides with soil bulk density, and porosity but may be lead to increasing bulk density and decreasing porosity, this belongs to the iron oxides increasing percentage coarse soil particles and cemented those hence decreasing pore spaces, and porosity in the study.

### Table 2. Some Physical Properties of Studied Soils

| Sample Number | Horizon Depth (Cm) | Horizon | Soil Horizon | Pedon Number and Slope position | Location | Texture          | Bulk Density | Particle Density | Porosity |
|---------------|-------------------|---------|-------------|---------------------------------|----------|------------------|--------------|------------------|----------|
| 1             | 0-15              | Ak      | A1o         | P2 Back slope                   | Clay     | 1.38             | 2.70         | 56.3             |
| 2             | 15-35             | B1st    | Ashty       | P1 Summit                       | Clay     | 1.25             | 2.69         | 32.8             |
| 3             | 35-75             | B2ot    | P2          | Sandy clay loam                 | 1.30     | 2.72             | 32.8         |
| 4             | 75-120            | Cq      | B1st        | Clay                            | 1.31     | 2.71             | 31.5         |
| 5             | 0-25              | A1o     | A2oq        | Clay                            | 1.31     | 2.68             | 50.3         |
| 6             | 25-80             | A2oq    | Bkst        | Sandy clay loam                 | 1.44     | 2.70             | 38.3         |
| 7             | 80-110            | Bkst    |            | Clay                            | 1.30     | 2.70             | 30.7         |
| 8             | 110-              | Cks     |             | Clay                            | 1.33     | 2.65             | 38.6         |
3.2 Total Free Iron Oxides Distribution in Study Soils on Catena

Total free iron oxides percent in study soils was ranged between (4.69 - 19.12%) in soil horizon (B2k), pedon (4) at summit and in soil horizon (Cqs), Pedon (6) at foot slope position respectively, at Shaqlawa location (Table 3). Total free iron oxides irregularly distributed in study pedons and vibrated between increasing and decreasing in both study locations (Figure, 4 and 5), but the results indicated to relatively concentrate of iron oxides in subsurface horizons and this connected with leaching process as a result of increasing rainfall and translocation of clay that was accumulated in subsurface horizons, because of the iron particles almost have extremely the similar size of clay particles and coated it, as well as, there is a directly proportional of iron oxides with clay content (Table 2). Commonly, total free iron oxides were high content in all study pedons on catena; this may be due to clay content and existing of ferromagnesian rocks or laterate (Ironstone) as a source of iron in study soils in addition to, the effect of weathering degree. The results showed that the percent of iron oxides at Shaqlawa location was more than it at Ashty location, additionally, may be increasing the amount of iron bearing minerals at Shaqlawa more than Ashty location.

In spite of, increasing total iron oxides percent (12.02%) in subsurface horizon (B1st) in Pedon (1) at summit position of Ashty location as a result of in situ formation but the vertical distribution of iron oxides indicates to an increasing towards the lower horizons and the largest accumulation of iron oxides in subsurface horizons can be attributed to the migration of iron oxides coated clay from upper to lower horizons. Generally, total free iron oxides percent was relatively increased towards downward of catena, that means it was low percent of iron oxides in pedons (1) and (4) at summit position and increasing to direction of foot slope position in pedons (3) and (6) and this is ordinarily related with climatic conditions (precipitation and temperature) that are corresponding with wetting- drying cycle and associated with alternation among reduction- oxidation that provide the best conditions for the Pedogenic formation of iron oxides. Total iron oxides percent in Pedon (1) and (4) was translocate from upper position at summit
of catena and accumulated at lower position of foot slope in Pedon (3) and (6) as a result of erosion process, hence can be proved occurring eluviations process at summit and illuviation at foot slope of catena as soil forming process. Moreover, distribution of total iron oxides percent on catena was related with micro-climate and micro-topography as a major factors of iron oxides distribution because of the same amount of precipitation was received in the study area. In contradiction to these each position of catena was received different amount of precipitation, in turn the amount of precipitation at summit and back slope was less than it at foot slope position. According to these interpretations total free iron oxides percent increasing at foot slope position more than summit and back slope.

Finally, can be proved the total iron oxides percent in the study soils highly related with parent material (ironstone and iron bearing minerals), topography, climate and vegetation cover as a soil forming factors additionally, related with the following soil forming processes, leaching, weathering, erosion, eluviations and illuviation.

![Graphs showing vertical distribution of iron oxides in study pedons at Ashty location.](image)

**Figure 4.** Vertical Distribution of Iron Oxides in Study Pedons at Ashty Location
Figure 5. Vertical Distribution of Iron Oxides in Study Pedons at Shaqlawa Location

Table 3. Some Chemical Properties of Study Soils

| Sample | Horizon Depth (Cm) | Horizon | Soil Slope Position and Pedon Number | Location | Ca | Mg | Na | K | CEC | pH | EC | Organic Carbonate | Total Fe₂O₃ | Active ratio |
|--------|--------------------|---------|-------------------------------------|----------|----|----|----|---|-----|----|----|------------------|-------------|-------------|
Moreover, concentrate of iron oxides in subsurface horizons and this connected with process of leaching. Total free iron oxides percent increasing at foot slope position more than summit and back slope. The vertical distribution of iron oxides indicates to an increasing towards the lower horizons that can oxide forms and distribution in a transect of Dasht-e- Tabriz soils, northwest Iran.

### 3.2.1 Iron Oxides and Soil Development

Iron oxides are an index of soil development and the study soils were different in the degree of development. Generally, increase iron oxides in study soils indicated to, soil development increase and the active ratio (Fe$_2$O$_3$/Clay) was used as an indicator for estimate the degree of study soils development. The results of active ratio indicated to, soil development was increased towards down slope of catena in both study locations (Table 3). The soil development at Shaqlawa location was more than it at Ashty location according to the active ratio that was high values at Shaqlawa, comparing with Ashty location. The soil development at foot slope was more than it in back slope and summit at Ashty location this is due to, increase iron oxides, in turn increase active ratio at foot slope (0.37) more than it at back slope (0.20) and summit position (0.23) at Ashty location, in contrast at Shaqlawa location in spite of increasing soil development but it was not significantly differences between slope positions on catena and there was approximately a similar development in study soils at different slope positions on catena as a result of, similarity in active ratio (0.54, 0.47, 0.45) at all slope positions on catena in Shaqlawa location. These results compatible with the similar results that were proved by Parisa Alamdari (2010) [6] in study of iron oxide forms and distribution in a transect of Dasht-e- Tabriz soils, northwest Iran.

### 4. Conclusions

Total free iron oxides percent increasing at foot slope position more than summit and back slope, moreover concentrate of iron oxides in subsurface horizons and this connected with process of leaching and the vertical distribution of iron oxides indicates to an increasing towards the lower horizons that can

|   | 0-15 | P1 Summit | P2 Back slope | P3 Foot slope | P4 Summit | P5 Back slope | P6 Foot slope |
|---|------|------------|---------------|---------------|------------|---------------|---------------|
| 1 | Ak   | 8.40       | 2.00          | 0.43          | 0.58       | 24.69         | 7.26          | 0.30          | 1.61        | 330.60      | 6.18   | 0.23     |
| 2 | B1st | 7.20       | 1.50          | 0.47          | 0.53       | 33.64         | 8.03          | 0.25          | 1.60        | 280.00      | 12.02  | 0.20     |
| 3 | B2ot | 4.50       | 2.16          | 0.47          | 0.40       | 30.17         | 8.13          | 0.33          | 0.20        | 284.00      | 5.24   | 0.13     |
| 4 | Cq   | 7.40       | 2.33          | 0.47          | 1.02       | 18.40         | 8.17          | 0.32          | 0.50        | 230.00      | 5.38   | 0.14     |
| 5 | A1o  | 5.70       | 1.00          | 0.43          | 0.92       | 32.03         | 7.50          | 0.36          | 0.97        | 264.00      | 7.87   | 0.20     |
| 6 | A2oq | 1.40       | 3.66          | 0.05          | 0.07       | 32.19         | 7.60          | 0.38          | 0.64        | 206.00      | 7.91   | 0.39     |
| 7 | Bkst | 3.10       | 1.16          | 0.39          | 0.74       | 41.78         | 8.1           | 0.40          | 0.40        | 360.00      | 7.20   | 0.18     |
| 8 | Cks  | 11.00      | 1.50          | 0.43          | 1.02       | 26.93         | 8.12          | 0.40          | 0.04        | 360.00      | 8.97   | 0.27     |
| 9 | Akq  | 3.60       | 1.16          | 0.34          | 0.97       | 33.58         | 7.28          | 0.36          | 1.17        | 350.00      | 8.02   | 0.37     |
| 10| Bst  | 5.90       | 6.66          | 0.52          | 0.63       | 39.59         | 7.60          | 0.32          | 0.92        | 238.00      | 8.42   | 0.21     |
| 11| C1s  | 5.10       | 1.33          | 0.43          | 1.09       | 35.06         | 7.75          | 0.36          | 0.47        | 224.00      | 9.26   | 0.33     |
| 12| C2ks | 4.50       | 1.50          | 0.52          | 1.20       | 23.27         | 7.63          | 0.34          | 0.27        | 316.00      | 7.77   | 0.21     |
| 13| A1q  | 2.70       | 2.66          | 0.17          | 0.17       | 8.72          | 7.44          | 0.18          | 0.54        | 216.00      | 15.36  | 0.54     |
| 14| A2oq | 4.20       | 3.00          | 0.30          | 0.23       | 9.48          | 7.55          | 0.25          | 0.44        | 280.00      | 13.58  | 0.67     |
| 15| B1kt | 4.00       | 2.50          | 0.13          | 0.12       | 13.90         | 7.68          | 0.23          | 0.70        | 326.00      | 12.47  | 0.32     |
| 16| B2k  | 3.60       | 3.50          | 0.04          | 0.12       | 13.14         | 7.65          | 0.32          | 0.30        | 368.00      | 4.69   | 0.14     |
| 17| A1ko | 4.10       | 3.16          | 0.26          | 0.15       | 8.99          | 7.77          | 0.14          | 0.80        | 254.00      | 13.40  | 0.47     |
| 18| A2qk | 3.60       | 2.83          | 0.43          | 0.20       | 14.84         | 7.90          | 0.20          | 1.65        | 316.00      | 10.13  | 0.46     |
| 19| B1st | 12.20      | 0.50          | 0.43          | 0.51       | 15.11         | 7.80          | 0.32          | 0.05        | 304.00      | 12.79  | 0.29     |
| 20| B2t  | 6.40       | 0.83          | 0.39          | 0.74       | 12.24         | 7.74          | 0.22          | 0.73        | 272.00      | 12.31  | 0.32     |
| 21| Ao   | 6.00       | 0.66          | 0.13          | 1.07       | 11.59         | 7.14          | 0.18          | 1.07        | 160.00      | 17.36  | 0.45     |
| 22| Bst  | 2.40       | 1.83          | 0.26          | 0.15       | 8.76          | 7.53          | 0.23          | 0.17        | 116.00      | 18.75  | 0.53     |
| 23| Cks  | 2.80       | 0.83          | 0.08          | 0.61       | 8.95          | 7.66          | 0.37          | 0.16        | 148.00      | 19.12  | 0.91     |
be attributed to the migration of iron oxides coated clay from upper to lower horizons. Additionally can be concluded, the active ratio in study soils, indicated to increase, soil development towards down slope of catena.

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