Economic Evaluation of Placer Gold Along River Indus From Ghazi to Kund, Khyber Pakhtunkhwa, Pakistan: Implications for Commercial Scale Pilot Plant

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Abstract: A detailed study was conducted on Indus river in order to evaluate the economic potential. Samples were collected for geochemical studies from both stream sediments (SS) and heavy mineral concentrates (HMC) along Indus river from Ghazi, Hund, Beka, Alladher and Kund in Khyber Pakhtunkhwa province. All the samples were analyzed for gold (Au), silver (Ag) and base metals in order to get information about geochemical associations. Panning and sluice methods were applied for the collection of these samples and extraction of visible gold. Results show that HMC have high Au contents, having maximum value of 44.15 g/t and 39.15 g/t in Kund and Beka areas respectively with an average value of 15.18 g/ton and 11.37 g/ton while the SS have average amount of Au as 0.8 g/t. In both these media higher concentration of gold was found in HMC. On the basis of results from both sampling media, the placer gold deposits in Kund, Alladher and Beka are considered highly economical for the commercial exploration of placer gold. Overall, the HMC derived from silt, sand, gravels and cobbles along Indus river indicated potential for placer gold that can be utilized for extraction of gold at commercial scale.

Keywords: HMC, SS, placer gold, commercial extraction, KPK.

Introduction

The Indus river having total length of approx. 2900 km with its course from Tibetan Plateau and runs across Ladakh region, towards Gilgit and Baltistan (Kifayatullah, 2009). It flows towards south all over the length of Pakistan and enter into the Arabian sea. As the river reaches at Tarbela (Swabi), it widens up and spread in the plain areas and the speed of water slow down abruptly and deposit the sediment load and ultimately it joins with Kabul river at Attack bridge (Kifayatullah, 2009). Presence of placer gold in the alluvium of the Indus river and its tributaries is mainly due to the erosion and transportation of sediments from the rocks of north-western part of Pakistan (Tahirkheli, 1974; Austromineral, 1976; Shah and Khan, 2004).

Indus river is well known for placer gold occurrences as gold is being locally extracted from its various locations. Gold washers use primitive methods and techniques for the extraction of gold since long period in the region for their livelihood. Pakistan Mineral and Development Corporation has studied the placer deposits in upper reaches along Indus river and indicated gold-source mineralization in Chitral, Gilgit and Skardu areas (northern Pakistan) and suggest gold source mineralization in these areas. The occurrence of placer gold in the upper reaches of Chilas, Gilgit, Skardu and Chitral has been confirmed through panning, washing and drilling in northern areas of Pakistan and along Indus river (Austromineral, 1976; Austromineral, 1978; Shah and Khan, 2004). Therefore, Indus placer deposits have got much attention of geologists and prospectors for the last few decades (Shah et al., 2007). Austromineral (1976) and (1978) carried out geochemical study of fluvial sediments and confirmed the presence of placer gold through panning and drilling along these rivers in Gilgit, Skardu and Chitral areas, northern regions of Pakistan. Shah and Khan (2004), carried out geochemical analysis of fluvial sediments in Bagrot valley (Gilgit), northern Pakistan.

The stream sediments are originated from the exposed rocks due to weathering and transport by the action of streams and rivers. The stream sediment geochemical survey is of vital importance in the exploration of important gold and base metals (Ali, 2011). The geochemical survey can also be helpful in exploring the bed rock geology of the exposed rock units (Ranasinghe et al., 2009). Both the stream sediments and heavy mineral concentrates samples are widely used media for exploration of minerals and ores. Worldwide the heavy pan concentrates are explored for gold with about 69% of the world gold are contributed using this media (Sutherland, 1985). In recent time much attention is given to placer deposits due to low cost and development in technology. However, Pakistan is not still on the globe for heavy mineral exploration and exploitation. An approach has been adopted in the current study in order to explore potential zones for placers various locations (Fig. 1). Since there has been no scientific investigation carried out pertaining to economic evaluation of the Indus river. Main aim of the current research is, 1) geochemical investigation of Indus river sediments, 2) To evaluate whether the heavy mineral concentrates can be explored and exploited on commercial
Materials and methods

Five locations were identified for geochemical sampling namely Ghazi, Hund, Beka, Alladher and Kund through google images as sample collection sites along the Indus river. Gravity methods (panning and sluicing) were applied in the field in order to collect heavy mineral concentrate (HMC) samples from the same location. A total of 32 HMC and 16 SS samples were collected the above mentioned locations. Out of the total 32 HMC samples, 16 samples were obtained through panning and 16 were obtained using sluice with each sample weigh about 20 kg. Coordinates of HMC and SS were noted through GPS for preparation of Au, Ag and base metals concentration and thematic GIS modelling.

Heavy mineral concentrates for gold, silver and base...
metals were collected at a depth of 3–4 ft. Midpoint bars and inner side of meandering were targeted for sample collection (Marsden and House, 2006) because these locations are feasible for the accumulation of placer gold (Fig. 2). About 20 kg sediment sample was collected in a bucket. Then material was passed through 7 mm sieve and ultimately panned to get about 200 grams concentrate sample. HMC samples were further processed for analysis. The samples were dried using oven and hotplate. After drying, the concentrates were passed through 1 mm sieve (Fletcher, 1997). In the next stage, iron bearing phases were separated from the concentrates by using a horse shoe magnet.

Stream sediment samples of about 10 kg each were collected in the field. The sediments were then sieved through 2 mm sieve. Then 5–7 kg of the sample was further passed through sieve no. -80 mesh (177 μm) in order to collect fine size of sediment sample. Representative samples for trace elements were taken from the sieved samples through quartering and conning technique (Freeman et al., 2012; Ranasinghe et al., 2009; Yilmaz, 2007). These – 80 mesh size samples were analysed in the geochemistry laboratory.

### Results and Discussion

Results of statistical parameters of Au, Ag and base metals (Cu, Pb, Zn, Ni, Cr, Co & Cd) in HMC samples are shown in Table 1. 2 and are graphically presented in Figure 3. Gold concentration in HMC of the study area has significant concentration, while other metals such as Ag, Pb, Zn, Ni, Cr, Co and Cd are present in very low concentration. In the HMC, maximum value for gold concentration along Indus river is 44.15 g/t, 39.15 g/t, 24.5 g/t, 17.29 g/t and 9.75 g/t at Kund, Beka, Alladher, Beka, Allader...

### Table 1 Results of Au, Ag and base metals in HMC of the study area.

| sample no. | location | Au ppm | Ag ppm | Cu ppm | Pb ppm | Zn ppm | Ni ppm | Cr ppm | Co ppm | Cd ppm |
|------------|----------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| GD-3       | Ghazi**  | 3.18   | 0.06   | 0.31   | 0.04   | 0.27   | 1.13   | 0.07   | 0.29   | 0.08   |
| HD-4       | Ghazi**  | 9.82   | 0.13   | 0.74   | 0.01   | 0.22   | 1.15   | 0.10   | 0.33   | 0.06   |
| HD-5       | Ghazi**  | 1.53   | 0.01   | 0.37   | 0.005  | 0.30   | 1.53   | 0.26   | 0.40   | 0.10   |
| HD-6       | Ghazi**  | 0.60   | 0.08   | 0.44   | 0.08   | 0.26   | 1.06   | 0.07   | 0.39   | 0.04   |
| HD-7       | Ghazi**  | 2.86   | 0.09   | 0.66   | 0.04   | 0.33   | 1.28   | 0.01   | 0.43   | 0.4    |
| HD-8       | Ghazi**  | 7.42   | 0.08   | 0.55   | 0.03   | 0.29   | 1.39   | 0.01   | 0.35   | 0.31   |
| HD-9       | Ghazi**  | 3.05   | 0.08   | 0.29   | 0.04   | 0.04   | 1.81   | 0.25   | 0.41   | 0.06   |
| HD-10      | Ghazi**  | 17.29  | 0.09   | 0.33   | 0.04   | 0.36   | 2.13   | 0.24   | 0.34   | 0.074  |

### Table 2 Statistical parameters of Au, Ag and base metals in HMC of the study area.

| Value (g/ton) | Au  | Ag  | Cu  | Pb  | Zn  | Ni  | Cr  | Co  | Cd  |
|--------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| No of samples| 32  | 32  | 32  | 32  | 32  | 32  | 32  | 32  | 32  |
| Mean         | 8.22| 0.17| 0.36| 0.07| 0.26| 1.21| 0.12| 0.35| 0.09|
| Std. Deviation| 10.72| 0.28| 0.15| 0.15| 0.08| 0.68| 0.10| 0.10| 0.09|
| Minimum      | 0.21| 0.004| 0.05| 0.001| 0.04| 0.13| 0.001| 0.18| 0.01|
| Maximum      | 44.15| 1.46| 0.74| 0.87| 0.39| 3.34| 0.33| 0.64| 0.40|

| Percentiles | 75  | 100 | 90  | 95  |
|-------------|-----|-----|-----|-----|
| 9.00        | 0.22| 0.42| 0.05| 0.29|
| 24.65       | 0.47| 0.63| 0.14| 0.36|
| 40.90       | 0.90| 0.72| 0.47| 0.39|
Ghazi and Hund areas respectively. The average value of Au in Kund (15.18g/t) and Beka (11.37g/t) are higher as compared to Allader (6.58g/t), Hund (5.96g/t) and Ghazi (5.72g/t). Overall the HMC of the study area have greater exploration impact for gold and other heavy minerals of placer origin. The concentration of Au is generally consistent with that of visible gold which indicate that the gold concentration is mainly contributed by native gold. While Ag and base metals (Cu, Pb, Zn, Cr, Co and Cd) show very low concentration (<1 g/ton) in HMC, however Ni shows slightly elevated average values of 1.21 g/t (Fig. 3).

![Graph showing average values (g/ton) of Au, Ag and base metals in HMC along Indus river.](image1)

Fig. 3 Graph showing average values (g/ton) of Au, Ag and base metals in HMC along Indus river.

Worldwide the placer heavy minerals are the sources of diamond, gold, silver, rutile, monazite and other precious metals and heavy minerals, (gold deposits of Arizona) in USA (Wilson, 1961), Ghana in west Africa (Komla and Sammy, 1995) and Witwatersrand in south Africa (Lalov and Tabolitch, 1997). The economical placer gold deposits rest on many factor such as concentration values, accessibility, environment, interest rates and price of gold in market. Dumoulin and Gray (1995) considered 150 g/t, 30 g/t and 200 g/t of Au concentration economical. According to Gupta and Singh (2003) placer gold recovered in range between 0.7-0.8 g/t can be considered economical.

![Map showing Au anomalies in HMC samples along Indus river.](image2)

Fig. 4 Map showing Au anomalies in HMC samples along Indus river.

| sample no. | location | Au-ppm | Ag ppm | Cu ppm | Pb ppm | Zn ppm | Ni ppm | Cr ppm | Co ppm | Cd ppm |
|------------|----------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| GH-3       | Ghazi    | 1.076  | 0.07   | 0.51   | 0.34   | 0.56   | 1.53   | 0.23   | 0.42   | 0.08   |
| GH-4       | Ghazi    | 0.956  | 0.13   | 0.08   | 0.04   | 0.03   | 2.07   | 0.05   | 0.02   | 0.02   |
| GH-5       | Ghazi    | 0.996  | 0.05   | 1.56   | 0.34   | 0.34   | 2.85   | 0.03   | 0.05   | 0.06   |
| GH-6       | Ghazi    | 0.936  | 0.02   | 0.67   | 0.05   | 0.02   | 2.87   | 0.87   | 0.68   | 0.37   |
| HD-7       | Hund     | 0.926  | 0.004  | 0.24   | 0.07   | 0.75   | 0.97   | 0.41   | 0.07   | 0.03   |
| HD-8       | Hund     | 0.102  | 0.06   | 1.07   | 0.04   | 0.04   | 0.14   | 0.04   | 0.05   | 0.06   |
| HD-9       | Hund     | 1.795  | 0.45   | 0.05   | 0.04   | 0.67   | 1.01   | 0.05   | 0.08   | 0.07   |
| BK-10      | Beka     | 0.914  | 0.09   | 0.60   | 0.23   | 0.36   | 0.29   | 0.58   | 0.28   |
| BK-11      | Beka     | 0.734  | 0.16   | 0.12   | 0.07   | 0.56   | 2.63   | 0.96   | 0.52   | 0.38   |
| BK-12      | Beka     | 0.201  | 0.80   | 0.95   | 0.03   | 0.46   | 1.99   | 0.03   | 0.93   | 0.58   |
| AL-13      | Allader  | 1.863  | 0.08   | 0.45   | 0.04   | 0.66   | 0.88   | 0.16   | 0.35   | 0.45   |
| AL-14      | Allader  | ND     | 0.19   | 0.58   | 0.08   | 0.60   | 0.83   | 0.26   | 0.48   | 0.17   |
| AL-15      | Allader  | ND     | 0.68   | 0.75   | 0.84   | 0.04   | 0.49   | 0.94   | 0.95   | 0.05   |
| AL-16      | Allader  | ND     | 0.08   | 0.45   | 0.94   | 0.01   | 0.97   | 0.85   | 0.85   | 0.03   |
| KD-17      | Kund     | 1.867  | 0.01   | 0.24   | 0.006  | 0.64   | 0.83   | 0.47   | 0.44   | 0.49   |
| KD-18      | Kund     | 0.413  | 0.03   | 0.63   | 0.04   | 0.59   | 0.40   | 0.62   | 0.59   | 0.068  |

Table 4 Statistical parameters of Au, Ag and base metals in SS of the study area.

| Value (g/ton) | Au | Ag | Cu | Pb | Zn | Ni | Cr | Co | Cd |
|---------------|----|----|----|----|----|----|----|----|----|
| No of samples | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 |
| Mean          | 0.58 | 0.18 | 0.55 | 0.24 | 0.37 | 1.46 | 0.42 | 0.44 | 0.17 |
| Std. Deviation | 0.65 | 0.24 | 0.40 | 0.33 | 0.29 | 0.95 | 0.37 | 0.32 | 0.18 |
| Minimum       | 0.10 | 0.01 | 0.05 | 0.01 | 0.01 | 0.14 | 0.03 | 0.02 | 0.02 |
| Maximum       | 1.87 | 0.80 | 1.56 | 0.94 | 0.75 | 2.87 | 0.96 | 0.95 | 0.58 |
| Percentiles   | 50 | 0.02 | 0.08 | 0.52 | 0.06 | 0.51 | 0.99 | 0.28 | 0.46 | 0.07 |
| 75 | 1.06 | 0.18 | 0.73 | 0.34 | 0.63 | 2.49 | 0.87 | 0.66 | 0.35 |
| 90 | 1.86 | 0.72 | 1.22 | 0.87 | 0.69 | 2.86 | 0.95 | 0.94 | 0.49 |
economic importance of these deposits and the relative ease, with which they can be exploited, makes the HMC deposits of the study area as promising exploration region and can be exploited on commercial scale using appropriate technology such as the small scale gold extraction pilot plants.

Fig. 5 Graph showing average values (g/ton) of Ag and base metals in stream sediments along Indus river.

Fig. 6 Map showing concentration of Au in stream sediment (SS) samples along Indus river.

Geochemistry of Stream Sediments

Results of the chemical analyses of SS samples along Indus river are given in Table. 3, 4 and are graphically presented in Figure. 5. The concentration of Au in SS is in the range of 0.1 - 2 g/t and the all the samples show less variation in Au concentration. The maximum concentration of Au is noticed in SS samples at Kund (1.87 g/t), Allader (1.86 g/t) and Hund (1.8 g/t). Relatively high average gold concentration is found in Kund (1.14 g/t), Ghazi (0.99 g/t) and Hund (0.94 g/t) as compared to Beka (0.62 g/t) and Allader (0.5 g/t). In contrast to HMC, SS samples show less significant concentration of Au in the surficial sediments of Indus. The results of Indus did not establish any correlation of Au with Ag and other base metals, which could not be associated with proximal source rock. However, some indication can be obtained about mafic-ultramafic source due to elevated concentration of Ni in SS as well as HMC (Fig. 5). The stream sediments survey is very useful in exploring the bed rock geology of the exposed geological terrains (Ranasinghe et al., 2009). The SS have its major contribution in the exploration of important metallic minerals like Au, Ag, Cu, Pb, Ni, Cr etc. (Cohen et al., 2005; Sheppard et al., 2009). However, unlike the stream sediments in the vicinity of source mineralization is showing different dispersal pattern in study area. Majority of the samples showing uniform chemical composition and hence high anomalies in the SS is well indicative of the potential zones of placer gold (Fig. 4, 6). Generally stream sediments have the capability to absorb certain elements, but also include precipitated materials and unaltered primary minerals. Semi-mobile to immobile elements like Cr is best studied from the stream sediments (Ramazanov and Ali, 2011).

Conclusion

Geochemical evaluation of HMC and SS in the current study provided useful information of the distribution of placer gold, silver and base metals along Indus river.

The heavy mineral concentrates were found useful as compare to stream sediments. Maximum gold is found at Kund, Beka and Alladher with 44.15 g/t, 39.15 g/t, 24.5 g/t, along Indus river. These sites are, therefore, recommended for economical extraction of placer gold.

The HMCs show good results of Au concentration, while Ag and other base metals are found in low abundances in both the sampling media. The panning technique is more useful for maximum possible recovery of placer gold in the study area.

This study helped in identifying feasible sites for placer gold and its subsequent exploration will help in promoting socio-economic conditions of the area. It will greatly enhance exploration, mining and development of appropriate processing techniques for commercial extraction of gold and associated heavy minerals.

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