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Analysing the black polished pottery of proto-historic-early historic India

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The development of ceramic technology in India can be traced back to a hoary past. Highly sophisticated potteries like black slipped ware (BSW), black-and-red ware (BRW), painted grey ware, grey ware and northern black polished ware (NBPW) were present in proto-historic and early historic times (circa 2000–300 BCE). The present communication aims to throw light on the technology of one of the important wares, viz. BSW especially from sites located in the Vindhya–Ganga region. Through analytical examination of the ware, the authors propose to fill in a lacuna in the field of ancient ceramics.

Keywords: Black slipped ware, energy-dispersive X-ray spectroscopy, firing technique, proto-historic, scanning electron microscopic study.

THE black slipped ware (BSW) is a black coloured glossy ware first reported by Lal[1] in pre-northern black polished ware (NBPW) deposit from excavations at Hastinapur. Initially it was variously referred by archaeologists as black polished ware[1] or black slipped ware or burnished black ware. Since then this pottery has been recovered in different contexts. The black-and-red ware (BRW), which generally co-exists with BSW has received greater attention of scholars while in-depth studies on BSW are few and far between, despite the fact that BSW is stated to have contributed to the make-up of the famous NBPW. The present discussion on BSW is focused primarily on its analytical study. It also tries to compare BSW with NBPW in fabric, form and finish.

BSW as its nomenclature suggests is a pottery which contains a black and smooth polished surface. BSW is carefully turned on fast wheel, treated with a smooth black slip, both on the inner and outer surface and possibly also burnished for a glossy slip. It has a medium to fine grey or blackish grey core[2]. The quality of the ware exhibits mastery in the pottery making technique. Like the other grey or black wares of its time, the most common shapes in this ware are bowls, dishes, basins and vases. Sometimes platter and miniature pots were also found at a few sites (Figure 1).

BSW has wide distribution both in time and space right from chalcolithic/pre-NBPW levels to the closing centuries of the 1st millennium BCE (second millennium BCE to 300–200 BCE). Geographically BSW commands an extensive distribution area extending from Manda

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Table 1. Results of sample analysis by X-ray fluorescence spectroscopy, Department of Chemical Engineering and Technology, BHU (Tripathi 2012:249)

Site and ware	Compounds present (w)													Surface average	Total pore value	Mean pore radius
	SiO_2	Fe_2O_3	Al_2O_3	CaO	TiO_2	MgO	MnO	BaO	ZrO_2	Sb_2O_3	SnO_2	CuO	Rb_2O			
ABR-14 BSW	43.6	30.0	10.4	12.0	2.9	0.4	0.3	0.30	0.2	0.2	0.2	–	–	4.7	0.76	105
ABR-16 GW	36.1	50.0	10.5	11.8	3.4	–	2.3	0.4	–	–	–	0.2	–	1.2	1.46	90
ABR-18 NBP	32.3	49.1	8.8	5.6	2.4	0.2	0.4	0.4	0.1	–	–	–	0.1	3.2	0.70	105

Figure 1. ***a***, Pot sherds of black slipped ware. ***b***, Pot sherds of northern black polised ware.

(Jammu-Kashmir) in the north to Puduru (Nellore district, Andhra Pradesh) in the south, Bikaner region of Rajasthan in the west to the Mahasthangarh (Bangladesh) in the east. BRW was found to occur though in limited quality, in Bikaner (Rajasthan) and at the sites of Andhra Pradesh. There is a different pattern of ceramic utilization as far as BRW and BSW are concerned. In a single geographical unit certain sites have profusion of BSW, while others exhibit dominance of BSW. Generally speaking, BSW appears to have three contexts of occurrence, viz. chalcolithic, Early Iron Age in the pre-NBPW archaeological context and thirdly along with the NBPW cultural period. However, BSW is an important ceramic tradition of the Early Iron Age[3]. Due to its fine finish in certain cases BSW (Figure 2 *a*) cannot be distinguished from NBPW. Archaeologists believe it to have given rise to the technique of producing NBPW, a deluxe ware of its age (Figure 2 *b*). Lal[1] observed that BSW represents a preliminary stage of ceramic technology which eventually culminated into the NBPW, a pottery which has been compared with silver ware by some. Sahay[4], Roy[5] and Narain[6] also reiterate that BSW is technically a forerunner of NBPW. The present work proposes to study BSW through analytical methods like energy dispersive X-ray analysis (EDAX), scanning electron microscope (SEM) study and presents the results of the same.

Rai and Roy[7] on the basis of the Mossbuaer study from Rajghat suggested that the compositions of BSW and NBPW are not similar and therefore, the two might be of independent origin.

The petrographic study done by K. Krishnan on pottery from Imlidih (Gorakhpur, Uttar Pradesh) and Senuwar (Rohtas, Bihar) as quoted by Kumar[8] shows that the NBPW and BSW pots showed more homogeneity.

More in-depth scientific work on BSW has been done in recent times by Ricciardi *et al.*[9]. The black slipped pottery of Gotihwa, Kapilbastu (Nepal) was selected for the Mossbauer spectroscopic study. This study concluded that the appearance of NBPW is quite similar to BSW, to such an extent that at times it becomes difficult to distinguish the two. More significantly, this suggested that the temperature at which the pottery was fired ranges from 900°C to 950°C.

In the area of this type of study, X-ray fluorescence analysis (XRF), X-ray diffraction analysis (XRD), energy dispersive X-ray analysis (EDS) and thin section study was done by Tripathi[10]. Microscopic study of BSW (Table 1), characterized it as opaque mineral (clay) and transparent mineral (quartz). BSW quartz ranges from 5% to 50%. The X-ray fluorescence spectroscopy study of BSW of Agiabir (Mirzapur, Uttar Pradesh) shows the presence of SiO_2 (43.6%), Fe_2O_3 (50.0%), Al_2O_3 (10.4%), CaO (12.8%), TiO_2 (2.9%), MgO (0.4%), MnO (0.3%), BaO (0.30%), ZrO_2 (0.2%) and Sb_2O_3 (0.2%).

SEM is a particularly suitable technique for studying surfaces of ceramics[11]. SEM combined with EDX is an excellent tool in many fields of science and has found many applications to problems of archaeological ceramics[12]. This study focuses on EDX/EDS and SEM on BSW and NBPW of pre-NBPW levels in Agiabir (Mirzapur, UP), Raipura (Sonbhadra, UP), Latif Shah (Chandauli, UP), Khairadih (Ballia, UP) and kabiz (slip) of black ware of Nizamabad (Azamgarh, UP) (Figure 2 and Table 2). This analytical study was conducted with the help of Central Instrument Facility Centre, IIT, Banaras Hindu University. The samples of BSW and Northern Black Slipped Ware belonging to different cultural periods were procured from various sites and analysed using EDX/EDS and SEM.

EDX analysis was done on the slip and cores of both the wares pertaining to two cultural periods, i.e. pre-NBPW and NBPW periods. Distinctive features were observed in the composition and structure of ceramic samples of BSW and NBPW.

The first sample (Figure 3) of BSW belongs to period I (Chalcolithic horizon) from the site of Agiabir. This cultural horizon at Agiabir has been dated to 4618 ± 156 BP (ref. 13) through C^{14} characterization. The microscopic analysis of the sample no. 1 denotes the evidence of

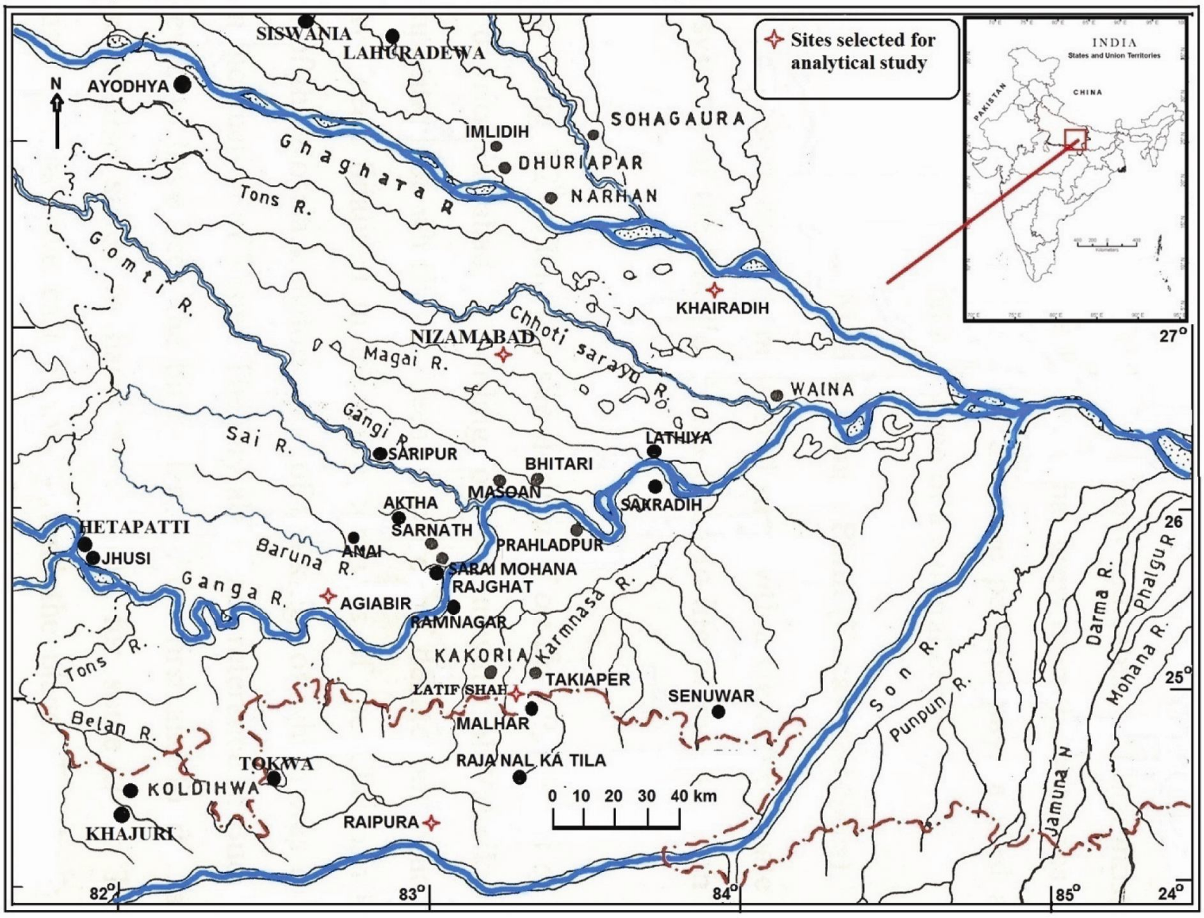

Figure 2. Archaeological map of Vindhya–Gangetic Plain (showing archaeological sites of Uttar Pradesh, India).

Table 2. Description of samples for analytical study

Sample no.	Wares	Name of site	Cultural period (date)	Remarks
1	Black slipped ware	Agiabir	Chalcolithic (*c* 1300–900 BCE)	Core
2	Black slipped ware	Agiabir	Chalcolithic (do)	Core
3	Black slipped ware	Raipura	Pre-NBPW without iron (*c* 3200–2200 BCE)	Core
4	Black slipped ware	Latif Shah	Early Iron Age (*c* 11/1000–600 BCE)	Slip
5	Black slipped ware	Latif Shah	Early Iron Age (do)	Core
6	Black slipped ware	Latif Shah	Early Iron Age (do)	Core
7	Northern black polished ware	Khairadih	NBPW (Early) (*c* 600–400 BCE)	Core
8	Black slipped ware	Khairadih	NBPW (Early) (*c* 600-400 BCE)	Core
9	Black slipped ware	Khairadih	NBPW (Late) (*c* 300–100 BCE)	Core
10	Black ware	Nizamabad	Modern times	Core

burnishing. Elemental analysis of the shred stipulates a high proportion of carbon (29.80%). Besides traces of carbon, silica, magnesium, potassium, niobium and iron were found in the sample. The percentage of oxidation was remarkably high. The percentage of iron (Fe_3O_4) was very small in this sample (1.23) (Table 3).

Sample no. 2 of BSW was also from the same site and the same cultural period. Noteworthy here is the high percentage of oxide in this sample. Comparatively speaking, unlike sample no. 1, carbon was totally absent in this particular specimen. The elemental analysis shows iron (Fe_3O_4) content of 2.54% (Table 3).

Sample no. 3 (Figure 4) is BSW of pre-metal (Chalcolithic? since no copper has been found, technically speaking it should not be labelled as Chalcolithic) period from Raipura, district Sonbhadra (Uttar Pradesh). On the basis of radiocarbon dates this cultural period has been dated to 3200–2200 BCE (ref. 14). The fabric and finish of the sample were very fine. The microscopic analysis gives an example of burnishing before firing. The level of oxide in

Table 3. Weight percentage and atomic percentage of the elements present in the sample nos 1–5

	Sample 1		Sample 2		Sample 3		Sample 4		Sample 5	
Elements	Std. wt%	Std. at%	Std. wt%	Std. at%	Std. wt%	Std. at%	Std. wt%	Std. at%	Std. wt%	Std. at%
C	19.90	29.80	–	–	51.62	63.47	–	–	–	–
O	45.86	51.55	46.67	66.26	31.19	28.79	76.68	85.93	42.18	61.73
Mg	1.46	1.08	1.27	1.19	0.64	0.39	1.25	0.92	1.14	1.09
Al	6.96	4.64	8.76	7.38	3.48	1.90	0.23	0.16	7.69	6.67
Si	14.94	9.56	24.38	19.72	7.67	4.03	2.64	1.69	20.65	17.22
K	2.91	1.34	2.28	1.32	0.77	0.29	–	–	3.37	2.02
Fe	3.80	1.23	6.25	2.54	2.37	0.63	2.20	0.70	20.09	8.42
Nb	4.17	0.81	–	–	1.64	0.26	–	–	–	–
Ca	–	–	0.88	0.50	0.63	0.23	1.19	0.53	4.79	2.80
Ti	–	–	–	–	–	–	1.02	0.38	0.09	0.04
Mn	–	–	–	–	–	–	0.54	0.18	–	–
Na	–	–	–	–	–	–	8.40	6.55	–	–
Cl	–	–	–	–	–	–	5.85	2.96	–	–

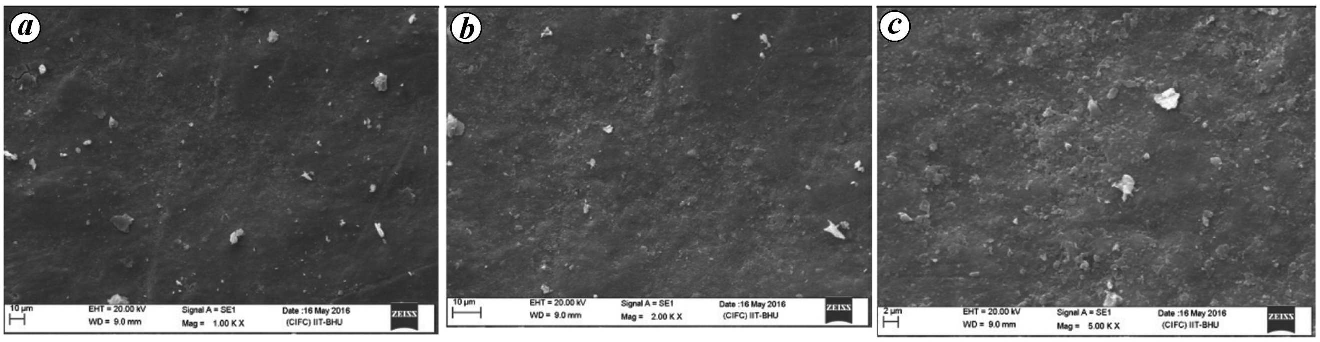

Figure 3. SEM photomicrographs of sample 1 at different magnifications. ***a***, 1000 ×; ***b***, 2000 ×; ***c***, 5000 ×.

the analysed sherd was comparatively higher (59.29%). Carbon was also present in much higher amount (63.47%). On the contrary, the percentage of iron was not very high (Table 3).

Sample no. 4 (Figure 5) was studied with a view to study the slip of BSW of Early Iron Age period (pre-NBPW period) from the site of Latif Shah, district Chandauli (Uttar Pradesh). For analysis, the slip was separated from the core of the sherd. The percentage of carbon in the slip was 30.65. It had notable traces of Mg, Al, Si, Cl, Ti, Mn, Na and Fe. The slip contained certain percentage of Titania and Iron (0.70 and 0.38–1.42 respectively). Could this be due to factors like chemical reaction or soil composition? This cannot be ascertained with the present knowledge. More work may be required in this regard (Table 3).

Sample no. 5 (Figure 6) is the core of BSW of Latif Shah (Early Iron Age). The elemental analysis showed Fe at 8.42%, Ti at 0.04%, Si at 17.22%, Cl at 2.80%, Al at 6.67%, Mg at 1.09% and K at 2.02%. Percentage of iron was high (8.42) in the core. When compared to the slip of the pot, the amount of Ti was very small. Noteworthy here is the fact that carbon was totally absent in the core of this sample, whereas it was found to be high in the slip (30.65%) (Table 3).

Sample no. 6 is the BSW of Latif Shah (Early Iron Age) belonging to the same period. The SEM image of the sample shows evidence of burnishing and application of slip. Traces of Mg, Al, Si, Ca, Mn, Ti, Fe and C were found in the elemental analysis. Percentage of carbon was high (41.05). Iron was found to be present in a small percentage (1.18%) (Table 4).

Sample no. 7 belongs to NBPW sherd of early NBPW period from Khairadih, district Ballia (Uttar Pradesh). Silica (Si) appeared to be the basic mineral. Besides silica, alumina, potassium, iron and titanium were also found. The percentage of iron was 10–24 in a different spectrum of the sample and the amount of titanium was 1–3% (Table 4).

Sample nos 8 and 9 are BSW of the late NBPW period from the same site of Khairadih, district Ballia (Uttar Pradesh). The base mineral was silica. Traces of carbon, potassium, calcium, alumina, magnesium, iron and titanium were found in the samples. Percentage of carbon was very high in both the samples (Table 4).

The sample no. 10 (Figure 7) is not an ancient one. This has been chosen for comparative purposes. It is a pre-fired slip or kabiz of black ware of modern times from Nizamabad (Azamgarh, Uttar Pradesh). Elemental analysis showed high percentage of Si (17.06%)

Table 4. Weight percentage and atomic percentage of the elements present in the sample nos 6–10

	Sample 6		Sample 7		Sample 8		Sample 9		Sample 10	
Elements	Std. wt%	Std. at%	Std. wt%	Std. at%	Std. wt%	Std. at%	Std. wt%	Std. at%	Std. wt%	Std. at%
C	29.67	41.05	–	–	–	–	37.25	50.94	–	–
O	41.94	43.56	19.63	34.70	43.20	59.42	31.81	32.65	49.48	66.74
Mg	0.63	0.43	–	–	–	–	1.49	1.01	0.26	0.23
Al	4.18	2.58	10.71	11.23	10.37	8.46	5.97	3.64	11.07	8.85
Si	17.63	10.43	34.47	34.71	33.99	26.63	16.71	9.77	22.20	17.06
K	–	–	6.37	4.61	3.23	1.82	–	–	2.85	1.57
Fe	3.95	1.18	26.86	13.60	8.51	3.35	6.78	1.99	13.57	5.24
Nb	–	–	–	–	–	–	–	–	–	–
Ca	1.26	0.52	–	–	–	–	–	–	0.57	0.31
Ti	0.67	0.23	1.95	1.15	0.69	0.32	–	–	–	–
Mn	0.06	0.02	–	–	–	–	–	–	–	–
Na	–	–	–	–	–	–	–	–	–	–
Cl	–	–	–	–	–	–	–	–	–	–

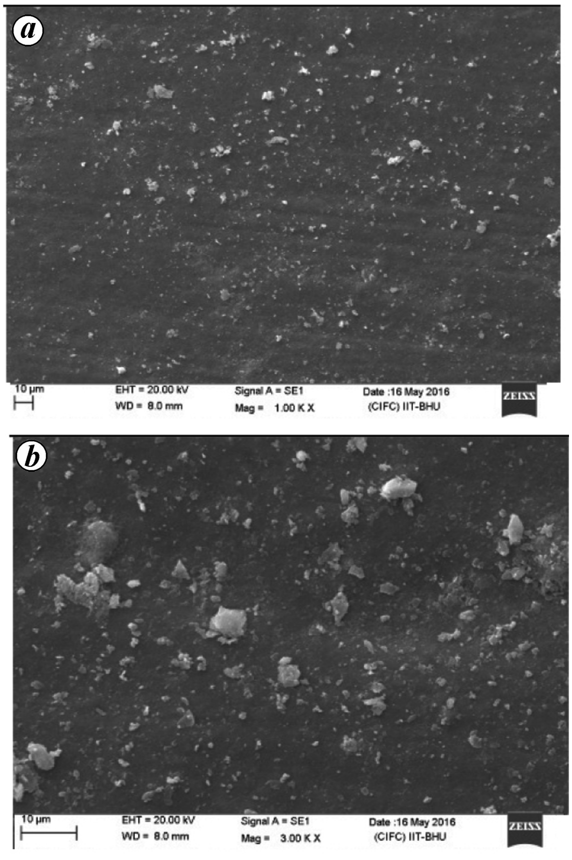

Figure 4. SEM photomicrographs of slip of sample 3 at different magnifications. ***a***, 1000 ×; ***b***, 3000 ×.

(Table 4). Besides Si, there were traces of Al, Mg, K, Ca and Fe (5.24%). This slip was made of organic material like very fine clay, mango tree bark, bamboo leaf, leaf of *Ahhatoda zeglanica medic* and natural soda called *reh*.

Iron Age pottery is better when compared to pre-Iron Age pottery. One may construe that during Iron Age, there was advancement in firing techniques with more efficient metallurgical furnaces used in smelting of iron. Higher temperature and better control and manipulation of temperature to attain desirable atmosphere within the firing chamber was mastered. As a consequence, the potter of this cultural phase generated higher temperature in the kilns. The high temperature reported in turning out BSW and NBPW (up to 900–950°C, BSW of NBPW period, Gotihwa)[15], was not observed in the pottery of pre or Early Iron Age wares such as the Chalcolithic black ware or even the painted grey ware. The ability to raise the temperature in the furnace must have influenced the kilning technique as well, a fact reflected in the improved ceramic technology.

It may also be deduced that the potters were trying to improve the quality of the end product through experimentations in clay and slip applied on the pots. The burnishing, when applied imparted smooth and shining surface. The slip contained certain organic material that gave additional lustre to the surface. Presumably, fibre of some kind was used as seen clearly in the sample of the slip (Sample no. 4). Use of double slip on NBPW has been suggested[16,17].

The most distinguishing feature revealed by the comparative analysis of BSW and NBPW is the presence of carbon. Carbon is absent in the samples of NBPW and found in fairly good quantity in BSW samples (mean 32–53%). Also, Titanium seems to have played some role in the making of these ceramics. It may be noted here that Titanium, a significantly distinguishable mineral was found in some of the analysed samples, especially in samples pertaining to the later period, that is, the NBPW period from some of the sites. The amount of Titanium varied in both ceramic traditions. We observed that in the NBPW samples percentage of Titanium was high when compared to BSW. In NBPW samples iron content was also found to be higher than the BSW samples. In most samples of BSW, the amount of oxide was high. Also

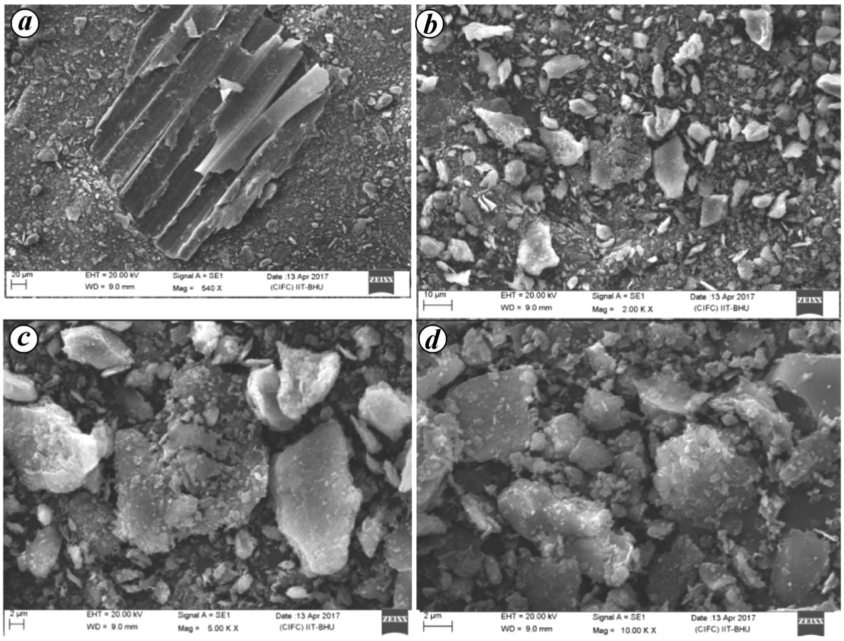

Figure 5. SEM photomicrographs of slip of sample 4 at different magnifications. ***a***, 540 ×; ***b***, 2000 ×; ***c***, 5000 ×; ***d***, 10,000 ×.

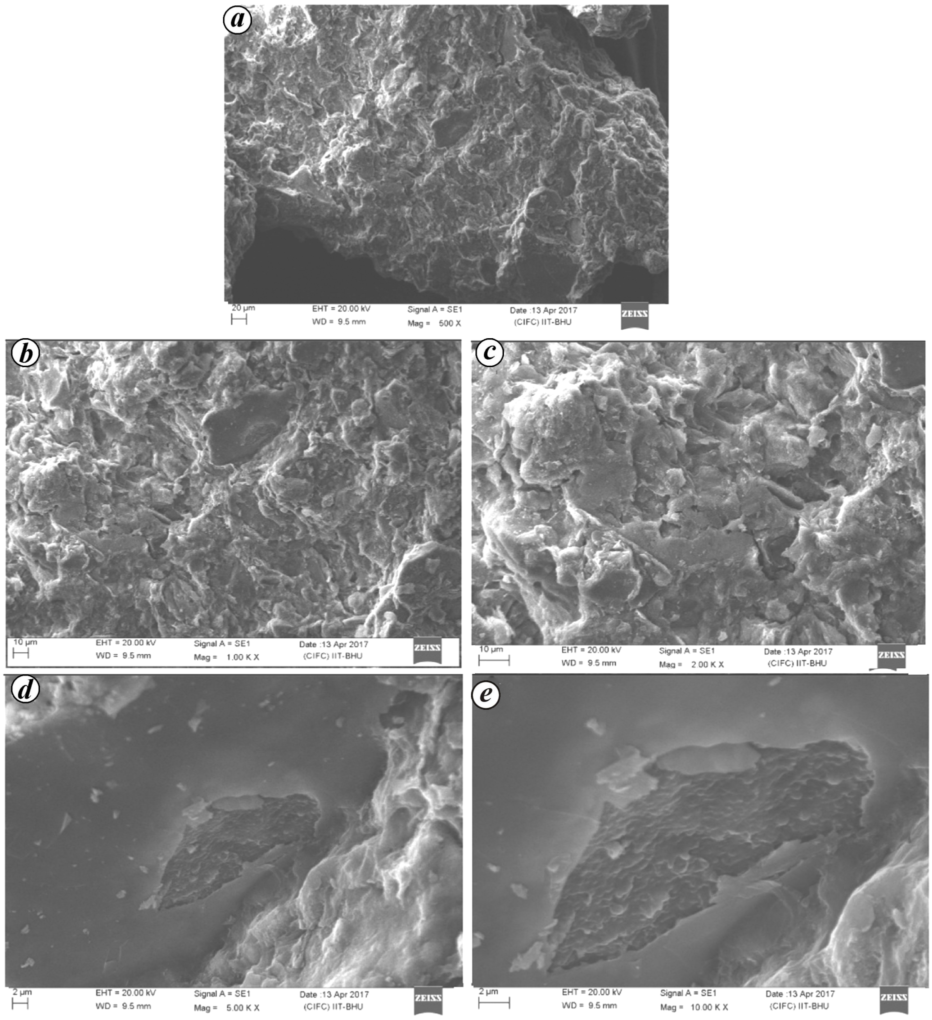

Figure 6. SEM photomicrographs of sample 5 at different magnifications. ***a***, 500 ×; ***b***, 1000 ×; ***c***, 2000 ×; ***d***, 5000 ×; ***e***, 10,000 ×.

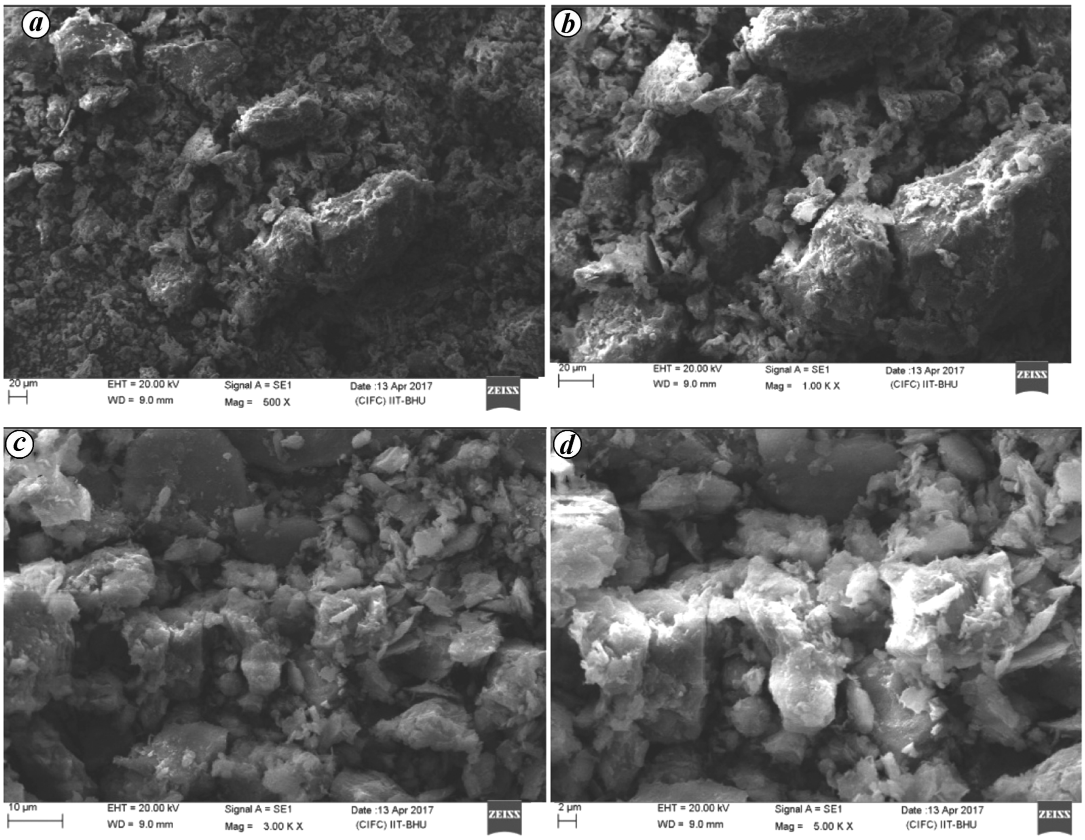

Figure 7. SEM photomicrographs of slip of modern black ware sample 10 at different magnifications. ***a***, 500 ×; ***b***, 1000 ×; ***c***, 3000 ×; ***d***, 5000 ×.

noteworthy is the fact that when compared to the surface, iron content was relatively lower in the core.

Concluding the analytical study of the two wares, we observe: (1) absence of carbon in the NBPW sherds and its presence in BSW; (2) the role of titanium (Ti) was inevitable in pottery making wherever it was applied; (3) iron was present in clay used for black wares – BSW, BRW or NBPW, though its proportion varied. Whether it was incidental, needs to be confirmed by analysing more samples; (4) presence of organic material was also suggested by earlier studies[18]. This is further confirmed by the study of Nizamabad potters. The use of organic material by them provides minerals which affect the end product and finish of the pottery; (5) further and more in-depth study by separating the slip and core of BSW and NBPW will be required to drive home the point.

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Impact of transport sustainability on air quality in Lahore, Pakistan

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Transport sustainability has direct association with improvement of urban emissions levels. Different sustainable steps like promotion of public transport, walking or the use of bicycles, reduction in the number of personal cars and improvement in speed (up to 50 km/h), fuel and model of vehicles can decrease emissions levels in the cities. In this study, emission factors of seven different vehicles have been calculated using the OSPM software. An estimated decrease of 7% in NO_x emission, 33% in CO emission and 25.8% in benzene emission has been observed with 10% reduction in the number of cars and 10 km/h gain in speed (from 40 to 50 km/h). It has also been observed that 2005 model buses using 1999 level fuel emit 1.3 times less benzene, NO_x and CO emissions compared to 2000 model buses using the quality of fuel, which was available in 1990 in Europe.

Keywords: Air quality, emission factor, fuel quality, public transport, transport sustainability.

THE world population has been increasing at a rapid rate, especially in the developing and under-developed nations. One of the main features of the developing nations is the emerging urbanization. According to the United Nations' (UN) estimates, more than 90% of the urbanization has been observed in developing nations[1]. The migration to big cities due to lack of facilities at grass-root level and small cities has created problems like dense population, traffic congestion, air pollution, poor slum conditions, health issues, etc. in big cities of developing countries. Under-developed countries are in a phase of economic development at a considerable rate. The rapid urbanization often results in enhanced ambient air pollution levels. In the coming 20 years, the urban population will be 2 billion in the developing countries, with an increasing rate of 70 million per year. The urban population will be doubled in Asia and Africa at that time. Almost 80% of the urban population of the world will be living in developing countries by 2030 (ref. 2). The results of enhanced fossil-fuel burning have also been observed at Himalayan glaciers with reduction in ice cap from 2000 to 2010 (ref. 3).

The UN has introduced 17 Sustainable Development Goals for a sustainable and peaceful world for mankind by 2030 (ref. 4). Goal 11 deals with sustainability of cities. The target 11.2 states that: 'By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons'[5].

Pakistan is one of the developing countries undergoing industrialization with considerable increase in motorization and energy use. The population and area of big cities in Pakistan have been increasing at a considerable rate. Lahore is the second largest city in Pakistan. In the past few years, an increase in population and car usage has been observed in Lahore. Vehicles are the main source of air pollution in urban areas and cause health impacts on road users and urban communities.

The number of vehicles has been increasing in Punjab Province and Lahore at a considerable rate. Figure 1 shows the trend of increase in the total number of vehicles, cars, motorcycles and auto rickshaws from 2006 to 2015.

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