Study on chemical speciation of phosphorus in the desert particles of western Inner Mongolia

Yuheng Peng1 and Hongwei Yang1*
1 College of Chemistry and Environmental Science, Inner Mongolia Key Laboratory of Environmental Chemistry, Inner Mongolia Normal University, Hohhot, 010022, China
*Corresponding author’s e-mail: 20184015033@mails.imnu.edu.cn

Abstract. The five speciation of phosphorus in the desert particles (<63 μm) of western Inner Mongolia was analyzed by sequential extraction method (SEDEX). The five speciation of phosphorus is exchangeable phosphorus (Pex), ferric iron-bound phosphorus (PFe), authigenic carbonate fluoroapatite and CaCO3 associated phosphorus (Pau), detrital apatite phosphorus (Pdet) and organic phosphorus (Porg), respectively. The results show that Pau is the main phosphorus in desert particles of western Inner Mongolia, the content of Pau in particles with natural particle size is 150-1840 mg·kg⁻¹. The content of Pau is inversely proportional to the particle size of particles, the smaller the particle size is, and the higher the content is. Secondly, the content of Pdet was 8-480 mg·kg⁻¹. The sum of the other two speciation of P (Pex, PFe) more easily used by living beings is 20-45 mg·kg⁻¹, which accounts for 0.27%-8.51% of TP. Comparison of two kinds of granularity, the sequence of TP content was GanSu-Linze > Badain Jaran (Alashom youqi) > Badain Jaran (Shangna wnoer) > Wu Lan Bohe Desert (Baying-gaule) > Tengger (Azuoqi) > Badain Jaran (Batong-brige). As the source of sandstorm, particles less than 63 μm are easy to form flying dust at high altitude, floating across the eastern sea area of China to the Pacific Ocean, and transporting phosphorus over a remote distance.

1. Introduction
The deserts in western Inner Mongolia mainly refer to Badain Jaran Desert, Tengger desert, Mu Us desert and Wu Lan Bohe desert. The sand and dust particles mainly come from the desert, wilderness, Gobi and so on of Inner Mongolia, which are characterized by a long distance of movement, a wide range of influence, and even arrive to the western Pacific[1-4]. Dust from northwest China was found to have flown over the Asian continent and the Pacific Ocean for 40000 years in the early 1980s, after about a week of travel, it deposited in the distant North Pacific Ocean and even reached the western coast of the United States[5-7]. In the North Pacific, some chemical elements that come with the atmosphere enter the ocean through the exchange of sea and air, just as the matter transported into the sea with the river, these elements have become an important source of marine material. Primary productivity is limited by iron in some sea areas [8-10], and is limited by phosphorus in the Eastern Mediterranean[11-12]. The primary productivity of the Yellow River Estuary and the adjacent waters of the Bohai Sea is also limited by phosphorus[13], and there is a growing trend, and offshore phosphorus is transported by dust and river sediments[14-16].

In this paper, the samples of desert particles in western Inner Mongolia are used. To determine the phosphorus adsorbed or exchanged on the surface of particles, the samples which are ground will make the morphological results unreliable, so the samples of desert particles less than 63 μm are taken...
by natural air drying and mechanical screening. The particle size of 63 μm is the dividing line between silt and fine sand on the international level, particles less than 63 μm can be transported over long distances during sandstorms and enter rivers and oceans to become suspended particles. Phosphorus is the basis of all marine primary productivity and biological chains[17-19]. Although particles less than 63 μm account for only about 1% of desert particles, their transport to phosphorus of various speciation affects the productivity of plankton[20]. In turn, the change of biosphere production indirectly affects the change of atmospheric CO₂, and then leads to climate change. It has been known that the air movement is global long ago, but it has been known in the 1980s that the particulate matter can also be transported over a long distance. In the North Pacific, some of the chemical elements that come with the atmosphere are exchanged by air and sea into the ocean. Like the substances transported to the sea with the river, these chemical elements have become an important source of marine material. Global climate change is closely related to C, N and S cycle, researchers at home and abroad focus more on the study of these elements, while the important role of P element in climate change is ignored.

2. Data sources and research methods

2.1. Collection of samples
Sand and dust weather mostly originate from the edge of the desert rather than from the interior of the desert[21-22]. Due to the dust particles in the desert edge are so thin in thickness and so small in density, that they are easy to be involved in the upper air and move westward with the air flow for a long distance under the action of wind. Sand samples were collected on the edge of the desert in September 2017, and the sampling sites are shown in Figure 1. Because the collected desert samples are pure and highly dispersed, they are weighed and cryopreserved after screening.
Desert particles are complex heterogeneous organic-inorganic complexes. There are significant differences in the composition and structure of particles in different deserts or the same desert with different particle sizes. Therefore, there are significant differences in the ability and capacity of combining phosphorus. Samples were collected in each station from four vertex samples in a square with a side length of 100 m, plus a sample of diagonal intersection (the sites in Figure 1). The mixture of five samples is the sample to be tested.
2.2. Sequential extraction method of phosphorus from particulate matter

P in particulate matter exists in the form of inorganic phosphorus and organic phosphorus. Because of the limitation of the research means, the structure, speciation and property of the organic phosphorus in the particulate matter is still not clear. It is difficult to separate the organic phosphorus. The existing method is limited to the analysis of the total phosphorus bound by organic matter. The extraction methods of various speciation of P in particulate matter are mainly aimed at inorganic phosphorus. According to the reaction activity of different extractants in each inorganic complexation phase, the specific extractant can be used selectively to release and determine the P in the binding phase. In the various methods before 1992, the environmental geochemical significance of the results of the study was not obvious due to the failure to distinguish between the primary clastic phosphorus and the authigenic phosphorus in the sedimentary environment. The morphological separation method for the speciation of P distinguishing primary clastic phosphorus from authigenic calcium combined phosphorus in marine sediments proposed by Ruttenberg for the first time in 1992, and a detailed standardization test was carried out [23]. The biggest improvement in this method is that the classification of phosphorus in particulate matter is suitable for the actual requirements of environmental geochemical research, therefore, it is applied to marine geochemical research immediately [24-25], which is called the SEDEX method. Although iron phosphorus ($P_{Fe}$), aluminum phosphorus ($P_{Al}$) and $P_{obs}$ are not separated by this method, the method is adopted in this paper. P is divided into five speciation. Because the content of $P_{obs}$ is small, $P_{Fe}$ and $P_{Al}$ are all phosphorus speciation with biological activity, which is combined into $P_{Fe}$ representation. The P content of each step extract was analyzed by molybdenum antimony anticolorimetric method [13], which has the advantages of high sensitivity, stable color and strong anti-interference ability. It is the best method for the determination of trace P in aqueous solution at present.
3. Results and analysis

3.1. Chemical composition of desert particles (<63 μm) in western Inner Mongolia

Table 1. The chemical analysis of the deserts particulates less than 63μm (%)

|          | GanSu-Linze (Shanga nwoer) | Badain Jaran (Batong-brige) | Tengger (Azuoqi) | Wu Lan Bohe Desert (Baying-gaule) |
|----------|-----------------------------|-----------------------------|------------------|----------------------------------|
| SiO₂     | 78.9                        | 61.6                        | 84.1             | 68.3                             |
| Al₂O₃    | 7.66                        | 11.1                        | 8.04             | 14.9                             |
| TFe      | 1.82                        | 2.49                        | 0.44             | 4.66                             |
| CaO      | 2.37                        | 3.38                        | 0.30             | 4.40                             |
| MgO      | 1.70                        | 3.38                        | 0.30             | 7.89                             |
| K₂O      | 1.70                        | 2.29                        | 2.21             | 2.16                             |
| Na₂O     | 1.68                        | 3.28                        | 2.34             | 4.78                             |
| P₂O₅     | 0.11                        | 0.12                        | 0.05             | 0.09                             |
| TiO₂     | 0.40                        | —                           | 0.66             | 0.70                             |

As can be seen from Table 1, the proportion of main element oxides in desert particles (< 63 μm) is SiO₂ > Al₂O₃ > CaO > TFe > Na₂O, K₂O and TiO₂, and the content of P₂O₅ is very low. The order of oxide content of main elements is about the same as that in Malan loess. 17 elements in sand and dust particles in China were analyzed by ICP, and the enrichment coefficients of related elements during non-dust and sandstorm periods were calculated by Zhuang GS et al[26]. It is proposed that Na is usually used as a reference element for marine sources. The content of Na in Beijing aerosol during non-sandstorm and sandstorm is 2.58% and 2.80%, respectively, which is close to the 2.36% of the earth's crust. It mainly comes from the source of crust. As can be seen from Table 1, the desert particles (< 63 μm) content of Na₂O is converted into element content. The content of Na₂O in the northern Badain Jaran (Shanga nwoer) desert is 3.28%, the percentage content of Na is 2.43%, and near the 2.36% of the crust abundance. Shanga nwoer is the source of sandstorm in the middle road of our country. According to the method of the study, the Na also mainly comes from the crust source [26]. There is a certain difference between the content of other elements and the abundance in the crust, but there is no comparison. The content of in desert particles is the highest, and most of them are α-quartz. Among them, the content of SiO₂ in Badain Jaran (Batong-brige) is the highest, and the Al₂O₃ in Tengger (Azuoqi) is slightly higher and the TFe is slightly higher. P₂O₅ is low, indicating that the amount of phosphorus in desert particles as source of phosphorus is also not high.

3.2. Contents of various speciation of phosphorus in desert particles with different particle sizes

The contents of various speciation of phosphorus in the desert particles and the ratio to the total phosphorus are shown in Table 2.

Table 2. The various speciation of phosphorus and the ratio to TP in the desert particles (g·kg⁻¹, %)

| Sampling sites          | Particle size | P_ex | P_Fe | P_aut | P_det | P_org | IP | TP |
|-------------------------|---------------|------|------|-------|-------|-------|----|----|
|                         | µg/g | %    | µg/g | %    | µg/g | %    | µg/g | %  | µg/g | %    |
| GanSu-Linze (natural   | 7    | 0.67 | 16   | 1.57 | 900  | 89.02| 23  | 60 | 6.23 | 950  |
|                         | <63μm| 5    | 0.27 | 14   | 0.73 | 1840 | 95.02| 16 | 6.09 | 3.15 |
| Badain Jaran (natural   | 11   | 1.17 | 11   | 1.23 | 760  | 84.31| 28  | 11 | 1.27 | 800  |
|                         | size |      |      |      |      |      |     |    |     |      |
|                         |      |      |      |      |      |      |     |    |     |      |
It can be seen from Table 2 that the total phosphorus content of desert particles original sample range is from 490 g·kg⁻¹ to 1010 g·kg⁻¹. The content of various phosphorus (< 63 μm) desert particles sample is higher than that in the original sample (280~1930 g·kg⁻¹). The self-generated calcium phosphorus content occupies the main body in the desert particles sample of two particle sizes. And the total phosphorus content is in the same order: GanSu-Linze (Hexi Corridor) surface particulate sample > Badain Jaran desert (Shanga nwoer) particulate sample > Badain Jaran desert (Alashom youqi) particulate sample > Wu Lan Bohe desert (Baying-gaule) particulate sample > Tengger desert (Azuoqi) particulate sample > Badain Jaran desert (Batong-brige) particulate sample. The high TP content of surface particles in Linze is related to the soil fertility higher made by the greening of Hexi Corridor and the development of agriculture. The high TP content in Badain Jaran desert (Shanga nwoer) is related to the sand made up by the lake sediment with high productivity, and its location in Ejina oasis and bordering on Mongolian grassland. Badain Jaran desert (Alashom youqi) contains higher TP, due to Alashom youqi is the most beautiful desert in China. There are many desert peaks, which are not moved by the wind, known as desert pyramids, became a desert tourist shrine. The content of TP in desert of western Inner Mongolia is lower than that of Malan loess, which is related to the high content of iron, aluminum and calcium oxides with strong binding ability to phosphorus in Malan loess [27] and the large number of particles with small loess particle size.

The content of TP in desert particles in western Inner Mongolia shows the characteristic with a high content in fine particles, which also explains the relationship between TP and the specific surface area of particles. When the desert particles fall into the water of the river, there will be a lot of solid-liquid interface reactions, for example, the adsorption and desorption of phosphorus make phosphorus participate in the geochemical cycle.

4. Discussion

4.1. Biological available phosphorus in desert particles in Inner Mongolia and its environmental significance

In a broad sense, all kinds of phosphorus speciation in desert are bioavailable phosphorus, which can be absorbed by organisms and participate in the global phosphorus cycle with the change of environment and the role of organisms. $P_{\text{ex}}$, $P_{\text{Ec}}$ is the most easily used speciation of organisms, called biological available phosphorus. Desert particles are so dry that there is almost no humidity or gap water that can be released at 105 °C. Only the crystal water was released above 1000 °C in the mineral. The effective phosphorus can only be the solid-solid bound phosphorus between the mineral or the oxide and the phosphorus salt. Although the content of SiO₂ in desert particles is very high, it has no
adsorption effect. The reason is that the silicon-oxygen tetrahedral is a regular tetrahedral symmetry structure, the bond angle is 109°28′, the layer charge is zero, and it does not act as an absorbent. The oxides of iron and aluminum are composed of polar molecules, and the phosphate can be adsorbed. The forces between solid and solid belong to the attraction and exclusion of static electricity, which is very small and weaker than the force of intermolecular attraction.

Pex is that K₃PO₄ and Na₃PO₄ compounds are adsorbed on the interface of clay mineral, the calcium and iron oxides. Because of the large electronegativity difference between alkali metal and oxygen, its bond has strong ionicity, which is analyzed and dissociated in river and sea water. With the condition of natural pH, the formation of HPO₄²⁻ enters the water body and becomes the nutritive salt of aquatic organisms.

PFe is adsorbed to the interface iron or aluminum oxides. Because iron, aluminum oxides belong to polar molecules and asymmetric structure, they can produce the attraction of charge layer. The phosphate adsorbed by the interface can be dissolved or exchanged in rivers and seas. PFe also has the advantage of providing both P and Fe to the ocean as nutrients for plankton. The content of PFe matches with the content of TFe in the natural particle size of desert particles, because PFe is adsorbed to the interface of iron ore or iron oxide in the form of phosphate. The content of Fe (II) in particle samples increased from 0.7% to 1.4%-2.6% during sandstorms, which was measured by Zhuang Guoshun. This is because Fe (III) is reduced by other low valence compounds including S, during the sandstorm aerosol long-distance transmission. However, the redox mechanism is still worthy of further discussion, because the coupling of iron and sulfur in the atmosphere and their positive feedback process is one of the important mechanisms that may affect the global change. The Fe(III) can be reduced to Fe(II) after entering the river or sea water, which is related to the electrode potential of the solution. In this paper, the redox potentials of the water along the Yellow River and the coastal waters of the Bohai Sea have been measured in the scene by YSI-556MPS water quality instrument produced by YSI Jinquan instrument Company of the United States. The pH is 8.40, the conductivity is 858 MS·cm⁻¹, and the electrode potential ORP is 0.1682 mV in the Yellow River Estuary. And the pH is 8.05, the conductivity and the electrode potential ORP are 37090 MS·cm⁻¹ and 0.1870 mV in the shallow waters of Bohai Sea, respectively. With standard conditions, the ORP value of Fe³+/Fe²⁺ is 0.77 V. Therefore, in the field temperature, salinity chlorine degree in river water, complexion and colloid environment, the ORP value is much less than 0.77 V, and Fe (III) is easily reduced to Fe(II) to be absorbed by marine organisms.

When desert particles settle in rivers, coastal waters or oceans, they become sediments. A series of interfacial reactions take place with the action of polar water molecules and other ions. The solid surface is negative due to the adsorption of hydroxyl groups, and then adsorbs phosphate. In the river, if the concentration of P is low, the solid interface will analyze the phosphorus salt as the phosphorus source. And if the concentration of phosphorus in the river is high, the solid interface will absorb phosphate and become a phosphorus sink. The thermodynamic equilibrium of solid-liquid interface is achieved in the above two ways[28]. While the situation is different in the sea. Due to the ocean is a phosphorus-poor environment, desert particles only analyze phosphate into seawater and become a source of phosphorus.

4.2 Organic phosphorus
Some of the organic phosphorus in particles enters the natural water body, under the condition of pH, temperature and ion intensity of river or seawater [29]. Such as chlorophyll, fatty acid, vitamin, sugar, nitrogen-free and nitrogen-containing organic matter, although the content is small, which play a very important role to change the morphology and properties of many substances or metals. The humic acid includes water-soluble substances with smaller molecular weight, such as humic acid (HA) and fulitic acid (FA). The molecular weight of FA is in the range of 500 to 2000, whose structure is difficult to express singly. There are various functional groups such as COOH, OH⁻, C=O and so on. The organic phosphorus falling into the desert particles of ocean, for example, sugar phosphate can coordinate with four forms of oxygen (hydroxyl, carboxy, ether, peroxide and other functional groups) in FA. ATP
adenosine triphosphate) and TPN (triphosphopyridine nucleotide) are produced by photosynthetic process under the action of light energy (electron source), chlorophyll, water (electron source) and CO₂, which made the organic soluble phosphorus in seawater such as in the surface of Northeast Pacific Ocean reach 0.006-0.012 mg·L⁻¹ to become biological available phosphorus[30]. Organic phosphorus that fails to be dissolved out from the particles is deposited into the bottom of the sea as deposited phosphorus, also known as phosphorus reservoir.

4.3. Calcium phosphorus

Calcium phosphorus is the main component of inorganic phosphorus in different particle size samples, such as desert particles, rivers or marine sediments. Table 2 among the six kinds of desert particles, Pₐ₅₄ and Pₐ₅₆ are dominated by authigenic calcium phosphorus (Pₐ₅₄), followed by Pₐ₅₆. There are the same rules in both natural granularity and particles less than 63 μm. In the process of extraction, Pₐ₅₄ is extracted with HAC-NaAC buffer solution of pH=4, which mainly refers to calcium carbonate bound phosphorus, authigenic apatite and sedimentary phosphorus related to biogenic phosphorus-bearing minerals. In the H₃PO₄-Ca (OH)₂-H₂O system, there are ten known calcium phosphate compounds[24]. The stable calcium phosphate in the soil is dicalcium phosphate dihydrate, anhydrous dicalcium phosphate, octapalcium phosphate, hydroxyapatite and fluoroapatite. The first two are water-soluble phosphate fertilizers. Octapalcium phosphate is the product of further transformation from dicalcium anhydrous phosphate. Apatite is the original mineral, that is, Pₐ₅₆. The reason of calcium and phosphorus cannot be dissolved and used in time, the key point is that the structural unit is calcium phosphate.

Phosphate is a ternary acid consisting of a single phosphorus-oxygen tetrahedral. In H₃PO₄ molecule, P is sp³ unequal hybrid, three hybrid orbitals and oxygen atoms form three single chains, and the other P-O three bonds is formed by a single bond between P and O and two dP bonds from O to P. Although it is a triple bond, the bond energy and bond length are between single bond and double bond, which can explain the stability of Pₐ₅₄ and Pₐ₅₆ calcium phosphorus. In calcium phosphorus, its structural unit Ca₉(PO₄)₂ has a smaller electronegativity difference between oxygen atom and Ca in phosphate than that of alkali metal, and its covalent property of bond is greater than that of ion bond property. In the mineral lattice and under the condition of pH of natural water, it is not easy to dissociate to form hydrogen phosphate, and most of the sediments go deep into the bottom of the sea or river and become phosphorus pools.

5. Conclusion

The content of total phosphorus and various speciation of particulate sample (<63 μm) in the western Inner Mongolia desert is larger than that of the desert particulate original sample. Pₐ₅₄ accounts for the vast majority of total inorganic phosphorus in the samples of two kinds of particle size particles, followed by Pₐ₅₆, Pₐ₅₆, Pₐ₅₆. The sequence of TP content was GanSu-Linze > Badain Jaran (Alashom youqi) > Badain Jaran (Shanga nwoer) > Wu Lan Bohe Desert (Baying-gaule) > Tengger (Azuqi) > Badain Jaran (Batong-brige).

Desert particles with a particle size less than 63 μm form some of the components of marine wind and dust, which has a profound impact on the delivery of phosphorus, the marine primary productivity, the content of CO₂ in the global atmosphere and the climate change.

Acknowledgments

This work was financially supported by Inner Mongolia Normal University Graduate Student' Research & Innovation Fund (CXJJS19124).

References

[1] Richon, C., Dutay, J.C., Dulac, F., Wang, R., Balkanski, Y. (2018) Modeling the biogeochemical impact of atmospheric phosphate deposition from desert dust and combustion sources to the Mediterranean Sea. Biogeosciences., 15: 2499-2524.
[2] Zhang, X.Y., Gong, S.L., Shen, Z.X., Mei, F.M., Xi, X.X., Liu, L.C., Zhou, Z.J., Wang, D. (2003) Characterization of soil dust aerosol in China and its transport and distribution during 2001 ACE-Asia: 1. Network observations. Journal of Geophysical Research-Atmospheres., 108: 4261-4273.

[3] Sun, J.M., Zhang, M.Y., Liu, T.S. (2001) Spatial and temporal characteristics of dust storms in China and its surrounding regions, 1960-1999: Relations to source area and climate. Journal of Geophysical Research-Atmospheres., 106: 10325-10333.

[4] Guo, Y.R., Zhao, H.L., Zuo, X.A., Drake, S., Zhao, X.Y. (2008) Biological soil crust development and its topsoil properties in the process of dune stabilization, Inner Mongolia, China. Environmental Geology., 54: 653-662.

[5] Duce, R.A., Arimoto, R., Ray, B.J. (1983) Atmospheric trace elements at Enewelak Atoll: 1 Concentration, sources, and temporal variability. Geophys Res (Atmos.), 88: 5321-5342.

[6] Duce, R.A., Unni, C.K., Ray, B.J., Prospero, J.M. (1980) Long-range atmospheric transport of soil dust from Asia to the tropical north pacific-temporal variability. Science., 209: 1522-1524.

[7] Bruland, G.L., Richardson, C.J. (2006) An assessment of the phosphorus retention capacity of wetlands in the Painter Creek Watershed, Minnesota, USA. Water Air and Soil Pollution., 171: 169-184.

[8] Zhuang, G., Duce, R.A., Kester, D.R. (1990) The dissolution of atmospheric iron in surface seawater of the open ocean. J Geophys Res [Ocean]., 95: 16207-16216.

[9] Duce, R.A., Tindale, N.W. (1991) Atmospheric transport of iron and its deposition in the ocean. Limnology and Oceanography., 36: 1715-1726.

[10] Bonnet, S., Guieu, C. (2004) Dissolution of atmospheric iron in seawater. Geophysical Research Letters., 31: L03303-L03306.

[11] Krom, M.D., Kress, N., Brenner, S., Gordon, L.I. (1991) Phosphorus limitation of primary productivity in the Eastern Mediterranean-Sea. Limnology and Oceanography., 36: 424-432.

[12] Rahav, E., Herut, B., Stambler, N., Bar-Zeev, E., Mulholland, M.R., Berman-Frank, I. (2013) Uncoupling between dinitrogen fixation and primary productivity in the eastern Mediterranean Sea. Journal of Geophysical Research-Biogeosciences., 118: 195-202.

[13] Peng, Y.H., Tian, C.C., Yang, H.W. (2019) Distribution of phosphorus species and their release risks in the surface sediments from different reaches along Yellow River. Environmental Science and Pollution Research., 26: 28202-28209.

[14] Zhang, W. Q., Jin, X., Zhu, X. L., Shan, B.Q., Zhao, Y. (2016) Phosphorus characteristics, distribution and relationship with environmental factors in surface sediments of river systems in Eastern China. Environmental Science and Pollution Research., 23: 19440-19449.

[15] Kuo, Y.M., Harris, W.G., Munoz-Carpena, R., Rhue, R., Li, Y.C. (2009) Apatite control of phosphorus release to runoff from soils of phosphate mine reclamation areas. Water Air and Soil Pollution., 202: 189-198.

[16] Ballantine, D., Walling, D.E. (2009) Mobilisation and Transport of Sediment-Associated Phosphorus by Surface Runoff. Water Air and Soil Pollution., 196: 311-320.

[17] Zhang, X., Lin, C.Y., Zhou, X.L., Lei, K., Guo, B.B., Cao, Y.X., Lu, S., Liu, X.T., He, M.C. (2019) Concentrations, fluxes, and potential sources of nitrogen and phosphorus species in atmospheric wet deposition of the Lake Qinghai Watershed, China. Science of the Total Environment., 682: 523-531.

[18] Barkley, A.E., Prospero, J.M., Mahowald, N., Hamilton, D.S., Blackwelder, P., Gaston, C.J. (2019) African biomass burning is a substantial source of phosphorus deposition to the Amazon, Tropical Atlantic Ocean, and Southern Ocean. Proceedings of the National Academy of the United States of America., 116: 16216-16221.

[19] Sarma, V.V.S.S., Rao, D.N., Rajula, G.R., Dalabehera, H.B., Yadav, K. (2019) Organic nutrients support high primary production in the bay of Bengal. Geophysical Research Letters., 46: 6706-6715.
[20] Li, J.B., Lai, Y.T., Xie, R.R., Ding, X.Y., Wu, C.S. (2018) Sediment phosphorus speciation and retention process affected by invasion time of Spartina alterniflora in a subtropical coastal wetland of China. Environmental Science and Pollution Research., 25: 35365-35375.
[21] Ghoneim, E. (2018) Rimaal: A sand buried structure of possible impact origin in the Sahara: Optical and radar remote sensing investigation. Remote Sensing., 10: 880.
[22] Zhang, B., Tsunekawa, A., Tsubo, M. (2008) Contributions of sandy lands and stony deserts to long-distance dust emission in China and Mongolia during 2000-2006. Global and Planetary Change., 60: 487-504.
[23] Ruttenberg, K.C. (1992) Development of a sequential extraction method for different forms of phosphorus in marine sediments. Limnol Oceanogr., 37: 1460-1482.
[24] Ruttenberg, K.C., Berner, R.A. (1993) Authigenic apatite formation and burial in sediments from non-upwelling continental margin environments. Geochim Cosmochim Acta., 57: 991-1007.
[25] Bener, R.A., Rao, J.L. (1994) Phosphorus in sediments of the Amazon River and Estuary: Implications for the global flux of phosphorus to sea. Geochim Cosmochim Acta., 58: 2333-2340.
[26] Zhuang, G.S, Guo, J.H., Yuan, H., Zhao, C.Y. (2001) The compositions, sources, and size distribution of the dust storm from China in spring of 2000 and its impact on the global environment. Chinese Science Bulletin., 46: 895-901.
[27] Cheremisina, O.V., Sergeev, V.V., Fedorov, A.T. (2019) Rare earth metal extraction from Apatite Ores. Metallurgist., 63: 300-307.
[28] Yang, H.W., Guo, B.S. (2010) Phosphate adsorption characteristics on the desert particulates of inflow Yellow River. Huanjing Kexue., 31: 1890-1896.
[29] Rahutomo, S., Kovar, J.L., Thompson, M.L. (2018) Inorganic and Organic Phosphorus in Sediments in the Walnut Creek Watershed of Central Iowa, USA. Water Air and Soil Pollution., 72 229.
[30] Pan, G., Krom, M.D., Herut, B. (2002) Adsorption-desorption of phosphate on airborne dust and river-borne particulates in East Mediterranean seawater. Environmental Science & Technology., 36: 3519-3524.