JJEES

JJEES (2021) 12 (3): 269-274
ISSN 1995-6681

Jordan Journal of Earth and Environmental Sciences

Soil phosphorus availability indices and saturation ratio as an index of environmental risk assessment

Jamiu Azeez[1*], Adeoba Aghorunse[1], Ganiyu Bankole[1], Melvis Anamezeonye[1], Timothy Adegbite[1], Saidat AbdulAzeez[2]

1Department of Soil Science and Land Management, Federal University of Agriculture Abeokuta, Nigeria
2Agricultural Technology Department, Yaba College of Technology, Epe Campus, Lagos

Received 7 December 2020; Accepted 15 March 2021

Abstract

The use of phosphorus saturation ratio (PSR) as the index for soil pollution potential in some animal waste dump sites of southwest Nigeria was evaluated. Surface and sub-surface soil samples were taken from 20 animal waste dump sites. Soil chemical properties, phosphorus availability indices and PSR were determined and analyzed. Results indicated that the unregulated dumping of manures in soils resulted in high phosphorus availability with a higher concentration in the top 20 cm of the soils. The PSR of the soils (0.42, topsoil and 0.32, subsoil) are more than the threshold values of 0.10-0.15, indicating soil P pollution of the environment. Some P availability indices could be used as a proxy for estimating soil PSR and hence soil P pollution potential. The soil P load is more than the amount that could be sorbed by the soil clay but has a strong correlation with soil organic matter. It was concluded that there is potential pollution of surface and groundwater in the vicinities of the dumpsites with possible attendant health hazards. Hence, the need to exploit alternative soluble P management options like precipitating the soluble P in the manure by applying materials rich in Al, Fe and Ca.

Keywords: Phosphorus saturation ratio; animal waste; dumpsites; phosphorus availability indices

1. Introduction

Across the globe, in the 1990s, the quantities of poultry meat and eggs from the developing countries was more than that of developed countries (Windhorst, 2006). Globally, data in 2005, showed that the contribution of the developing countries was 67 % in egg production (Windhorst, 2006), and was adjudged low. This is largely due to the proportion of these products dedicated to local consumption, and for use as raw materials in local food industries.

Recent agricultural policy of both state and federal government in Nigeria and other sub-Saharan African countries are geared towards increasing the production of poultry products. Primarily to meet up with global expectation and increase of balance of trade, and curb protein malnutrition. These have resulted in the increased production and consumption of livestock meat and meat products. Recently, the numbers of livestock producers have increased tremendously, particularly poultry farmers. Perhaps, due to the short gestation period of the venture (broiler production). The lucrative nature of these production ventures has attracted many unemployed people into the business.

Intensive livestock production entails the use of highly nutritious feed ingredients and additives. However, only a fraction of the ingredients and additives are utilized by the animals while some percentage of it is excreted. The disposal and management of the animal waste generated from the livestock industry are of great environmental concern, the drudgery and the high volume to nutrient content ratio have made the use of these resources limited in Sub-Saharan Africa. This has led to the accumulation of a huge mass of livestock wastes at dumpsites with the attendant pollution of the soil with heavy metals (Azeez et al., 2009).

Though, the land application of wastes from confined animal pens and cages is an effective disposal system, because it supplies nutrients to crops and pasture land (Soupir et al., 2005). However, the runoff from such land is a potential source of fecal contamination in water (Crowther et al., 2002; Gerba and Smith, 2005; Tian et al., 2002).

Animal wastes are rich in nutrients. Typically, poultry litter contains 8 to 25.8 g P kg^{-1} dry weight, with about 4.9 g P kg^{-1} being water-soluble reactive P. This is because P is added to chicken (Gallus gallus) diets to ensure rapid growth (Codling et al., 2000; Edwards and Daniel, 1992). The application of excess P through the deliberate deposition of the animal waste could results in environmental disaster (Sauer et al., 1999). In crop husbandry, excessive and unsynchronized application of excessive amounts of inorganic or organic P fertilizers is not desirable. Doing this will lead to loss of phosphorus to nearby water bodies, through runoff and subsurface losses (Nair, 2014; Hooda et al., 2000; Sharpley and Tunney, 2000). The consequent loss of P to soil and water bodies has an adverse impact on water quality. This eventually affects human and animals' health, ecological diversity, the cycling of nutrients and the proper functioning of the ecosystems (Nair, 2014).

Eutrophication and environmental degradation are some

* Corresponding author e-mail: azeez2001ng@yahoo.com

of the problems emanating from P loss to the environment (Liao et al., 2015). Unfortunately, there are many such dumpsites scattered across livestock farms with little or no regards for the consequences of such unregulated and improperly managed disposal systems, particularly in sub-Saharan Africa. Hence, to enhance the economic and ecological sustainability of these livestock production ventures, it is imperative to document the soil P status. Also, there is the need to evaluate the potential risk assessments, because, it was reported that non-point pollution from agricultural ventures is major causes of degradation to water bodies (USEPA, 2002 and 2003).

Iron and aluminum oxides play a substantial role in determining the soil P status (Azeez and Van Averbeke, 2010) and the amount of P loss to the environment. Hence, the direct measurement of P loading in agricultural systems without the concurrent measure of the Fe and Al in the soil could be challenging (Nair, 2014). This has led to the development of 'phosphorus saturation ratio' (PSR) with threshold values indicating risk assessment in land-use systems. Extensive use of the ratio has been reported in the literature for Europe and America (Breeuwsma and Silva, 1992; Nair et al., 2004; Sharpley et al., 2013), to predict environmental limits for soil P in soils. However, no documented information on its use in Africa and other less developed countries.

The P saturation ratio (PSR) was calculated as the molar ratio of Mehlich-1 P (P_{M1}) to Mehlich-1 Fe and Al (Fe_{M1} and Al_{M1}). The ratio was reported by Breeuwsma and Silva (1992) and Nair et al., (2004) to be related to soil solution P concentration. It computes threshold values that correspond to a set critical solution concentration.

Mathematically, it is expressed as:

$$PSR_{M1} = (P_{M1}/31) / [(Fe_{M1}/56) + (Al_{M1}/27)].$$

The use of this index for the evaluation of the soil of animal dumpsites will thus provide information for environmentalists and policymakers on the impact of dumping animal wastes on soils. It will also provide information on the status of the soils and the possible management options that could be adopted to make the practice ecologically sustainable. Consequent to above, the objectives of this study were to characterize soil P availability on manure impacted soils; evaluate the risk of P loss to the environment and determine the relationship between P availability indices, some soil properties and the P risk assessment index (PSR).

2. Materials and methods

2.1. Site Characterization

Representative samples were taken from twenty (20) different locations of animal waste dumpsites within Ogun and Oyo States, Nigeria. Ten of the locations were poultry waste dumpsite and the other ten locations were either cattle or goat or pig waste dumpsites. The Soil samples were collected at 1 meter away from the respective dumpsites at depths of 0-20 cm and 20-60cm, the coordinates of the sampling site were taken with the aid of Hand-Held Garmin (GPS) while data on the history of the sites were also taken. Details of the history and coordinates of the sites are shown in Table 1.

Table 1. Soil history and the GPS coordinate of the sampling sites.

Soil	Years	Location (Abeokuta)	Soil	Years	Location (Ibadan)
A1	>10	University farm (cattle)	B1	> 10	Eleyele (Poultry)
A2	> 10	University farm (pig)	B2	> 10	Mokola (Poultry)
A3	> 10	University farm (Goat)	B3	12	Egbeda (Poultry)
A4	> 10	University farm (sheep)	B4	> 15	Ring Road (Poultry)
A5	> 10	University farm (goat)	B5	8	Agugu (cattle)
A6	0.7	Kihinleyin, Camp (poultry)	B6	> 30	Oranyan Market Ibadan (Goat)
A7	2	Apakila, Abeokuta (poultry).	B7	3	Lagos-Ibadan expressway (cattle)
A8	5	Osiele, Abeokuta (poultry)	B8	>10	Alapafon Airport (Poultry)
A9	> 10	University Project Farm (poultry)	B9	> 30	Central Abattior (cattle)
A10	3	University farm (Poultry)	B10	> 20	Bodija (cattle)

2.2. Soil Determinations

The soil samples were air-dried, pulverized and screened with a 2mm sieve. The samples were analyzed for the particle size distribution using the hydrometer method (Bouyoucos, 1965). Soil pH was determined using the pH meter by preparing soil and water mixture of (1:2) solution after shaking using a mechanical shaker (Mclean, 1982). The organic matter content of the samples was determined by the dichromate acid oxidation method (Nelson and Sommer, 1982).

In triplicates, phosphorus availability indices were evaluated by determining the soil P content by colour formation using an ascorbic acid solution, potassium antinomy tartrate, sulfuric acid, and molybdate solution. The P was read on the spectrophotometer at a wavelength of 882 nm (Murphy and Riley, 1962). The P determinations were done after extraction with the following chemicals used as indices of P availability:

1. Distilled water extractants: Distilled H2O (Nair, 2004).
2. Mehlich 1, double acid extractant; 0.1 M sulfuric acid (H2SO4) + 0.1 M HCl (Mehlich, 1953).
3. Bray 1 extractant; 0.03 M NH4F + 0.025 M HCl (Bray and Kurtz 1945).53).
4. Olsen extractant; 0.5 M NaHCO3 and pH adjusted to 8.5 (Watanabe and Olsen 1965).ch, 1953).

From the supernatant of the Mehlich + soil solution mixture, extractable Fe was determined colorimetrically using the orthophenanthroline method at 510 nm. Aluminum was determined colorimetrically by the xylenol orange method at 550 nm, both using a spectrophotometer. Phosphorus saturation ratio (PSR) was estimated as described earlier above.

2.3. Data Analyses

Data obtained were subjected to analysis of variance (ANOVA), and treatment means were separated using the Duncan's multiple range test at the 5% probability level using a statistical analysis system (SAS, 1990). Correlation and regression analyses were done to estimate relationships and their magnitude among the soil P availability indices, PSR and other soil properties.

3. Results and Discussion

3.1. Site Characteristics

In Table 1, it is obvious that the history of the dumpsites varies widely. Animal wastes have been dumped on the farm for as small as two years to more than 30 years, expectedly, the impact of these contrasting years is expected to vary. Sites in Ibadan also had more years of deposition of the waste compared with the sites in Abeokuta. The pictorial representation of the study sites is shown in Figure 1.

3.2. Effect of the Soil depth on P availability indices, PSR and soil properties

The effect of the soil sampling depths on the PSR, soil P availability indices and some soil properties is shown in Table 2. The four availability indices (water-extractable P, Olsen P, Mehlich P and Bray-1 P) were significantly higher in the topsoil (0-20 cm) compared with the subsoil. The high P values in this depth explain why many plants (arable and surface feeders) could not survive on the sites, probably due to P toxicities. The few higher plants (trees and shrubs) that survive are deep feeders that could tolerate the relatively lower nutrients at the subsoil. The environmental implication of this was that water that flows on the soil surface, even at 60 cm soil depth, as runoff or lateral flows stands the chance of exporting a large amount of P to the receiving water bodies. This could cause eutrophication and environmental degradation; such water will not be portable for human use. Mehlich extractable Fe was concentrated in the 0-20 cm depth while Al was higher at 20-60 cm depth. Generally, the PSR at both soil depths is higher than the threshold of 0.1-0.15 suggested by Nair, (2004) and Dari et al. (2018). This implies potential pollution of the soil with phosphorus. However, the tendency to pollute was higher at the 0-20 cm depth. The soil pH and dissolved salt are expectedly higher at the topsoil. The differences in value were only significant in the soil pH.

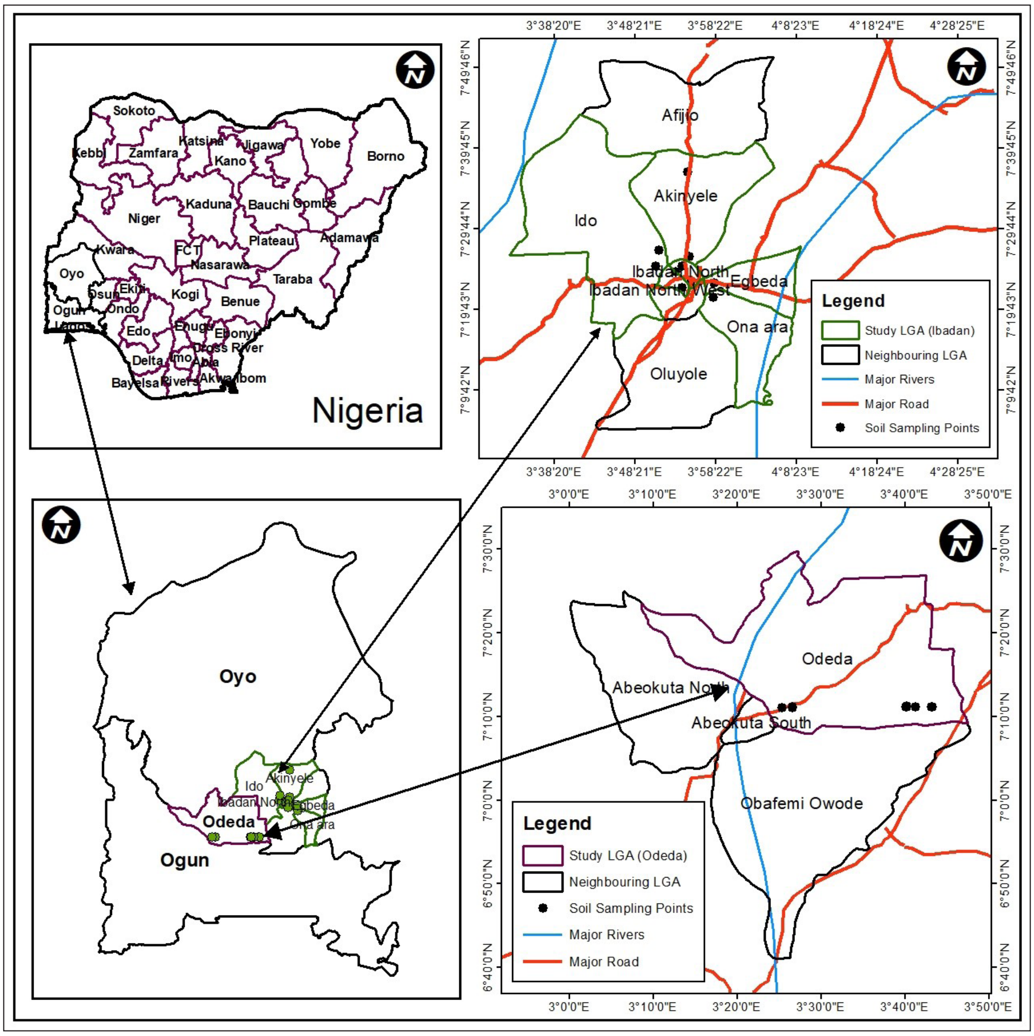

Figure 1. Map showing the study area.

Table 2. Effect of soil depth on PSR, P amounts and some soil chemical properties.

Depth (cm)	Water soluble	Olsen	Mehlich-1	Bray-1	M-Al	M-Fe	PSR	pH	EC
	---------------------------------- mg kg^{-1} ----------------------------------								μS cm^{-1}
0-20	278.16 ± 5.89 a	359.35 ± 15.27 a	426.24 ± 11.25 a	385.64 ± 12.69 a	527.32 ± 27.95 b	1174.3 ± 158.47a	0.42 ± 0.02 a	8.34 ± 0.05 a	872.30 ± 131.50 a
20-60	256.15 ± 3.36 b	305.59 ± 12.61 b	386.35 ± 15.03 b	378.10 ± 15.91 a	809.60 ± 48.39 a	760.80 ± 62.88 b	0.32 ± 0.02 b	7.33 ± 0.07 b	664.30 ± 133. 79 a

M-Al - Mehlich attractable aluminum *PSR – Phosphorus saturation ratio*
M-Fe - Mehlich attractable iron *EC – Electrical conductivity ± Standard error of mean*

3.3. Relationship between phosphorus saturation ratio availability indices and their implications

Figure 2, shows that the relationship between soil PSR and water-extractable P is positive and significant. The figure indicates that all the sites had PSR values higher than the threshold value of 0.10-0.15. It implies that the soils are all polluted with P from the accumulation of animal wastes. Water-soluble P (WSP) is an index of P pollution/availability and the strong relationship ($p < 0.01$) between the PSR and WSP shows that PSR is a valid tool that could be used in determining soil P pollution potential. Other researchers have also reported high PSR value in manure impacted soil with a strong relationship with WSP (Nair 2004; Liao et al., 2015).

Other soil P availability indices showed in Figures 3 and 4 show the same trend. Phosphorus extracted with acids (HCl in Bray 1; and HCl and H_2SO_4 in Mehlich), had all the P amounts higher than the threshold values. With acid extraction, the amount of P extracted is expected to be higher than the WSP. The significant relationship between the PSR and the P amounts by these extractants shows they could be used to predict the PSR. Bray-1 P and Mehlich-P are routinely determined in soil laboratories and hence could be used in the estimation of PSR values of soils. Other earlier researchers have reported that the potential loss of P from soils can be assessed using soil test phosphorus (STP). Extractants like Olsen, Mehlich-3, and acetic acid have been recommended by Miller et al. (1993), though were originally designed to estimate plant-available P. They also reported a certain degree of relationship between STP and the loss of P in runoff in soils of the same type (Hooda et al., 1999)

The effect of the soil organic matter on the PSR is shown in Figure 5. It was observed that the increase in soil organic matter as a result of the deposition of the manures had a significant and positive relationship with the PSR. Hence the more the increase in soil organic matter as a result of manure deposition, the more the soil PSR. It could then be concluded that the soil P pollution as measured by the PSR was caused by the manure deposition. Humus is the product of the decomposition of soil organic matter and it has been reported to be responsible for the sorption of nutrients like phosphate (Azeez and Van Averbeke, 2010). The contribution of the inorganic colloids (clay) to the PSR was estimated as shown in Figure 6. It was revealed that the relationship was negative and significant. This implies that the clay content of the soil had no positive effect on the P saturation of the soil. Hitherto, clay was presumed to be one of the soil components that adsorb phosphate in the soil, but this study shows that the heavy amount of phosphate in the soil is independent of the soil clay amounts. The heavy deposition of the manures could have impacted such a huge effect, over the soil clay P sorption capacity. Hence, for soil near manure dump sites, the soil colloidal ability to sorb P is usually exceeded particularly if such period of dumping is in excess of 10 years as seen in this study.

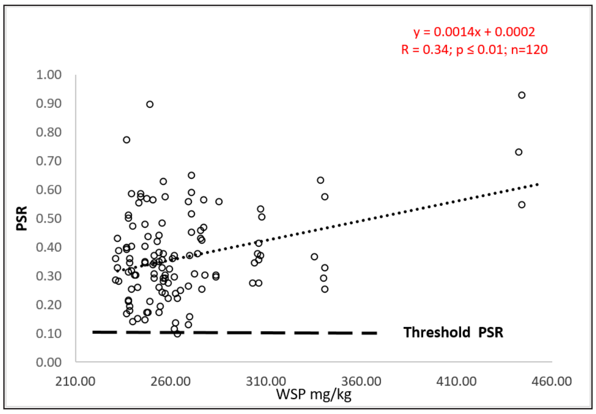

Figure 2. Relationship between P saturation ratio and water-soluble P (WSP).

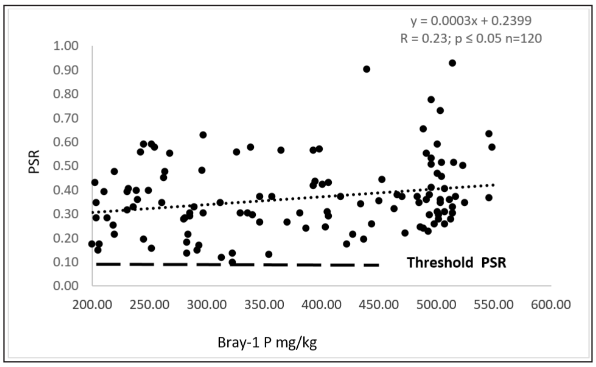

Figure 3. Relationship between P saturation ratio and Bray-1P.

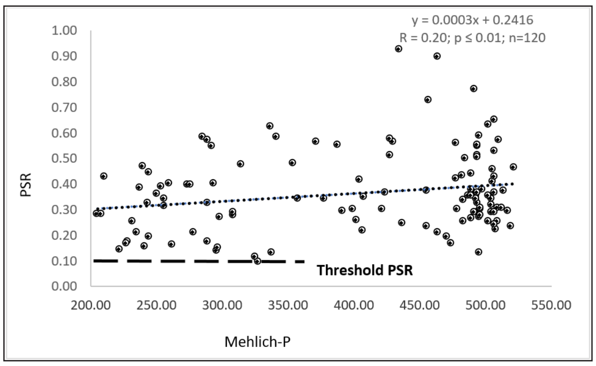

Figure 4. Relationship between P saturation ratio and Mehlich-P.

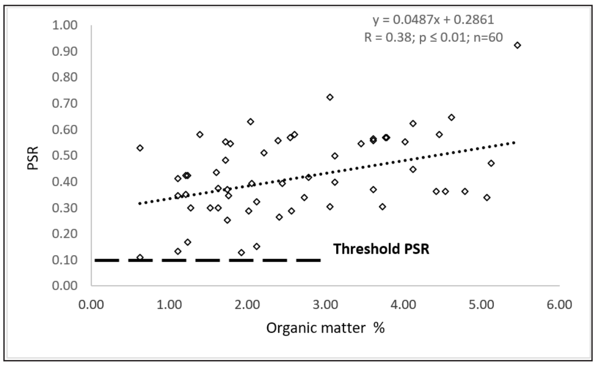

Figure 5. Relationship between P saturation ratio and organic matter.

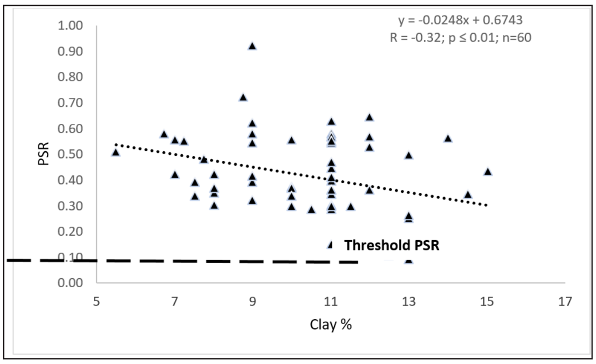

Figure 6. Relationship between P saturation ratio and clay percentage.

The correlation (Table 3) shows that the relationships between the soil P availability indices were positive and significant. This shows the validity in the use of any of the extractant in estimating soil P. The soil PSR had a negative but not significant relationship with Olsen extractable P while the relationship between the soil dissolved salts as measured by the soil electrical conductivity and the soil P availability indices were all positive and significant. It implies that the phosphate salts are among the dominant salts from the manures dumped on the sites. This was also confirmed by the PSR values. The soil clay has a significant correlation with Olsen extractable-P, and Mehlich extractable Fe.

Table 3. Correlation matrix of the Extractants, PSR and other Physico-chemical parameters (n=120).

	Water Soluble $mg\ kg^{-1}$	Olsen $mg\ kg^{-1}$	Mehlich-1 $mg\ kg^{-1}$	Bray-1 $mg\ kg^{-1}$	M-Al $mg\ kg^{-1}$	M-Fe $mg\ kg^{-1}$	PSR	pH	EC (ds/m)	OM§ %
Olsen	0.29**									
Mehlich-1	0.45**	0.64**								
Bray-1	0.50**	0.52**	0.87**							
M-Al	0.03 ns	0.16 ns	0.26**	0.24**						
M-Fe	-0.02 ns	0.31**	0.18 ns	0.09 ns	-0.11 ns					
PSR	0.34**	-0.03 ns	0.20*	0.23*	-0.50**	-0.50**				
pH	0.02 ns	0.14 ns	0.13 ns	-0.02 ns	-0.47**	0.34**	0.16 ns			
EC	0.21*	0.50**	0.32**	0.40**	0.02 ns	0.04 ns	0.11 ns	-0.16 ns		
OM§	0.16 ns	-0.07 ns	-0.05 ns	0.04 ns	-0.18 ns	-0.24 ns	0.38**	-0.32 ns	0.24 ns	
Clay§	-0.13ns	0.34**	0.07 ns	0.13 ns	0.21 ns	0.34**	-0.32*	0.02 ns	0.01 ns	0.03 ns

*** Significant at P0.01;* ** significant at P0.05; § n=60*
M-Al - Mehlich extractable aluminum *M-Fe - Mehlich extractable iron* *PSR – Phosphorus saturation ratio*
OM – Organic Matter *EC – Electrical conductivity*

5. Conclusions

From the study, it could be concluded that:

1. Unregulated and prolonged dumping of manures in soils led to the excess accumulation of phosphorus in the soil environment.
2. Some of the soil P availability indices could be used as a proxy for estimating soil PSR and hence soil P pollution potential.
3. The soil organic matter is a stronger determinant of soil P pollution than clay for soils of manure dump sites.
4. There is potential pollution of surface and groundwater in the vicinities of the dumpsites with the attendant health hazards.

Acknowledgment

The authors wish to acknowledge the assistance of Mr. Anthony Tobore in the graphics.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Azeez, J.O., and Van Averbeke, W. (2010). Fate of manure phosphorus in a weathered sandy clayloam soil amended with three animal manures. Bioresource Technology 101: 6584–6588.

Azeez, J. O., Adekunle, I.O., Atiku, O.O., Akande, K.B., Jamiu-Azeez, S.O. (2009). Effect ofnine years of animal waste deposition on profile distribution of heavy metals in Abeokuta, south-western Nigeria and its implication for environmental quality. Waste Management 29: 2582–2586.

Bouyoucos, G.H. (1965). A calibration of the hydrometer method for testing mechanical analysisof soils. Agronomy Journal 43: 434–438.

Bray, R. H., and Kurtz, L. T. (1945). Determination of total, organic, and available form ofphosphorus in soils. Soil Science Society of America Journal 59: 39–45.

Breeuwsma, A., and Silva, S. (1992). "Phosphorus fertilization and environmental effects in the Netherlands and the PoRegion (Italy),"in Report57. Agricultural Research Department (Wageningen: The Win and Staring Centre for Integrated Land, Soil, and Water Research).

Codling, E. E., Chaney, R. L., Mulchi, C. L. (2000). Use of aluminum and iron rich residues to immobilize phosphorus in poultry litter and litter-amended soils. Journal of Environmental

Quality 29: 1924-1931.

Crowther, J., Kay, D., Wyer, M.D. (2002). 'Faecal-indicator concentrations in waters draining lowland pastoral catchments in the UK: Relationships with land use and farming practices', Water Research 36(7): 1725–1734.

Dari, B., Nair, V.D., Sharpley, A.N., Kleinman, P., Franklin, D., Harris, W.G. (2018). Consistency of the Threshold Phosphorus Saturation Ratio across a Wide Geographic Range of Acid Soils. Agrosystems Geoscience Environment. 1:180028. DOI:10.2134/age2018.08.0028.

Edwards, D.R., and Daniel, T.C. (1992). Environmental impacts of on farm poultry waste disposal- A review. Bioresource Technology 41: 9-33.

Gerba, C.P., and Smith, J.E. (2005). Sources of pathogenic microorganisms and their fate during land application of wastes. Journal of Environmental Quality 34: 42–48.

Hooda, P.S., Rendell, A.R., Edwards, A.C., Withers, P.J.A., Aitken, M.N., Truesdale, V.W. (2000). Relating soil phosphorus indices to potential phosphorus release to water. Journal of Environmental Quality 29:1166–1171. DOI: 10.2134/jeq2000.00472425002900040018x

Hooda, P.S., Moynagh, M., Svoboda, I.F., Thurlow, M., Stewart, M., Anderson, H.A., Sym, G. (1999). Phosphorus loss in drain flow from intensively managed grassland soils. Journal of Environmental Quality 28: 1235-1242.

Liao, X., Liu, G., Hogue, B., Li, Y. (2015). Phosphorus availability and environmental risks in potato fields in North Florida. Soil Use and Management 31: 308–312.

Mclean, E.O. (1982). Soil pH and lime requirement. In: Page A.L. (Ed.), Methods of Soil Analysis. Part 2: Chemical and Microbiological properties, 9.2.2 Second edition. American Society of Agronomy, Inc., Soil Science Society of America, Inc. Agronomy Monographs. DOI: 10.2134/agronmonogr9.2.2ed.c12.

Mehlich, A. (1953). Determination of P, K, Na, Mg, and NH4. Soil Testing Division Publication No. 1–53. North Carolina Department of Agriculture, Agronomic Division. Raleigh, NC.

Murphy, J., and Riley, J.P. (1962). A modified single solution method for the determination of phosphate in natural waters. Analytical Chemistry Acta 27: 31–36.

Miller, D.M., Moore, Jr., P.A., Edwards, D.R., Stephen, D.A., Gbur, E.E. (1993). Determination of water-soluble phosphorus in soil. Arkansas Farm Research 42: 10-11.

Nair, V.D. (2014). Soil phosphorus saturation ratio for risk assessment in land use systems. Frontiers in Environmental Science. Mini review 2 (6): 1-4. DOI: 10.3389/fenvs.2014.00006.

Nair, V.D., Portier, K.M., Graetz, D.A., Walker, M.L. (2004). An environmental threshold for degree of phosphorus saturation in sandy soils. Journal of Environmental Quality 33: 107–113. DOI:10.2134/jeq2004.1070.

Nelson, D.W., and Sommers, L.E. (1982). Total carbon, organic carbon and organic matter. In: Page A.L. (Ed.), Methods of Soil Analysis. Part 2: Chemical and Microbiological properties, 9.2.2 Second edition. American Society of Agronomy, Inc., Soil Science Society of America, Inc. Agronomy Monographs. DOI:10.2134/agronmonogr9.2.2ed.c29.

SAS Institute. (1990). SAS/STAT user's guide, release 6, 4th ed. Cary, N.C.: SAS Institute.

Sauer, T.J., Daniel, T.C. Moore, Jr. P.A., Coffey, K.P. Nichols, D.J., West, C.P. (1999). Poultry Litter and Grazing Animal Waste Effects on Runoff Water Journal of Environmental Quality 28: 860-865.

Sharpley, A., and Tunney, H. (2000). Phosphorus research strategies to meet agricultural and environmental challenges in the 21st century. Journal of Environmental Quality 29: 176–181. DOI:10.2134/jeq2000.00472425002900 010022x.

Sharpley, A., Jarvie, H.P., Buda, A., May, L., Spears, B., Kleinman, P. (2013). Phosphorus legacy: practices to mitigate future water quality impairment. Journal of Environmental Quality 42:1308– 1326. DOI:10.2134/jeq2013.03.0098.

Soupir, M.L., Mostaghimi, S., Yagow, E. R., Hagedorn, C., Vaughan, D.H. (2006).Transport of fecal bacteria from poultry litter and cattle manures applied to pastureland. Water, Air, and Soil Pollution 169: 125–136.

Tian, Y.Q., Gong, P., Radke, J.D., Scarborough, J. (2002). Spatial and temporal modeling of microbial contaminants on grazing farmlands. Journal of Environmental Quality 31(3): 860–869.

United States Environmental Protection Agency (USEPA) (2002). Environmental Indicators of Water Quality in the United States. EPA841-R-02-001. Washington, DC: USEPA Office of Water Quality.

United States Environmental Protection Agency (USEPA) (2003). 'National pollutant discharge elimination system permit regulation and effluent limitation guidelines and standards for concentrated animal feeding operations (CAFOs); final rule', Federal Register 68(29): 7176–7274.

Watanabe, F.S., and Olsen, S.R. (1965). Test of an ascorbic acid method for determining phosphorus in water and NaHCO3 extracts from soil. Soil Science Society of America Proceedings 29: 677–678.

Windhorst, H.W. (2006). Changes in poultry production and trade Worldwide. World's Poultry Science Journal 62: 585-602.