Water quality indicators of the Nima Creek, and potential for sustainable urban agriculture in Ghana

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ABSTRACT
Urban and peri-urban agriculture, a widely accepted practice of food cultivation in urban centers contributes to positive environment. It has the benefits of job creation, increased access to healthy and affordable food, and important means of improving community health. Use of wastewater or disturbed surface water for urban agriculture is a common practice in the developing world due to lack of adequate infrastructure and widespread poverty. This study assessed the urban water quality parameters of the Nima Creek, a major water resource for peri-urban and urban farming in Southeastern Accra. Water sampled from six locations along the NE – SW stretch of the creek were evaluated for physicochemical parameters including pH, conductivity, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), cations, zinc, iron, oil and grease, Biological Oxygen demand (BOD), Chemical Oxygen demand (COD). Results show high enrichment of nutrients, ammonia (NH₃), nitrate (NO₃), and phosphate (PO₄) as well as elevated levels of BOD, COD, and grease at sites receiving solid and liquid wastes. The physicochemical parameters such as conductivity, TSS, and TDS exhibited periods of elevated values that were congruent with seasonal rainfall patterns within the catchment area. Sodium concentration ranged from 32 to 297 mg/L. Nitrate levels generally ranged from 1.3 to 7.13 mg/ L. The cation concentrations showed broad temporal and spatial variation characteristic of disturbed surface freshwater. Principal component analysis of the data discriminated four distinct components accounting for 63.6% of the total variance. The component plots constrained three major classes explaining the physical quality of the water and two other groups defining nutrient and alkalinity levels in the water.

Introduction
Many studies, including Rogerson (1993), Mbiba (1995), and Thornton and Nel (2007) have outlined the benefits of urban/peri-urban agriculture in poverty alleviation and as viable development tools in cities worldwide. Discussions of urban agriculture have often hinged, inter alia, on food crop production, animal husbandry, horticulture, agroforestry, and aquaculture. However, urban/peri-urban agriculture in its wider application covers processing and marketing in intra-urban and peripheries of populated urban zones (Hovorka, 2005). Today, about 55% of the world’s population lives in urban areas, a proportion that is expected to increase to 68% by 2050. The rural-urban shift is expected to be rapid in the developing world, especially in Africa and Asia, accounting for up to 90% of the projected population drift (Drechsel et al., 1999; FAO, 2010; Mougeot, 2000). The increased demand and scramble for food that accompany such population spurs often has dire consequences for the marginalized and urban poor. Urban/peri-urban agriculture when properly implemented has the capacity to increase food production and alleviate poverty through employment creation.

These benefits have inspired many African countries to not only promote but aggressively pursue policies to expand urban/peri-urban agriculture as sustainable approach to intensifying food crop and livestock production (Ahmadi & Merkley, 2017). The broad acceptance of the policy has increased the conversion of many open spaces into flourishing vegetable gardens (Rogerson, 1993). Despite the mass acceptance, widespread poverty and rudimentary farming practices that characterize urban/peri-urban farming in the developing world, remain major setbacks to expansion. Challenges with unreliable rainfall patterns, lack of irrigation infrastructure, and the high cost of sinking groundwater irrigation wells have resulted in increased use of untreated wastewater and/or contaminated surface water for irrigation.

Use of wastewater and surface water irrigation has the advantage of mitigating the impacts of seasonal variations associated with rain-fed agriculture and

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minimize irrigation costs. Wastewater irrigation also promotes water conservation, nutrient recycling, and minimizes fertilizer usage (Benis & Ferrão, 2017; Leslie, Anu, & Priyanie, 2017). However, while the aforesaid benefits contribute positively to crop yield and lower costs, there are real challenges of food crops and soil contamination with pathogens and chemical pollutants, particularly, hydrocarbons, heavy metals, and fecal coliforms (Margenat et al., 2017; Mayilla et al., 2017).

The Nima creek in the city of Accra, Ghana, is a freshwater creek draining vast areas inhabited by a growing urban population. The Creek has its headwaters originating from the Akwapem Mountain range, east of Accra and drains a vast range of settler communities along the foothills of the mountains into the Odaw river. Water from the creek is used for urban agriculture due to its strategic location as the only freshwater resource. Previous studies investigated the pollution risk to soils and crops cultivation (Mohammed et al., 2019; Tay & Biney, 2013) but no major work has assessed the suitability of the water for urban/peri-urban irrigation. This study assessed the physicochemical properties and suitability of water from the Nima Creek for irrigation of urban/peri-urban farm fields.

Methodology

Sampling site description

The Nima Creek in the city of Accra, Ghana, covers a catchment area of 6.7 Km² and receives drainage from a 5.2 Km² urban watershed with headwaters originating from the Akwapem mountain range (latitude 5° 52’N), east of Accra (Amuzu et al., 1995). The Creek lies within latitude 5°35.5’- 5° 35.9’N and longitude 0° 10.9–0° 11.4 W (Figure 1) and traverses a vast expanse of sprawling urban development on the fringes of the capital city where it is diverted for agricultural and industrial uses. The southwesterly flowing creek drains into the Odaw River, a southern major tributary of the Korle lagoon that discharges into the Gulf of Guinea. Land use and land cover in the region consist primarily of sparsely distributed patches of grassland and rapidly sprawling slum settlements. The direct discharge of domestic sewage and agricultural runoffs coupled with discharges of industrial effluents in the creek have potential impacts on the water quality and aquatic life.

This sub-urbanized zone has witnessed a massive surge in agricultural activities (mainly small-scale urban/peri-urban vegetable farming) in the last decades due to an expanding slum settlement on the fringes of the creek. For the purpose of this study

![Figure 1. Northeastern course of the Nima Creek showing six sample locations.](image-url)
Table 1. Mean annual concentration of water quality variables in the Nima Creek.

| Parameters       | NC1  | Stdev.P | NC2  | Stdev.P | NC3  | Stdev.P | NC4  | Stdev.P | NC5  | Stdev.P | NC6  | Stdev.P |
|------------------|------|---------|------|---------|------|---------|------|---------|------|---------|------|---------|
| pH               | 7.28 | 0.31    | 7.34 | 0.40    | 7.38 | 0.38    | 7.45 | 0.43    | 7.47 | 0.40    | 7.55 | 0.46    |
| Conductivity (μS/cm) | 1119.58 | 258.32 | 1079.33 | 201.01 | 1121.25 | 143.44 | 119.58 | 145.80 | 1174.92 | 163.96 | 1207.11 | 197.28 |
| Turbidity (NTU)  | 123.25 | 22.45   | 77.46 | 25.47   | 63.11 | 33.25   | 86.53 | 75.04   | 65.76 | 70.94   | 56.45 | 58.81   |
| TSS (mg/L)       | 301.92 | 438.54  | 112.96 | 65.16   | 359.34 | 604.41  | 171.25 | 183.68  | 124.91 | 138.31  | 108.57 | 119.08  |
| TDS (mg/L)       | 662.17 | 202.14  | 542.17 | 151.79  | 545.58 | 225.52  | 621.17 | 141.07  | 614.50 | 114.35  | 613.58 | 144.91  |
| BOD (mg/L)       | 64.43  | 37.28   | 50.48  | 28.73   | 44.88  | 26.17   | 41.88  | 27.34   | 43.94  | 31.98   | 28.45  | 21.07   |
| COD (mg/L)       | 280.61 | 198.91  | 229.33 | 161.17  | 245.74  | 160.33  | 260.63 | 210.52  | 215.31 | 171.36  | 173.06 | 153.69  |
| Oil/Grease       | 9.04  | 18.83   | 6.28   | 10.67   | 5.49   | 9.32    | 6.36   | 7.94    | 5.64   | 6.09    | 3.92   | 4.44    |
| Ammonia (mg/L)   | 4.20  | 3.36    | 4.19   | 3.73    | 4.68   | 5.34    | 3.67   | 3.82    | 3.96   | 2.62    | 3.89   | 4.64    |
| Nitrate (mg/L)   | 0.65  | 0.91    | 0.60   | 0.90    | 0.34   | 0.56    | 0.29   | 0.51    | 0.34   | 0.33    | 1.20   | 3.35    |
| Phosphate (mg/L) | 0.56  | 0.36    | 0.50   | 0.26    | 0.42   | 0.28    | 0.55   | 0.50    | 0.46   | 0.35    | 0.60   | 0.62    |
| Iron (mg/L)      | 0.25  | 0.12    | 0.27   | 0.13    | 0.26   | 0.15    | 0.23   | 0.17    | 0.24   | 0.15    | 0.20   | 0.14    |
| Lead (mg/L)      | 0.01  | 0.02    | 0.01   | 0.01    | 0.01   | 0.01    | 0.01   | 0.01    | 0.01   | 0.01    | 0.01   | 0.01    |
| Zinc (mg/L)      | 0.07  | 0.12    | 0.04   | 0.07    | 0.06   | 0.08    | 0.03   | 0.04    | 0.03   | 0.05    | 0.03   | 0.04    |
| Calcium (mg/L)   | 36.93 | 11.46   | 41.37  | 9.44    | 39.81  | 10.66   | 42.40  | 10.08   | 43.84  | 12.23   | 42.32  | 11.41   |
| Magnesium(mg/L)  | 21.99 | 14.47   | 21.61  | 10.67   | 25.68  | 15.21   | 26.52  | 14.48   | 26.42  | 14.88   | 24.84  | 10.44   |
| Sodium (mg/L)    | 127.61| 55.60   | 122.78 | 47.47   | 130.21 | 54.77   | 129.06 | 51.05   | 136.84 | 72.50   | 144.44 | 72.27   |
analysis, ANOVA, and Pearson correlation coefficient were conducted using IBM SPSS Statistics, version 25.

Results and discussion

Table 1, highlights of the mean annual water quality parameters at the various sample sites. The data showed minimum variation in water quality parameters across all sample sites except for total dissolved solids (TDS) and conductivity which exhibited trends of increasing concentration from site, NC2 to the downstream location of NC6. Moreover, total suspended solids (TSS) showed elevated peaks at stations NC1 and NC3, recording average values of 302 mg/L and 359 mg/L respectively.

Some of the water quality parameters demonstrated broad seasonal patterns within the catchment area. For instance, periods of elevated TDS, TSS, and turbidity showed a positive correlation with the rainy season (Table 2). Turbidity ranged from 5 to 874 NTU, recording peak values in June and lowest (<50 NTU) in the dry season, particularly, in August and December – February. In addition to domestic wastewater discharge, the creek receives high sediment (e.g. clay, silt, organic matter, etc.) input via urban runoff during the rainy season. Similarly, periods of elevated TSS and TDS, 1630 mg/L, and 1055 mg/L respectively, showed great congruence with the rainy season (Figures 1 and Figures 2). It is worth noting that the portion of the Creek recording elevated TSS and TDS also receives significant agricultural runoff. There is, however, a lack of statistical significance (ANOVA, P > 0.05) in the mean annual TDS (542 to 662 mg/L) recorded at the individual sample sites. The monthly measurements showed marginal increases in the rainfall months, with TDS increasing to >800 mg/L. Although the high Rainfall Season recorded elevated values (800–1055 mg/L), the TDS levels remain within the permissible limits of water for agricultural use (Canadian Council of Ministers of the Environment [CCME], 2012). Consequently, soil salinity problems associated with high TDS in irrigation water will likely not occur in the short to medium term under normal irrigation practices. It is also worth mentioning that most vegetables cultivated within the catchment of the Nima Creek (e.g. onion, pepper, spinach, cucumber) typically have a high tolerance for elevated salinity, up to 2500 mg/L (CCME, 2012). This notwithstanding, long-term irrigation could impair the soil’s capacity to sustainably support long-term vegetable production due to potential salinity buildup from recurrent irrigation. Salinization of agricultural soils increases the osmotic pressure of soil solution with a concomitant decline in water availability for plant uptake (Machado & Serralheiro, 2017). The potential long-term soil salinization could be mitigated by the adoption of modern irrigation practices such as a drip irrigation.

Conductivity values were generally high at all sample locations, ranging from 588 to 1630 μS/cm and showed a positive correlation with dissolved ions (calcium, sodium, and magnesium), albeit moderate associations for Ca and Na (Table 2, Figure 2). The highest mean conductivity of 1630 μS/cm was recorded in October at the downstream site, NC6 relative to the 588 μS/cm measured in August at the upstream location, NC1. Analysis of variance (ANOVA) suggests statistically significant (P < 0.05) differences between the monthly conductivity levels in the Creek. Although Figure 2, exhibits a trend of increasing mean annual electrical conductivity downstream, there is a lack of significant differences between the individual sample locations. Mean year-round conductivity at the individual sites approximated to the upper limit (i.e. 1000 μS/cm) of the permissible conductivity range for freshwaters with values ranging from 1079 μS/cm at NC2, to >1207 μS/cm at station NC6. It is not uncommon to record values >1000 μS/cm in freshwaters receiving urban runoffs and industrial effluent.

Sodium concentration ranged from 32 to 297 mg/L. The cation concentration was greatest at downstream stations, NC5 and NC6, recording the concentrations >200 mg/L (Figure 3(a)) in the period February – March. Figure 3(a), shows a gradual monthly decline from the peak February value of 285 mg/L, to 91 mg/L in August. It is important to note that Na readings of September to December were excluded from further assessment due to a defective probe. The elevated levels in February and March are attributable to point source discharges. Other major cations, Ca and Mg exhibited variable patterns of enrichment (Figure 3(b, Figure 3c) respectively). Calcium levels in the water samples were particularly high at all sample locations, recording values from 53.6 to 70 mg/L (Figure 4(a–Figure 4f)). Downstream locations, NC4, NC5, and NC6 were the most enriched (Figure 4(d–Figure 4f)), recording mean annual concentrations of 65.4 mg/L, 78 mg/L, 70 mg/L, respectively, while the upstream site, NC1 recorded the lowest concentration. Magnesium, on the other hand, showed a pattern of high enrichment in November and December (Figure 3(c)).

While the three major cations, Na, Ca, and Mg occur naturally in surface waters, the levels in freshwater could significantly be impacted by land use activities and point source input within the catchment area. To evaluate the suitability of water for irrigation based on sodium and related major cation enrichments, the sodium adsorption ratio (SAR) was calculated to assess the sodium hazard associated with the use of water from the Creek for irrigation. The mean annual SAR values at all sample stations ranged from 3.8 to 4.3, suggesting a slightly sodic water. According
|          | pH   | Conductivity | Turbidity | TSS  | TDS  | BOD  | COD   | Grease | NH4  | NO3  | PO4  | Fe    | Zn    | Ca    | Mg    | Na    |
|----------|------|--------------|-----------|------|------|------|-------|--------|------|------|------|-------|-------|-------|-------|-------|
| pH       | 1.000| 0.118        | 0.198     | 0.081| -0.137| -0.261| -0.0183| 0.370  | -0.031| -0.141| -0.085| -0.264| 0.008 | 0.486 | 0.008 | 0.339 |
| Conductivity | 0.118| 1.000        | 0.391     | 0.389| 0.443 | 0.326 | 0.225  | 0.576  | -0.008| 0.226  | -0.203| -0.276 | -0.085 | 0.373 | 0.672 | 0.454 |
| Turbidity | 0.198| 0.391        | 1.000     | 0.592| -0.022| 0.227 | 0.381  | 0.767  | 0.128  | -0.069| 0.022  | -0.170| 0.337  | 0.298  | 0.267 | 0.231 |
| TSS      | 0.081| 0.389        | 0.592     | 1.000| -0.112| 0.166 | 0.231  | 0.478  | 0.012  | -0.046| -0.003| 0.008 | 0.114  | 0.169  | 0.292 | 0.157 |
| TDS      | -0.137| 0.443       | 0.022     | -0.112| 1.000| 0.472 | 0.181  | -0.126| 0.147  | -0.091| -0.100| -0.293| -0.042 | -0.350 | 0.272 | -0.177 |
| BOD      | -0.261| 0.326       | 0.217     | 0.166| 0.472 | 1.000 | 0.545  | 0.143  | 0.415  | -0.241| -0.319| -0.225| 0.144  | 0.389  | 0.176 | -0.198 |
| COD      | -0.183| 0.225       | 0.381     | 0.231| 0.181 | 0.545 | 1.000  | 0.196  | 0.644  | -0.199| 0.125  | 0.073  | 0.005  | -0.059 | 0.094 | 0.061 |
| Grease   | 0.370| 0.576        | 0.767     | 0.478| -0.126| 0.143 | 0.196  | 1.000  | -0.126| 0.113  | -0.166| -0.214| 0.246  | 0.600  | 0.248 | 0.492 |
| NH₄      | -0.031| 0.008       | 0.128    | 0.012| 0.147 | 0.415 | 0.644  | -0.126| 1.000  | -0.248| 0.018  | -0.027 | 0.016  | -0.149| -0.054 | -0.127 |
| NO₃      | -0.141| 0.226       | -0.069   | -0.046| -0.091| -0.241| -0.199 | 0.133  | -0.248| 1.000  | -0.041| -0.177| -0.091 | 0.255  | 0.284 | 0.353 |
| PO₄      | -0.085| 0.203       | 0.022    | -0.003| -0.100| -0.319| 0.125  | -0.166| 0.018  | -0.041| 1.000  | 0.340  | -0.143 | -0.068 | -0.132 | 0.008 |
| Fe       | -0.264| -0.276      | -0.170   | 0.008| -0.293| -0.225| 0.073  | -0.214| -0.027| -0.177| 0.340  | 1.000  | 0.049  | 0.130  | -0.086 | -0.092 |
| Zn       | 0.008| -0.085      | 0.337    | 0.114| 0.042 | 0.144 | 0.005  | 0.246  | 0.016  | -0.091| -0.143| 0.049  | 1.000  | 0.023  | -0.093 | -0.235 |
| Ca       | 0.486| 0.373       | 0.298    | 0.169| -0.350| -0.389| -0.059 | 0.600  | -0.149| 0.255  | -0.068| 0.130  | 0.023  | 1.000  | 0.210 | 0.603 |
| Mg       | 0.008| 0.672       | 0.267    | 0.292| 0.272 | 0.176 | 0.094  | 0.248  | -0.054| 0.284  | -0.132| -0.068 | -0.093 | 0.210  | 1.000 | 0.254 |
| Na       | 0.339| 0.454       | 0.231    | 0.157| -0.177| -0.198| 0.061  | 0.492  | -0.127| 0.053  | 0.008  | -0.092 | -0.235 | 0.603  | 0.254 | 1.000 |
to FAO classification, measured SAR >3.0 coupled with the low Ca²⁺ and Mg²⁺ concentration in the water could pose medium risks to soil structure by reducing its permeability.

The biochemical oxygen demand (BOD) and chemical oxygen demand (COD) levels in water are indirect indicators of the health and capacity of the water to support biological life. Like all parameters, BOD levels in the water samples showed broad temporal and spatial variation with values ranging from 1.5 to 136 mg/L. The site, NC1, recorded high BOD values of 136 mg/L and 112 mg/L in the months of June and September, respectively (mean annual value of 72 mg/L). The elevated BOD at NC1, is a consequence of nutrient input from peri-urban fields and domestic sewage discharges from the expanding settlements along catchment area. In contrast, the downstream location, NC6, an area with minimum anthropogenic impact recorded the lowest BOD, 4.2–70.1 mg/L. Periods of low BOD, <10 mg/L corresponded with periods of low rainfall (May and July–August), suggesting minimal biological activity associated with edge-of-field nutrient input. There is, however, no statistically significant difference (ANOVA, P > 0.5) between BOD levels at the individual sample locations as well as between the monthly measurements. The exception, nonetheless, is in February where BOD peaked at 97 mg/L. Previous studies on sections of the Creek reported a broad range of BOD at different times in the Creek. For instance, Amuzu et al. (1995) recorded BOD in the range 2.5 mg/L to 690 mg/L, Baa-poku, Asante, and Amake (2013) reported 5.0 to 54 mg/L and Dartey (1999) recorded mean BOD of 39 mg/L.

Similarly, the COD levels in the Creek exhibited clear patterns of temporal and spatial variation, recording peak values in November and minimum in August. The highest COD of 879 mg/L and 898 mg/L were recorded, respectively, at sites, NC3 and NC5. The measured COD showed no significant difference (ANOVA, p < 0.05) between the sampling sites. It is worth noting that BOD and COD levels in the Creek showed congruence with the seasonal rainfall patterns. The main contributors to the observed temporal and spatial variations are land use and anthropogenic input of municipal/domestic wastes. Particularly, areas receiving untreated waste, agricultural runoff (natural and inorganic fertilizers), and agriculture/industrial effluent, e.g. waxes and hydrocarbons from car repair garages and related small-scale manufacturing seemed most enriched.

Nutrients – nitrate, nitrite, and ammonia are responsible for productivity of surface waters. Figure 4(a–Figure 4f), show the variable nitrate enrichment at different sampling stations with annual nitrate concentrations in the Creek ranged from 0.001 to 7.13 mg/L. Nitrate level was generally >1.5 mg/L in the Creek but below the chronic guideline of 3.0 mg/L for freshwater for aquatic life (CCME, 2012; Nordin, 1986) except at the downstream site, NC6 where the concentration peaked at 7.13 mg/L in May (Figure 3(b)). The elevated May concentration is linked to the onset of the raining season and peak planting season where nitrate fertilizer and manure are heavily applied to cropland. Chapman (1996), explained that elevated nitrates (>5 mg/L) in freshwater are generally associated with an anthropogenic nutrient input. Sources of nitrates at this downstream site include contributions from inorganic fertilizer, poultry manure, and untreated municipal waste.

While the average annual concentration of ammonia at all sample sites appeared relatively stable with concentrations ranging from 5.34 to 18.7 mg/L (Figure 3(a)), the April levels at upstream sites, NC1, NC2, and NC3 were relatively high, ranging 12.1–18.7 mg/L (Figure 4(a–Figure 4c)). Notwithstanding the high peaks recorded in April (Figure 3(a)), no significant differences (ANOVA p > 0.05) were observed between mean annual concentrations across the different sample sites, suggesting an edge-of-field nutrient input. Unlike NO₃ and NH₄, phosphate presented bimodal peaks that are consistent with the rainfall pattern.
The concentration of PO$_4$ ranged from 0.1 to 2.5 mg/L. Thus, the highest concentrations were recorded at the downstream site, NC6, and the lowest, 0.1 at NC3. The low phosphate level in the Creek is consistent with low chemical fertilizer usage that characterize urban/peri-urban farming.

Oil and grease (OG) content of the water was generally low, <10 mg/L year-round, except February, which recorded markedly high concentrations, 16.0 mg/L to 71 mg/L at all sample sites. Samples collected in February exhibited a trend of decreasing OG concentration downstream. The concentration declined from the maximum value of 71 mg/L at NC1 to 16 mg/L at NC6. The spatial variation is attributed to anthropogenic input at locations upstream of the study site. In contrast to the February values, the average annual concentration at each sample site was markedly low, varying from 4 mg/L to 9.0 mg/L. Pearson correlation coefficients in Table 2, illustrate a strong association between OG, turbidity, and TSS in the water.
Table 3. The extracted principal components of water quality variables in the Nima Creek.

| Component | 1         | 2         | 3         | 4         |
|-----------|-----------|-----------|-----------|-----------|
| Grease    | 0.877     | −0.100    | 0.221     | −0.191    |
| Conductivity | 0.803    | 0.193     | −0.388    | 0.172     |
| Turbidity (NTU) | 0.741   | 0.203     | 0.412     | −0.114    |
| Na        | 0.616     | −0.427    | −0.098    | 0.296     |
| Ca        | 0.614     | −0.582    | 0.167     | 0.079     |
| TSS       | 0.585     | 0.132     | 0.320     | 0.058     |
| Mg        | 0.565     | 0.117     | −0.420    | 0.292     |
| BOD       | 0.198     | 0.861     | −0.088    | −0.103    |
| COD       | 0.277     | 0.650     | 0.359     | 0.401     |
| TDS       | 0.070     | 0.609     | −0.517    | 0.000     |
| NH4       | −0.002    | 0.605     | 0.296     | 0.197     |
| NO3       | 0.220     | −0.378    | −0.479    | 0.232     |
| Fe        | −0.285    | −0.172    | 0.474     | 0.474     |
| PO4       | −0.210    | −0.144    | 0.363     | 0.579     |
| Zn        | 0.109     | 0.144     | 0.387     | −0.544    |
| pH        | 0.380     | −0.381    | 0.130     | −0.370    |

Extraction Method: Principal Component Analysis.
a. four components extracted.

Principal component analysis discriminated four major components (Table 3) with Eigen values >1 and accounted for 63.6% of the total variance. The first component accounting for 23.9% of the total variance is constrained by inputs associated with urban runoffs. It is characterized by high positive loadings for grease, conductivity, turbidity, Na, Ca, TSS and Mg. Component two, is explained by 18.1% of the total variance and has high positive loading for NH4, NO3, COD, and TDS. This component clearly represents the influence of peri-urban agriculture on the Creek and is defined most importantly by soil organic nitrates and edge-of-field nutrient transport from farm fields within the catchment of the Nima Creek. Ammonia, a major component of fertilizer and manure is highly soluble in water. Component three, has high to moderate positive loadings for Fe, PO4, Zn, and turbidity that are strikingly incongruous with TSS, TDS, NO3, conductivity, and Mg and is discriminated by 12% of the total variance. Contributions to this component likely include heavy metal leaching from soil and anthropogenic contributions associated with nutrient-rich (NO3, PO4, etc.) industrial and municipal sewage. Component four, on the other hand, explains the biological activity in the water and...
accounts for 9.5% of the total variance. This component has high loadings for BOD, COD, NH₄, and NO₃.

A two-component plot (Figure 5) of the defined PCA factors discriminated three major groups — group one, comprised of Zn, TSS, turbidity, and grease defines the physical quality parameters whereas groups two and three, respectively, highlight nutrient and alkalinity levels of the Creek. In a related study, PCA analysis of spatial water quality and contaminant provenance in Northern, Eastern, and Western regions of the Pearl River delta (China) constrained organic related parameters (DO and COD₅), inorganic nutrients and metal Hg as dominant controls of the water quality (Fan et al., 2010). The year round sodium adsorption ratio range ranged from no alternative source of irrigation water. The Creek is, therefore, a very important resource for urban/peri-urban farming because of its year-round supply of irrigation water. The use of this low-quality water has the added advantage of increased soil and crop nutrients in irrigation water, low utilization of chemical fertilizers, vegetable production all year round, sustainable income, and also job creation in the predominantly settler community.

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### Disclosure statement

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### References

Ahmadi, L., & Merkley, G. P. (2017). Wastewater reuse potential for irrigated agriculture. *Irrigation Science, 35* (4), 275–285.

Amuzu, A. T., Nana-Amankwaah, E., & Bosque-Hamilton, E. K. (1995). Impact of development and urbanization on urban river water quality – The Nima Creek Example (Technical Report #33). CSIR - Water Research Institute. Baa-poku, J., Asante, F., & Amakye, J. S. (2013). Impact of urban effluent on microinvertebrates of a Creek in Accra, 2017.
Leslie, FAO, Fan, Dartey, Chapman, Canadian (2017). Standard methods for the examination of water and wastewater (23rd ed.). Washington, DC: American Public Health Association.

Benis, K., & Ferrão, P. (2017). Potential mitigation of the environmental impacts of food systems through urban and peri-urban agriculture (UPA) – A life cycle assessment approach. Journal of Cleaner Production, 140(Part 2), 784–795.

Canadian Council of Ministers of the Environment (CCME). (2012). Canadian water quality guidelines for the protection of aquatic life: Nitrate. In Canadian environmental quality guidelines. Winnipeg: Canadian Council of Ministers of the Environment. ISBN 1-896997-34-1. No. 1299

Chapman, D. (1996). Water quality assessments – A guide to use of biota, sediments and water in environmental monitoring (2nd ed.). Cambridge: University Press.

Dartey, G. A. (1999). Assessment of microbial population of a stream and a hotel effluent. Institute of science and technology (pp. 43). Ghana: Water Research Institute.

Drechsel, P., Quansah, C., & Penning De Vries, F. (1999). Urban and peri-urban agriculture in West Africa: Characteristics, challenges, and need for action. In Urban agriculture in West Africa: Contributing to food security and urban sanitation. Ottawa, ON: IDRC. ISBN 0-88936-890-2. pg 19

Fan, X., Cui, B., Zhao, H., Zhang, Z., & Zhang, H. (2010). Assessment of river water quality in Pearl River Delta using multivariate statistical techniques, international society for environmental information sciences 2010 annual conference (ISEIS). Procedia Environmental Sciences, 2, 1220–1234.

FAO, F (2010). Climate-smart agriculture. Policies, practices and financing for food security, adaptation and mitigation. In The Hague Conference on Agriculture. Food Security and Climate Change, pg 13

Hovorka, A. J. (2005). The production of gendered positionality in Botswana’s commercial urban agriculture sector. Annals of the Association of Geographers, 95(2), 294–313.

Leslie, M. R., Anu, R., & Priyanie, A. (2017). Wastewater treatment and reuse in urban agriculture: Exploring the food, energy, water, and health nexus in Hyderabad, India. Environmental Research Letters, 12(7), 075005.

Machado, R. M. A., & Serralheiro, R. P. (2017). Soil salinity: Effect on vegetable crop growth. Management practices to prevent and mitigate soil salinization. Horticulture, 3(30), 1–13.

Margenat, A., Matamoros, V., Diez, S., Canameras, N., Comas, J., & Bayona, J. M. (2017). Occurrence of chemical contaminants in peri-urban agricultural irrigation waters and assessment of their phytotoxicity and crop productivity. Science of the Total Environment, 599 (Supplement C), 1140–1148.

Mayilla, W., Keraita, B., Ngowi, H., Konradsen, F., & Magyane, F. (2017). Perceptions of using low-quality irrigation water in vegetable production in Morogoro, Tanzania. Environment, Development and Sustainability, 19(1), 165–183.

Mbiba, B. (1995). Urban agriculture in Zimbabwe: Implications for urban management and poverty (pp. 213–220). Avebury, Aldershot: Urban Food Systems Governance and Poverty in Africa.

Mohammed, S., Obiri, S., Ana-Asare, O. D., Dartey, G., Kuddy, R., & Appiah, S. (2019). Assessment of concentration of polycyclic aromatic hydrocarbons (PAHs) in vegetables from farms in Accra, Ghana. Environmental Monitoring and Assessment, 191(7), 417.

Mougeot, L. J. (2000). Urban agriculture: Definition, presence, potentials and risks, and policy challenges. Cities Feeding People Series, Rept. 31.

Nordin, R. N. (1986). Water quality criteria for nitrogen (nitrate, nitrite, and ammonia): Technical appendix. Canada.

Rogerson, C. M. (1993). Urban agriculture in South Africa: Scope, issues and potential. Geoforum, 30, 21–28.

Tay, C. K., & Biney, C. A. (2013). Levels and sources of polycyclic aromatic hydrocarbons (PAHs) in selected irrigated urban agricultural soils in Accra, Ghana. Environmental Earth Sciences, 68(6), 1773–1782.

Thornton, A. C., & Nel, E. (2007). The Significance of urban and peri-urban agriculture in Peddie the Eastern Cape Province, South Africa. Africanus, 9(1), 13–20.