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Spatio-temporal variations in chemical-physical water quality parameters influencing water reuse for irrigated agriculture in tropical urbanized deltas

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1.0 Introduction

Water is one of the most vibrant resources on this planet, and only 2.5% of the total global water resource is fresh (Shiklomanov, 1998). Climate change, rapid urbanization is affecting water quality and threatening the availability of freshwater sources causing water scarcity in many regions of the world (Eslamian, 2016; Frederick and Major, 1997; Sophocleous, 2004). At present, water scarcity is considered to be one of the most significant threats to society, and also a constraint for ensuring sustainable development (Eslamian, 2016; Jiménez and Asano, 2008). Delta areas around the world are more vulnerable to water scarcity due to their proximity to the sea. Sea level rise induces salt water intrusion, a serious threat for agricultural production feeding growing populations in delta regions. Besides, intensified anthropogenic activities in the delta areas have led to the increasing discharge of solid waste and wastewater into the environment without prior treatment leading to the deterioration of surface water and groundwater quality. Wastewater originates mainly from drinking water and represents, therefore, a potential freshwater resource; it is often only considered as a source of pollution to be treated and discharged and not reused as a valuable resource. Urban water reuse is an

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inevitable solution to scarcity in irrigation water, especially in the delta regions due to its availability, freshwater character, and its richness with nutrients essential for agricultural production. Research indicated that water reuse could help cities and surrounding areas in closing water cycle and decrease the water demand to improve their water self-sufficiency (Agudelo-Vera et al., 2012; Leusbrock et al., 2015). Upgraded wastewater can be cascaded to nearby agriculture in the delta areas to provide with freshwater and nutrients and help to mitigate salinization.

Water quality is an essential indicator to determine the reuse potential. Water quality varies with geographic location, season, weather, human activities, site-specific conditions and the presence of pollution sources. Point source pollution like domestic or industrial wastewater loads can easily be identified, and therefore managed, whereas non-point source pollution like urban or agricultural runoff increases the complexity in finding and implementing quality improvement measures (Ongley et al., 2010; Shi et al., 2017; Tran et al., 2019, 2015; Wang et al., 2016). Land use and environmental land use conflicts represented by the use of land disrespecting soil capability is a source of water pollution that plays a pivotal role in determining water quality (Giri and Qiu, 2016; Junior et al., 2014; Pacheco and Fernandes, 2016). Numerous previous studies concluded that there is a significant correlation between land use and water quality (Bu et al., 2014; Ding et al., 2016; Giri et al., 2018; Mainali and Chang, 2018; Rozario et al., 2016; Saeidi et al., 2018; Tran et al., 2015; Tu, 2011; Wang and Zhang, 2018; Wijesiri et al., 2018; Yua et al., 2016). In general, the higher percentage of anthropogenic land use associated with a higher level of activities contribute to a higher concentration of pollutants in water systems in comparison with natural areas like a forest, urban vegetation that sustain good water quality (Álvarez et al., 2017; Pacheco et al., 2015; Santos et al., 2015; Tu, 2011). However, this relationship is interpreted inconsistently in literature due to the varieties in the physical environment, changing economic activities, and entanglement of the natural and

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anthropogenic area's in contact with water bodies making a comprehensive assessment difficult. Moreover, in the delta areas, this relationship has not yet been addressed in a consistent quantitative way. In this study, we address this knowledge gap for the delta areas by developing a spatio-temporal method in which a multitude of water quality parameters is mapped spatialy and then evaluated concerning the suitability for reuse in irrigated agriculture. The research objectives of this paper are, (1) to provide a method to assess the spatial variations of water quality for macro quality parameters relevant for agriculture in different seasons; (2) to quantify the influence of land-use on water quality and identify the influence radii and finally; (3) to determine the spatio-temporal potential area for reuse of urban water in agriculture.

The method is tested in Khulna, the delta city of Bangladesh which is one of the most vulnerable regions in the world because of climate change induced natural disasters (flood, cyclones, draught) and resources degradations (higher salinity level in soil and water) (Karim and Mimura, 2008). Without proper mitigation measures, farmers living in the region will increasingly struggle to find adequate irrigation water, due to climate change induced salinity increase in solid and water and competition over available freshwater sources. Planned urban water reuse along with other sustainable methods like rainwater harvesting, multi-sourcing could provide a significant share of the required irrigation water and help farmers in combating irrigation water scarcity.

2.0 Materials and Methods:

2.1 Study area selected for testing the method:

The south-west coastal region of Bangladesh is one of the most vulnerable areas to climate change, and Khulna city is the central administrative capital of this region. Khulna is also the third-largest city in the country and one of the primary recipient of migrants from surrounding areas (Kartiki, 2011). The city has two big rivers, Rupsha, and Bhairab on the east side and Mayur river flows on the west side (Figure 1) and they are the major recipient of the discharged

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wastewater. Large volumes of urban wastewater are disposed-off in these rivers without utilizing its real potential. The city has 22 natural canals running throughout the city and about 1165 km man-made drains, which play a crucial role in water circulation as well as wastewater transportation (KCC, 2011; Roy et al., 2018). The city accommodates more than 0.6 million people (BBS, 2011) within its existing 45km^2 jurisdictional area. Due to population pressure and increased economic significance, the city authority is planning to acquire an adjacent 40 km^2 area on the west side to extend the city area. Residential land use (23%) followed by waterbody (10%) dominates the land-use in the city (KCC, 2011). The adjacent area of the city is dominated by agricultural land use (27%), which is awaiting transformation to meet the demand of the rapid urbanization. The topographic map of the study area shows that the general slope of the land is from north to south alongside the bank of Rupsha and Bhairab river and the lateral slope is downward from the river bank meaning the eastern part of the city is higher than the western side (Figure 1).

Figure 1

The peri-urban areas of South Asia always play an important role in the development of urban areas by providing land and water resources to the urban residents (Prakash and Singh, 2013). However, defining a peri-urban area in the context of rapidly urbanizing delta areas is quite challenging as it goes beyond geographic location. In general, the peri-urban area can be termed as the area in the "proximity to the city" which undermines the clear understanding of urban-rural spectrum as interactive, dynamic and transformative (Iaquinta and Drescher, 2000). The area is also referred to as rural fringe but should also coexist in the social, environmental, physical, institution, and economic terms (Allen et al., 2006; Narain and Nischal, 2007). The adjacent areas of the Khulna city still dominated by agricultural areas which produce agricultural products mostly consumed by the urban population. Existing infrastructural development trend and need of the city indicates that those agricultural areas are soon to be

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transformed into urban built-up areas. However, to determine the system boundary for this study, the proposed adjacent areas of the city (more than 40km^2) will be termed as peri-urban area whereas the city's existing administrative area (more than 45km^2) will be called as a main urban area.

2.2 Sampling: Collection and Laboratory Analysis

The wastewater generated by different anthropogenic activities in Khulna city is discharged into open water sources. Wastewater generated in the residential areas is collected in open drains and canals, which then finally released into the rivers without treatment. In most cases, mills-industries also discharges the effluent directly into the rivers. Farmers extract irrigation water from these polluted rivers resulting in indirect wastewater use in agriculture (Qadir et al., 2010). The city also has a number of enclosed waterbodies (also known as ponds) that are being used for small scale agriculture (home gardening) as well for daily activities (bathing, washing, etc.). A total of 25 water quality monitoring stations (Figure 2) including rivers, canals, drains and enclosed waterbody were selected for sample collection. Monitoring stations were chosen considering the land-use pattern, accessibility (for example a large area in the northern part of the city has restricted entry so no sample could be taken there), distance to the laboratory and the ability to cover the distance within a day.

Figure 2

Based on the Koppen-Geiger climate classification map, Khulna city falls within the tropical climate zone which has an equatorial wet and dry climate (Kottek et al., 2006; Mourshed, 2011). By analyzing the climatic data of last 15 years, the climate of Khulna city can be divided into: hot summer from March to June with high temperature (between 32°C to 36°C) with occasional rainfall, hot and humid monsoon from July to October with heavy rainfall (more than 67% of the total annual rainfall) with moderate temperature (around 32°C) and finally the cooler (between 13°C to 19°C) drier winter from November to March. Based on the climate

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126 classification of the city, sample collection and analysis for the winter period was performed in
127 January-February, for the summer period in April-May and for the monsoon period in
128 September-October, 2018.
129 Water quality can be assessed based on chemical-physical, biological, and radiological and
130 micro-chemical characteristics, and this study focuses on only the macro chemical-physical
131 parameters. Samples were collected at 40-50 cm depths in 2-liter PET bottles from the sampling
132 stations. The bottles were labeled correctly and sealed before transporting to the laboratory. All
133 analysis was performed based on the standard methods developed for the examination of a
134 chemical-physical parameter of water (APHA/AWWA/WEF, 2012; Ramesh and Anbu, 1996).
135 Basic physical measures like pH, electrical conductivity (EC), temperature, total dissolved
136 solids (TDS), dissolved oxygen (DO), turbidity were determined by portable water quality
137 multi-probe meters. Nitrate (NO_3^-) was measured using ultraviolet spectrophotometric
138 screening method, whereas sulfate (SO_4^{2-}) was measured using the turbidimetric method, and
139 phosphate (PO_4^{3-}) was measured using the ascorbic acid method. Ammonia-Nitrogen (NH_3-N)
140 was measured using spectrophotometer while sodium (Na^+) and potassium (K^+) were measured
141 using flame photometer. Calcium (Ca^{2+}), chloride (Cl^-), bicarbonate (HCO_3^-), and magnesium
142 (Mg^{2+}) were determined through titration method. Total suspended solids (TSS) was measured
143 using oven dried method.
144 These parameters were further divided into three groups (Table 1) for further use in the
145 study as i) generic parameters ii) saltwater influenced indicator parameters and iii) urban
146 wastewater-impacted indicator parameters.
147 **Table 1**
148 Salinity is considered as one of the most critical factors for determining water quality for
149 agricultural use as the soil can create an unfavorable environment and provoke toxicity due to
150 salinity (Bauder et al., 2014; Jeong et al., 2016). In addition to that, the yield can be reduced

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due to sodium imbalance, also known as Sodium Absorption Ratio (SAR). SAR is used to assess the potential infiltration problem caused by excessive sodium in irrigation water. SAR can be derived using the following formula based on (Ayers and Westcot, 1985; Bauder et al., 2014):

$$\text{SAR} = \frac{Na^{+} meq/L}{\sqrt{\frac{(Ca^{++} meq/L) + (Mg^{++} meq/L)}{2}}} \qquad (1)$$

where meq/L = mg/L divided by atomic weight of ion divided by ionic charge

2.3 Land-use within a different radius of sampling stations

Geo-database of the city was collected from the municipal service and land-use planning authority (Khulna City Corporation and Khulna Development Authority). The database has vast information about the administrative boundary, rivers, and canals, roads and drainage network, buildings etc. Land-use patterns in the study area were then further categorized into five major categories: built-up area (includes residential buildings, road network, educational institutions etc.), agriculture (mostly in the peri-urban area), waterbody (includes rivers, canals, ponds), economic activity (includes commercial areas, industrial areas) and urban vegetation (includes recreational areas, vacant areas). The northern part of the city has several restricted areas which are also demarked in the maps based on the information from the database. To understand the extent of influence of land-use on water quality for the study area three different buffer radius (200m, 500m and 1000m) from the sampling sites were considered and land-use percentage within these buffer radiuses were analyzed using ArcGIS 10.5. Land use areas within different buffer radius are submitted as additional material.

2.4 Statistical Analysis

The percentage of five different land-use types and water quality at the sampling station were used for the analysis of the spatial relationship. Pearson correlation analysis was performed to understand the influence among different water quality parameter in different seasons. The

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correlation coefficient (r) near +1 or −1 means a good relationship between two variables, and value around zero implies no relationship between them. For this study, correlation coefficient ($r \geq 0.7$) is considered as strong, while r between 0.4 to 0.7 is considered as moderately strong and finally, r value below 0.4 is considered as weak correlation (Gidey, 2018; Giridharan et al., 2008; Kumar et al., 2006). Shapiro-Wilko test, visual interpretation through histogram, and Q-Q plot were used to identify the normality of the data. Analysis indicated that the value of COD, HCO_3^-, PO_4^{3-} and Ca^{2+} were normally distributed, and thus, Pearson's correlation was used to identify the relationship between land-use and these variables. Rest of the water quality variables were not normally distributed, and thus natural log transfer was carried out to normalize the data. The percentage of land-use within the buffer is dominated by the built-up area, and urban vegetation is the lowest. Spearman rank correlation analysis is used to perform simple linear bivariate regression, and scatter plot was created to explain the changes in water quality with the changes in the land-use pattern. IBM SPSS Statistics 23 and Microsoft Excel 2016 was used to perform the necessary statistical analysis.

2.5 Concept of Inverse Distance Weighted (IDW) Interpolation

Inverse Distance Weighted (IDW) interpolation method was developed based on the first law of geography coined by W. Tobler in 1970. The law states, "everything is related to everything else, but near things are more related than distant things" (Tobler, 1970). Inverse distance weighted (IDW) interpolation determines the cell value of an unsampled point using a linearly weighted combination of a set of sample points (ESRI, 2016). IDW method assumes that the variable being mapped decreases in influence with distance from its sampled location (Johnston et al., 2003). IDW is a deterministic method as it requires less calculation to meet specific statistical assumptions compared to another stochastic method like kriging (Chen and Liu, 2012). IDW has the ability to handle the extreme values (outliers) in the datasets compared to other spatial analysts and easier to explain the results and comprehensively used in literature

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to determine values in unknown areas (Chen and Liu, 2012; Dhanasekarapandian et al., 2016; Gidey, 2018; Madhloom et al., 2017). The value of the unknown point is the weighted sum of the values of N known points. In this study, the IDW method has been used to interpolate spatial data, which will estimate the unknown water quality data based on the known water quality data. The following equations describe the formulas employed for the IDW:

$$\hat{Q}_w = \sum_{i=1}^{N} w_i Q_i \qquad (2)$$

$$w_i = \frac{{d_i}^{-\alpha}}{\sum_{i=1}^{N} {d_i}^{-\alpha}} \qquad (3)$$

where, $\hat{Q}_w$ is the unknown water quality, Q_i is the known water quality data of the sampled stations, N is the total number of sampling stations, w_i is the weighting of each sampling station, d_i is the distance from each sampling station to unknown points and α is the power parameter which allows controlling the significance of known points on the interpolated values based on their distance. It is a positive, real number, and its default value is 2. Interpolated maps were generated and legend was created using equal interval of the concentration in each parameter. Due to higher variation in concentration it was not possible to create similar color ranged legend but more close-by color ranged legend was assigned. In addition, an increased number of sampling points especially in the non-sampled areas with different interpolation method would further improve the mapping accuracy.

2.6 Concept of Weighted Overlay

Over the years, interest among researchers has grown towards the integration of GIS and multi-criteria decision analysis due to their synergic capabilities (Malczewski, 2007). An integrated map can be produced by applying a common measurement scale for diverse and dissimilar inputs (Riad et al., 2011). The weighted overlay is used to create suitability models by solving multi-criteria problems. The formula employed to produce the maps can be interpreted as:

$$Q_w = \sum_{i=1}^{n} W_i X_i (4)$$

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where, Q_w = degree of restriction for each pixel in the map, W_i = the weight of i and X_i = criteria score of the class of factor i.

The analysis follows a three-step procedure (Junior et al., 2015; Malczewski, 1999) i) selection of the water quality parameters and reclassification of the pixel-based (raster) maps ii) allocation of weight to each water quality parameter and iii) combining weighted parameters and generating final maps. FAO water quality guideline has a degree of restriction for irrigation for pH, bicarbonate, TDS, SAR, Chloride, and Nitrate (Ayers and Westcot, 1985). So, interpolated maps of pH, bicarbonate, TDS, SAR, Chloride, and Nitrate were reclassified using ArcGIS 10.3 based on the guideline and measurement scale from 1 to 3 where 1 means no degree of restriction for irrigation, 2 meaning the moderate degree of restriction for irrigation and 3 meaning the severe degree of restriction for irrigation (Table 2).

Table 2

Then equal weight was (16%) assigned for all the water quality parameters by ArcGIS and SAR weighted 20% automatically as the last assigned parameter in the analysis. Finally, weighted overlay analysis was performed to obtain the final degree of restriction maps for a different season. The total weights of each pixel of the final merged layer were derived based on the following formula:

$$Q_w = (W_{pH} . X_{pH} + W_{Bi\text{-}carbonate} . X_{Bi\text{-}carbonate} + W_{TDS} . X_{TDS} + W_{SAR} . X_{SAR} + W_{Chloride} . X_{Chloride} + W_{Nitrate} . X_{Nitrate}) \quad (5)$$

where W = the weight of each parameter and X = criteria score of each parameter

3.0 Results and Discussion

3.1 Spatio-temporal Variation in Water Quality

A statistical summary of surface water quality parameters of three different seasons (winter, summer, and monsoon) are presented in the following table (Table 3). Results indicate that there are different levels of variation in quality as influenced by seasons. A very strong and

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significant variation was demonstrated by statistical analysis (ANOVA, $p<0.05$) for pH, TDS, Turbidity, water temperature, HCO_3^-, EC, NO^{3-}, NH_3-N, SO_4^{2-}, Na^+, Ca^{2+}, Mg^{2+}, K^+ and smaller insignificant changes occurred for TSS, DO, BOD_5, and PO_4^{3-} .

Table 3

TSS, DO, BOD_5 and PO_4^{3-} are indicatory for impact by urban wastewater, and throughout the year such an impact appears to occur. A significant variation occurs in the parameters that fall under the "generic" and "saltwater influenced" categories. For instance, in summer TDS/EC increases three times compared to the winter and almost six times compared to the monsoon season. This is presumably under the influence of salinity variations in surrounding rivers, and seasonal weather conditions are varying between dry and heavy precipitation.

Pearson correlation indicated the correlation among parameters within a specific season, showing that the parameters indicating saltwater influence, had a strong and significant correlation with each other. In contrast, generic and urban wastewater impact parameters had moderate to no correlation. Table 4 illustrates the correlation matrix during the winter season, indicating that TDS and EC were strongly positively correlated with Na^+, Cl^-, Mg^{2+}, K^+, and SO_4^{2-}. In addition to that, Na^+ was strongly positively correlated with Cl^-, SO_4^{2-}, Mg^{2+}, and K^+. This correlation can be explained due to the lack of rainfall and a stronger effect of salts on water quality (Roy et al., 2018; Shammi et al., 2017). In contrast, DO was strongly negatively correlated with BOD_5 and PO_4^{3-} indicating wastewater impacts.

Analysis indicates that correlation among saltwater influenced parameters is stronger during summer (Table 5) than in winter and monsoon seasons. TDS and EC are strongly positively correlated with Cl^-, SO_4^{2-}, Na^+, Ca^{2+}, Mg^{2+}, and K^+. Also, a strong positive correlation was found for Cl^- with SO_4^{2-}, Na^+, Ca^{2+}, Mg^{2+}, K^+, and SO_4^{2-} with Na^+, Ca^{2+}, Mg^{2+}, and K^+. Lack of rainfall, excessive heat enhancing evaporation, and saltwater inlets from rivers are likely reasons for the correlation among "saltwater influence" related water quality parameters.

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Table 4

Table 5

Table 6

During monsoon correlation among the water quality parameters changes compared to the previous seasons. Table 6 presents the correlation between water quality parameters during the monsoon season. Results indicate that TDS and EC have a strong positive correlation with HCO_3^-, NO_3^-, Cl^-, $Na^{+,}$ and Ca^{2+} during monsoon season. In addition to that, BOD_5 with HCO_3^- and Ca^{2+}, HCO_3^- with NO_3^- and PO_4^{3-}, NO_3^- with PO_4^{3-} and Cl^- with Na^+ are strongly positively correlated. This strong parameter association appears to be a result of excessive rainfall that washes away a lot of soil and related dust particles from the land by surface run off and by re-suspending deposits of sewage drains, which both influence the urban water quality.

To summarize, all the seasons influence water quality parameters, but in the summer – the most critical regarding urban water potential for use in irrigation, salt water impacts and waste water influences are both most apparent. To further evaluate this, we conducted a multilayered geographical and temporal evaluation of water quality parameters.

Interpolation maps can explain the spatial variation of water quality. Standard deviation indicates that most of the parameters have higher variability in the data-set except for the generic parameters and wastewater-impacted parameters (DO, BOD_5, COD, and PO_4^{3-}). Figure 3 shows the spatial variation of bicarbonate and TDS, and it indicates that TDS in the southern part of the city increases during summer most likely due to the increase in salinity in the river Rupsha and Bhairab. During monsoon, surface water gets diluted with the excessive rainfall and contributes to lowering the TDS. However, the concentration of TDS remains within a similar range in different seasons around the central part of the city due to the prevailing presence of ponds in that part. HCO_3^- remains similar all over the year and the middle part of the city, which is residential and commercial has the highest concentration.

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Figure 3

Figure 4 illustrates that during the summer concentration values of Na^{+}, Cl^{-}, Mg^{2+} ions increase in the southern part of the city and decreases during monsoon due to the dilution with excessive rainfall. Also, topographically, the southern part is lower compared to the eastern part, which also leads to washout from east to west after the occurrence of a rainfall event.

Figure 4

It is evident from the maps that during summer concentration of Ca^{2+}, $K^{+,}$ and SO_4^{2-} increases compared to the concentration during winter and monsoon (Figure 5). Higher concentrations for Ca^{2+}, $K^{+,}$ and SO_4^{2-} are present in the southern part of the city whereas values remain the same in the northern part over the seasons. However, sulfate concentration values seem higher in the south-eastern part of the city during monsoon, which can be explained due to the occurrence of soil and sewage drain runoff events during excessive rainfall.

Figure 5

Figure 6 indicates that a lower concentration of NH_3-N and higher concentration of TSS are present in the water throughout the season. Surface runoff and sediment brought during high tide can be the major contributors for a higher level of TSS in the summer, whereas surface runoff can also contribute to this during monsoon. NO_3^{-} and NH_3-N also vary in the study area, especially in the south-eastern part.

Figure 6

3.2 Influence of land-use on overall water quality

Water quality at a sampling site is likely to be influenced by anthropogenic activities in its upstream area rather than within the limit of an administrative region (Tu, 2011). Effects of land-use on surface water pollution suggested that within 200m radius the relationship between land-use and fluorescence component (microscopic algae, colored dissolved organic matter, etc.) is most significant (Wang and Zhang, 2018). However, this is not uniform for every area,

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and in this study, three different buffer radii (200m, 500m, and 1000m) have been tested to identify the optimum buffer radius for relating land-use to water quality.

Correlation analysis indicates that the correlation between the percentage of land-use and water quality parameter is strongest at 500m buffer radius. The results indicate that the percentages of the waterbody (%WB), built-up area (%BA), and economic activity (%EA) within a 500m radius from the monitoring stations have a significant correlation with several water quality parameters. (Table 7).

Table 7

For %WB, this relationship is positive with TDS/EC, Na^{+}, Cl^{-}, Mg^{2+}, Ca^{2+}, K^{+}, $SO4^{3-}$ and negative with HCO_3^{-}, BOD_5, NO_3^{-} and PO_4^{3-}. An increase in the waterbody area within the 500m buffer radius leads to increased concentrations for the parameters indicating saltwater influence (such as the elevation for TDS/EC) in the dry season, i.e., by the intrusion of saltwater from the river towards the inland water bodies (Ratnayake et al., 2018). For the %BA this correlation is positive with water temperature and NO_3^{-} whereas negative with TDS, Na^{+}, Cl^{-}, Mg^{2+}, $Ca^{2+,}$ and TSS, i.e., showing a high dilution potential to mitigate irrigation water salinity to be present in the urban wastewater. A smaller percentage of urban green areas, climate change, and urbanization induced impervious concrete surface can influence water body temperature (Palmer and Nelson, 2007). Anthropogenic activities are known to accelerate the rate and level of eutrophication by nutrient emissions as exemplified by elevated concentrations in N and P in waterbodies (Chislock et al., 2013; Eslamian, 2016; Hossain and Rahman, 2012), were also observed at higher percentages of urban land use. Increased %WB reduces the urban discharge areas per volume of the waterbody and thus the higher dilution/lower input lowers the NO_3^{-} and PO_4^{3-} concentrations. Built-up areas are reducing the area of the open soil surface, decreasing soil erosion, which has been sustained by a negative relation between the %BA and TSS. Percentage of economic activity is significantly positively correlated with Ca^{2+} and

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negatively correlated with PO_4^{3-}. In addition, the role of rivers and canals in quick transportation of wastewater resulted in a weaker correlation between built-up area and parameters related to wastewater. The relationship between agricultural land and water quality parameters found in this study negates some of the findings from several previous studies. In general runoff from agricultural areas contributes to the increase of nutrients in nearby water sources. However, in the study area, most of the agricultural areas are outskirts of the city and often a negligible percentage of the area within the buffer radius, which automatically led to a weaker relationship. To better address, the impact of agricultural land on surface water quality, a larger area around the city needs to be taken into account, which was, however, not the focus of this study. The spatial variation in water quality parameters in response to the change in the percentage of land-use can be explained through the scatter plot and simple linear bivariate regression (Figure 7 and Figure 8). Figure 7 shows that the change in %WB explains 32%, 34%, 44%, 43%, 23%, 33%, 39%, 22%, 31% and 39% of the spatial variance of HCO_3^-, PO_4^{3-}, Ca^{2+}, TDS, TSS, NO_3^-, Cl^-, K^+, Na^{2+}, and Mg^{2+} ($p=0.000$ to $p<0.05$).

Figure 7

Figure 8 shows that change in %BA explains the spatial variance ($p = 0.000$ to $p<0.05$) of water temperature, TDS, Cl^-, Na^{2+}, Mg^{2+}, and Ca^{2+}, with 22%, 34%, 35%, 21%, 35% and 27%, respectively and change in %EA explains 21% and 28% of the spatial variances of PO_4^{3-} and Ca^{2+} respectively ($p = 0.000$ to $p<0.05$).

Figure 8

3.3 Water quality evaluation for indirect reuse in agriculture

Irrigation water quality may differ greatly depending on the quantity and type of salt present in the water, and this salt profile is a convenient indicator to evaluate the quality the water for ist suitability for irrigation (Ayers and Westcot, 1985; Bauder et al., 2014). The FAO guideline identified water quality-related problems in irrigated agriculture is associated with salinity,

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375 water infiltration rate, specific ion toxicity, and miscellaneous (NO_3^-, HCO_3^-, pH) ion
376 contributions. Evaluation of water quality based on these factors may vary depending on soil
377 type, geographic location, and type of crop but is very useful for effective interpretation (Ayers
378 and Westcot, 1985). Table 8 presents the evaluation of water quality in the study area using
379 FAO guideline values (Table 2) for the degree of restriction in use with the study area: under
380 "no restriction" no cropping or soil-related problems are expected, under "moderate restriction"
381 careful crop selection and alternative management is required to achieve full yield, and under
382 "severe restriction" problems associated to soil performance and strong limitations to crops are
383 expected (Ayers and Westcot, 1985). Based on the following table, it can be observed that water
384 quality remains under moderate to severe throughout the year. Even during monsoon season,
385 water quality remains under moderate restriction. Rainfall inducing low salinity creates
386 excessive runoff placing some sources to be affected by high TSS triggering potential severe
387 reductions for the rate of infiltration during irrigation use.

388 **Table 8**

389 Even though the water use is moderately restricted during monsoon, it is not expected to have
390 any significant effect on irrigation. The crops that are cultivated in the coastal areas of
391 Bangladesh during monsoon season are entirely rainfed and do not require external irrigation
392 (Mondol et al., 2018; Shammi et al., 2014; Shelley et al., 2016). Nevertheless, looking into the
393 spatial distribution will give ideas for determining the areas with urban water sources suitable
394 for irrigation. Overlaying interpolated maps using the parameters prescribed by FAO shows the
395 spatial distribution of restriction on use for irrigation. Figure 9 illustrates the overall degrees of
396 restriction of water use in the three different seasons. During summer approximately 1/3rd of
397 the area (the northern and south-western part of the city) falls under a severe degree of
398 restriction area for using water from those areas. That water poses a severe threat to the crops
399 in cultivation and also to the functioning of the soil due to the exchange of sodium with calcium,

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magnesium and other multi-valiant cations creating strongly swelling clays with strongly reduced infiltration rates (Ayers and Westcot, 1985; Bauder et al., 2014). During winter and monsoon (in the southern part of the city), water quality will improve compared to the summer season but still will not meet the adequate quality standard partly because of the influence of nearby rivers on water quality in the area.

Figure 9

Due to the lack of available water resources, farmers are currently using urban water sources with poor quality for irrigation (indicated by the severe or moderate degree of restriction). This current practice is expected to have an adverse effect on soil health and food production in the study area. Future planning measures should focus on improving the surface water quality to enable it for reuse in agriculture.

4. Conclusion

In urban delta areas people are increasingly concentrating every day in extending and new agglomerations, and their demand for resources, especially water and food, is correspondingly growing. Salt water intrusion is already threatening the existing available freshwater sources for irrigation in the delta areas, in Bangladesh, and world-wide. Alternative irrigation sources with adequate quality for agriculture are increasingly needed to sustain current and future food production in these climate change affected delta areas. Urban wastewater has the potential to provide such a freshwater resource for irrigation if quality and utilization are properly managed. For this, a spatial and time inclusive information system is needed on water quality in such Delta's, and this research aims to provide the basic elements for that.

In this study, we provide a method that gives insights in spatial and seasonal dependent variations in water quality, the significance of these variations, and the interdependencies among water quality parameters. From this, the usefulness and restrictions of water sources for irrigation can be deduced and visualized. Also, we can differentiate by this method between the

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influence of salt water carried by rivers to water resources in the adjacent areas and the effects on water quality by anthropogenic activities. The information mapped by using this procedure gives a solid basis for land use planning and water management in service of providing high-quality irrigation water. In this way, targeted and effective management actions become possible such as planned urbanization, maintaining green spaces, restricting direct discharge and enforcing the proper treatment of urban wastewater. Also, infrastructural measures can be taken to prevent saltwater intrusion in existing water resources.

We have used chemical-physical parameters of the FAO guideline to identify the usefulness or restrictions for water resources for irrigation use. Although salinity related water quality is of utmost importance, other aspects, especially related to urban wastewater as a resource are also important and it would be interesting to combine more parameters to understand the suitability of water for irrigation. For instance, the concentrations of pathogenic microorganisms, micropollutants such as pharmaceuticals, pesticides, industrial chemicals, and heavy metals, also need to be taken into account to provide a complete evaluation on the suitability of urban water for reuse in irrigation agriculture, and this will be the focus of our future studies.

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Table 1: Grouping of chemical-physical parameters

Group	**Parameters**
Generic	pH, Temperature, Turbidity, HCO_3^-
Salt water influenced	TDS, EC, Na^+, Cl^-, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}
Urban wastewater-impacted	TSS, DO, BOD_5, COD, NO_3^-, PO_4^{3-}, NH_3-N

Table 2: Water quality reclassification scale based on FAO Water Quality Guideline (Ayers and Westcot, 1985)

Parameter[a]	**The degree of restrictions on use**		
	None	**Moderate**	**Severe**
	Reclassification measurement scale		
	1	**2**	**3**
EC_W or	<0.7	0.7-3.0	>3.0
TDS	≤450	450-2000	≥2000
Na^+	≤3	3-9	≥9
Cl^-	≤140	140-350	≥350
NO_3^-	≤5	5 - 30	≥30
HCO_3^-	≤90	90-500	≥500
pH	Normal range 6.5 – 8.4		

[a] *All the values presented in the table are in mg/L except for Sodium (which is indicated as SAR)*

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Table 3: Water quality in different season in the study area

Group	Parameter[b]	Winter *(n=25)*		Summer *(n=25)*		Monsoon *(n=25)*		Overall *(n=75)*	
		Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Generic	**pH**	6.8	0.2	7.3	0.4	7.2	0.3	7.1	0.4
	Temp.	23.5	1.1	31.8	1.5	30.2	1.0	28.5	3.8
	Turbid.	6.8	5.2	196.9	384.6	133.8	41.5	112.5	30.2
	HCO_3^-	430.2	168.7	380.8	150.5	259.2	150.1	356.7	170.6
Salt water influenced	**TDS**	987.0	529.0	2884.9	2803.6	500.2	331.1	1457.4	1936.0
	EC	2.0	1.1	5.8	5.6	1.0	0.7	2.9	3.9
	Na^+	290.6	150.0	1277.0	1446.8	157.8	113.0	575.1	971.1
	Cl^-	485.7	327.5	1685.1	1931.7	163.0	162.1	777.9	1299.3
	Mg^{2+}	40.2	21.3	113.0	118.9	22.6	20.0	58.6	80.1
	Ca^{2+}	62.8	33.8	277.1	237.7	86.8	30.1	142.3	168.2
	K^+	17.9	6.3	42.0	33.9	10.5	6.9	23.5	24.2
	SO_4^{2-}	26.7	44.6	286.1	267.9	77.3	103.7	130.0	200.5
Wastewater impacted	TSS	245.1	365.7	471.8	598.0	544.3	406.6	420.4	479.0
	DO	3.0	2.0	2.8	2.0	3.4	2.2	3.1	2.1
	BOD_5	30.0	30.1	38.1	23.8	44.5	43.1	37.5	33.4
	COD	85.5	40.2	186.9	96.7	87.0	31.4	119.8	78.5
	NO_3^-	5.8	2.9	43.7	31.1	36.1	52.0	28.5	38.3
	PO_4^{3-}	3.1	3.1	5.2	3.0	3.2	3.8	3.8	3.4
	NH_3-N	0.8	1.1	3.8	4.3	0.5	0.6	1.7	2.9

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[b] *Values presented in the table are in mg/L except for pH, Turbidity (NTU), Water Temperature (^{0}C) and EC (dS/m) and bold parameter indicates the significant ($p<0.05$) temporal variation*

Table 4: Correlation coefficient[c] matrix of water quality during winter

	pH	Temp.	Turb.	HCO_3^-	TDS	EC	Na^+	Cl^-	Mg^{2+}	Ca^{2+}	K^+	SO_4^{2-}	TSS	DO	BOD_5	COD	NO_3^-	PO_4^{3-}	NH_3-N
pH	1.000																		
Temp.	0.109	1.000																	
Turbidity	-0.131	-0.061	1.000																
HCO_3^-	-0.162	0.021	0.255	1.000															
TDS	-0.386	-0.123	-0.015	-0.085	1.000														
EC	-0.385	-0.124	-0.016	-0.086	1.000	1.000													
Na^+	-0.441	-0.151	-0.012	-0.145	**0.968**	**0.968**	1.000												
Cl^-	-0.377	-0.158	-0.103	-0.273	**0.853**	**0.852**	**0.890**	1.000											
Mg^{2+}	-0.418	-0.038	-0.021	-0.134	**0.844**	**0.842**	**0.879**	**0.830**	1.000										
Ca^{2+}	-0.119	0.195	0.139	0.523	0.255	0.254	0.104	0.143	0.134	1.000									
K^+	-0.411	-0.226	0.344	0.086	**0.731**	**0.730**	**0.780**	0.617	0.591	0.040	1.000								
SO_4^{2-}	-0.250	-0.112	-0.346	-0.535	**0.734**	**0.735**	**0.747**	0.692	0.615	-0.200	0.442	1.000							
TSS	-0.212	-0.254	0.080	-0.242	0.419	0.420	0.489	0.695	0.487	-0.132	0.406	0.286	1.000						
DO	0.143	0.278	-0.150	-0.770	0.109	0.109	0.208	0.268	0.224	-0.406	0.044	0.354	0.176	1.000					
BOD_5	0.106	-0.134	0.180	0.696	-0.159	-0.159	-0.251	-0.329	-0.151	0.371	-0.161	-0.477	-0.169	**-0.757**	1.000				
COD	0.421	-0.311	0.348	0.123	-0.303	-0.300	-0.346	-0.259	-0.351	0.048	-0.289	-0.280	0.090	-0.306	0.257	1.000			

[c] *The bold number indicates the strong correlation ($r \geq 0.7$) at the 0.05 level*

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NO_3^-	-0.549	-0.097	0.233	-0.022	0.431	0.428	0.466	0.391	0.423	0.062	0.651	0.368	0.025	0.000	-0.289	-0.393	1.000		
PO_4^{3-}	-0.009	-0.183	0.479	**0.780**	-0.140	-0.140	-0.177	-0.326	-0.253	0.231	0.227	-0.470	-0.123	**-0.723**	0.637	0.397	0.086	1.000	
NH_3-N	-0.355	-0.331	0.313	0.441	0.134	0.132	0.119	0.018	0.131	0.013	0.277	-0.093	0.062	-0.330	0.206	0.193	0.352	0.533	1.000

Table 5: Correlation coefficient[d] matrix of water quality during summer

	pH	**Temp.**	**Turb.**	**HCO_3^-**	**TDS**	**EC**	**Na^+**	**Cl^-**	**Mg^{2+}**	**Ca^{2+}**	**K^+**	**SO_4^{2-}**	**TSS**	**DO**	**BOD_5**	**COD**	**NO_3^-**	**PO_4^{3-}**	**NH_3-N**
pH	1.000																		
Temp.	**0.721**	1.000																	
Turbidity	-0.202	-0.313	1.000																
HCO_3^-	-0.142	0.128	-0.444	1.000															
TDS	-0.127	-0.191	0.323	-0.490	1.000														
EC	-0.127	-0.192	0.323	-0.490	1.000	1.000													
Na^+	-0.105	-0.227	0.254	-0.502	**0.828**	**0.828**	1.000												
Cl^-	-0.143	-0.193	0.278	-0.474	**0.973**	**0.974**	**0.783**	1.000											
Mg^{2+}	-0.118	-0.183	0.325	-0.498	**0.995**	**0.995**	**0.830**	**0.970**	1.000										
Ca^{2+}	-0.161	-0.218	0.306	-0.436	**0.991**	**0.991**	**0.804**	**0.969**	**0.993**	1.000									
K^+	-0.094	-0.115	0.414	-0.517	**0.978**	**0.978**	**0.829**	**0.944**	**0.974**	**0.959**	1.000								
SO_4^{2-}	-0.112	-0.129	0.422	-0.607	**0.949**	**0.949**	**0.763**	**0.911**	**0.956**	**0.936**	**0.948**	1.000							
TSS	-0.245	-0.167	0.694	-0.320	0.370	0.369	0.269	0.330	0.362	0.360	0.427	0.436	1.000						

[d] *The bold number indicates the strong correlation ($r \geq 0.7$) at the 0.05 level*

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DO	0.652	0.419	0.147	-0.441	0.002	0.001	0.147	-0.035	0.042	-0.038	0.038	0.099	-0.048	1.000					
BOD_5	-0.633	-0.403	-0.045	0.545	-0.066	-0.065	-0.297	-0.060	-0.100	-0.032	-0.117	-0.157	0.050	**-0.767**	1.000				
COD	-0.009	-0.061	0.330	-0.172	0.573	0.574	0.456	0.506	0.575	0.573	0.618	0.530	0.322	-0.052	0.027	1.000			
NO_3^-	-0.256	-0.141	-0.330	0.287	-0.395	-0.396	-0.145	-0.401	-0.385	-0.374	-0.408	-0.450	-0.082	-0.234	0.124	-0.447	1.000		
PO_4^{3-}	-0.399	-0.193	-0.426	**0.702**	-0.438	-0.439	-0.226	-0.435	-0.454	-0.407	-0.451	-0.547	-0.240	-0.561	0.456	-0.289	0.502	1.000	
NH_3-N	-0.138	-0.170	-0.242	-0.024	0.302	0.299	0.375	0.264	0.257	0.255	0.250	0.227	-0.231	-0.181	0.046	-0.112	-0.022	0.189	1.000

Table 6: Correlation coefficient[e] matrix of water quality during monsoon

	pH	**Temp.**	**Turb.**	**HCO_3^-**	**TDS**	**EC**	**Na^+**	**Cl^-**	**Mg^{2+}**	**Ca^{2+}**	**K^+**	**SO_4^{2-}**	**TSS**	**DO**	**BOD_5**	**COD**	**NO_3^-**	**PO_4^{3-}**	**NH_3-N**
pH	1.000																		
Temp.	0.168	1.000																	
Turbidity	0.061	-0.311	1.000																
HCO_3^-	-0.085	-0.130	-0.524	1.000															
TDS	0.004	-0.063	-0.618	**0.860**	1.000														
EC	-0.028	-0.088	-0.606	**0.853**	**0.997**	1.000													
Na^+	0.126	0.026	-0.365	0.666	**0.864**	**0.868**	1.000												
Cl^-	0.024	-0.021	-0.451	0.605	**0.845**	**0.853**	**0.815**	1.000											
Mg^{2+}	0.073	-0.149	-0.200	0.508	0.641	0.651	0.573	0.492	1.000										
Ca^{2+}	-0.269	-0.234	-0.448	0.612	**0.749**	**0.769**	0.695	0.655	0.375	1.000									

[e] *The bold number indicates the strong correlation ($r \geq 0.7$) at the 0.05 level*

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K^+	-0.400	0.292	-0.449	0.627	0.511	0.498	0.338	0.343	0.199	0.327	1.000								
SO_4^{2-}	0.011	0.303	0.496	-0.326	-0.273	-0.266	0.068	-0.151	-0.184	-0.175	0.073	1.000							
TSS	0.141	-0.124	0.318	-0.277	-0.317	-0.303	-0.204	-0.234	-0.079	-0.286	-0.258	0.446	1.000						
DO	0.620	0.347	0.206	-0.577	-0.531	-0.563	-0.426	-0.428	-0.208	**-0.714**	-0.557	0.086	0.286	1.000					
BOD_5	-0.385	-0.241	-0.396	0.698	0.622	0.633	0.505	0.520	0.151	**0.813**	0.520	-0.134	-0.287	-0.830	1.000				
COD	-0.141	-0.435	0.028	0.506	0.359	0.352	0.357	0.220	-0.014	0.421	0.218	-0.100	-0.386	-0.579	0.588	1.000			
NO_3^-	-0.142	-0.219	-0.357	**0.907**	**0.713**	0.717	0.574	0.471	0.581	0.503	0.551	-0.235	-0.154	-0.528	0.600	0.434	1.000		
PO_4^{3-}	-0.331	-0.089	-0.335	**0.860**	0.622	0.628	0.451	0.469	0.352	0.403	**0.768**	-0.094	-0.146	-0.631	0.656	0.442	**0.893**	1.000	
NH_3-N	-0.132	-0.148	-0.179	0.023	0.162	0.172	0.068	0.014	0.220	0.083	-0.023	-0.290	-0.237	-0.156	-0.124	-0.027	0.025	-0.093	1.000

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Table 7: Correlation matrix between percentage of land-use and water quality variables

Parameter	Waterbody	Built-up Area	Economic Activity	Agriculture	Urban Vegetation
pH	-0.153	0.029	0.116	0.012	0.115
Temp	-0.187	0.487*[f]	0.382	-0.348	0.389
Turbidity	0.329	-0.272	0.110	-0.150	-0.195
HCO_3^-	-0.568**[g]	0.254	-0.395	0.330	0.074
TDS/EC	0.651**	-0.564**	0.144	0.052	0.037
Na^+	0.600**	-0.445*	0.162	0.079	0.078
Cl^-	0.655**	-0.526**	0.238	-0.001	0.113
Mg^{2+}	0.602**	-0.558**	0.265	-0.034	0.130
Ca^{2+}	0.662**	-0.520**	0.528**	-0.208	0.048
K^+	0.452*	-0.394	0.090	0.019	-0.099
SO_4^{3-}	0.602**	-0.335	0.355	-0.342	0.288
TSS	0.361	-0.466*	0.233	-0.174	0.099
DO	0.382	-0.212	0.146	-0.132	-0.103
BOD_5	-0.452*	0.162	-0.200	0.182	-0.113
COD	0.123	-0.289	0.075	0.184	-0.174
NO_3^-	-0.714**	0.409*	-0.277	0.223	-0.134
PO_4^{3-}	-0.585**	0.365	-0.457*	0.275	-0.069
NH_3-N	0.309	-0.258	-0.340	0.382	-0.176

[f] * *Correlation is significant at the 0.05 level (2-tailed).*
[g] ** *Correlation is significant at the 0.01 level (2-tailed).*

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Table 8: Comparison of water quality parameter in the study area with FAO irrigation water quality guideline

Parameter[h]	**Observed value (mean±sd) in the study area (n=25 in each season)**					
	Winter	**Restriction**	**Summer**	**Restriction**	**Monsoon**	**Restriction**
EC_W or	2.0±1.1	Moderate	5.8±5.6	Severe	1.0±0.7	Moderate
TDS	987±529	Moderate	2884.9±2803	Severe	500±331	Moderate
Na^+	6.83±0.5	Moderate	14.14±2.92	Severe	3.69±0.46	Moderate
Cl^-	485±327	Severe	1685.1±1931	Severe	163±162.1	Moderate
NO_3^-	5.8±2.9	Moderate	43.7±31.1	Severe	36.1±52	Severe
HCO_3^-	430±168	Moderate	380.8±150.5	Moderate	133.8±41	Moderate
pH	6.8±0.2	None	7.3±0.4	None	7.2±0.3	None

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[h] *All the values presented in the table are in mg/L except for Sodium (which is indicated as SAR)*

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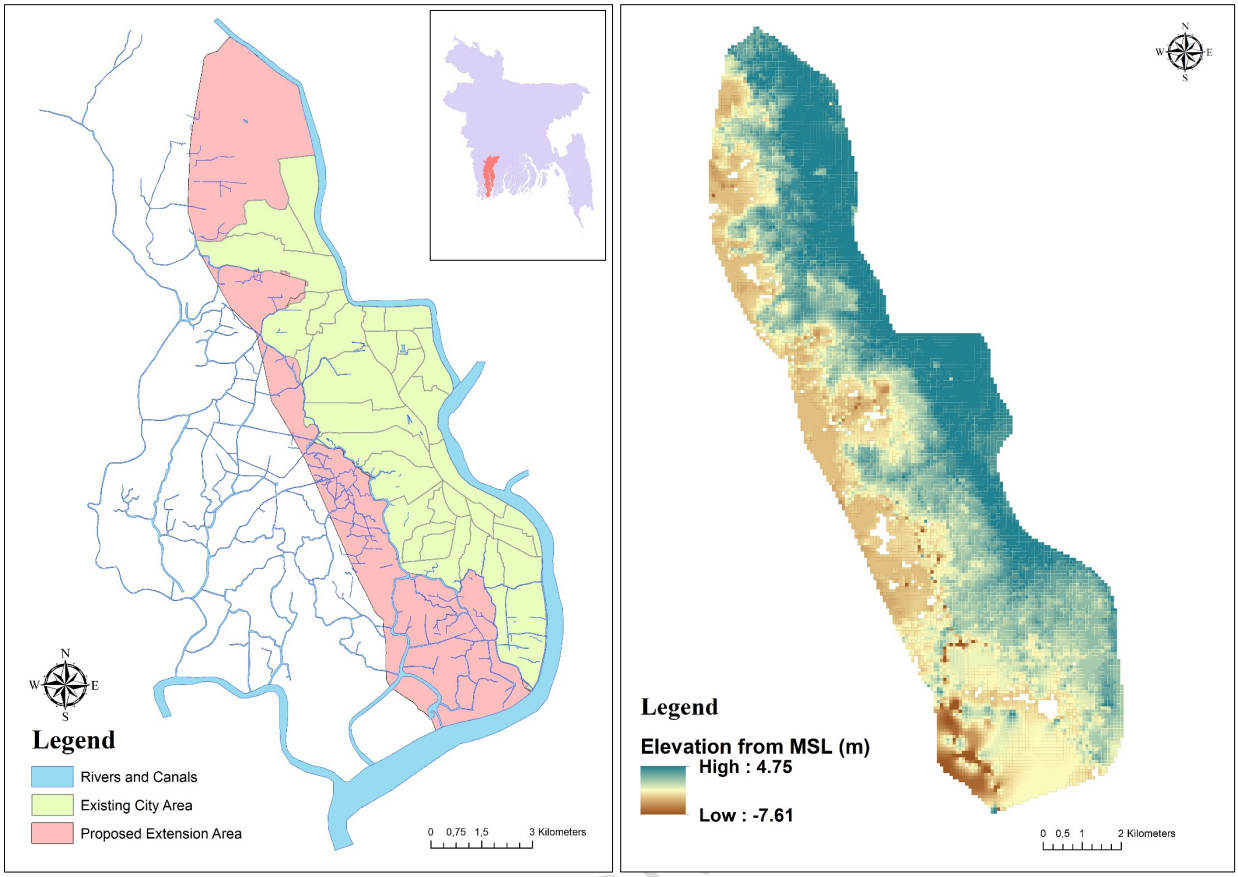


Figure 1: Map of the study area (left) and topography of the study area (right)

Figure 1 is a double column artwork

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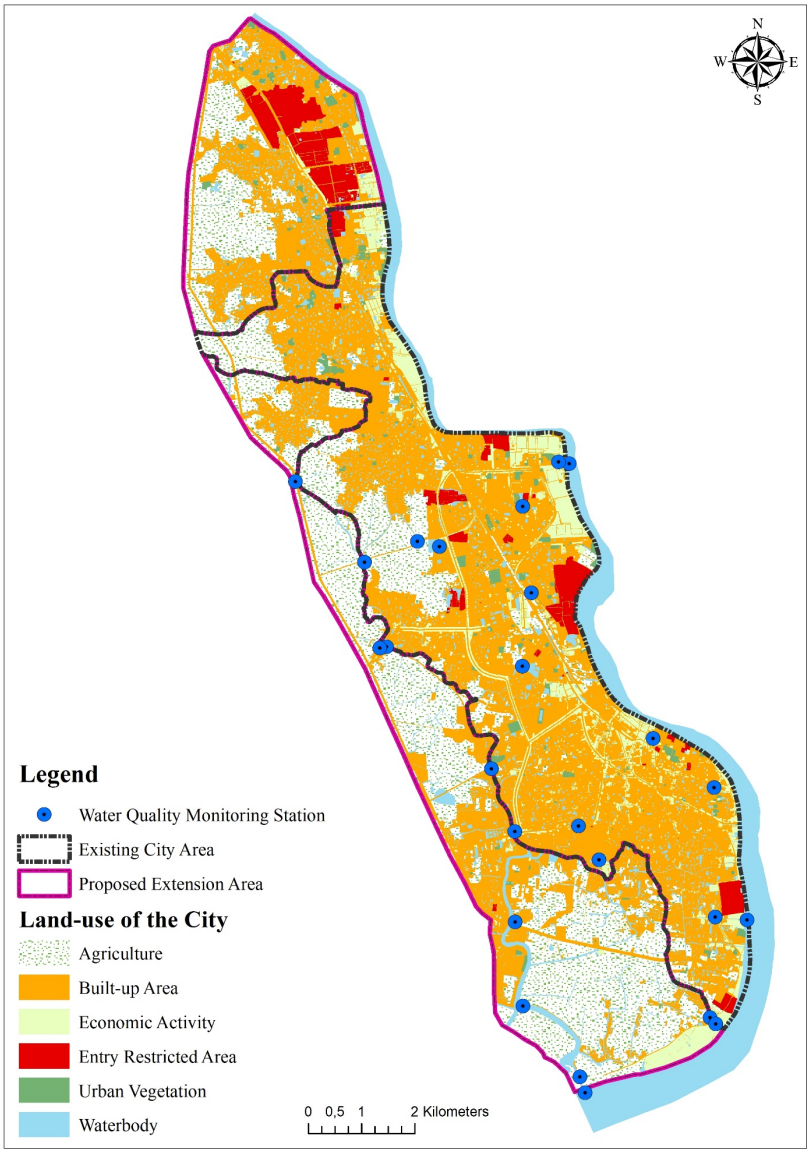


Figure 2: Water Quality Monitoring Stations embedded on the land-use map

Figure 2 is a 1.5 column artwork

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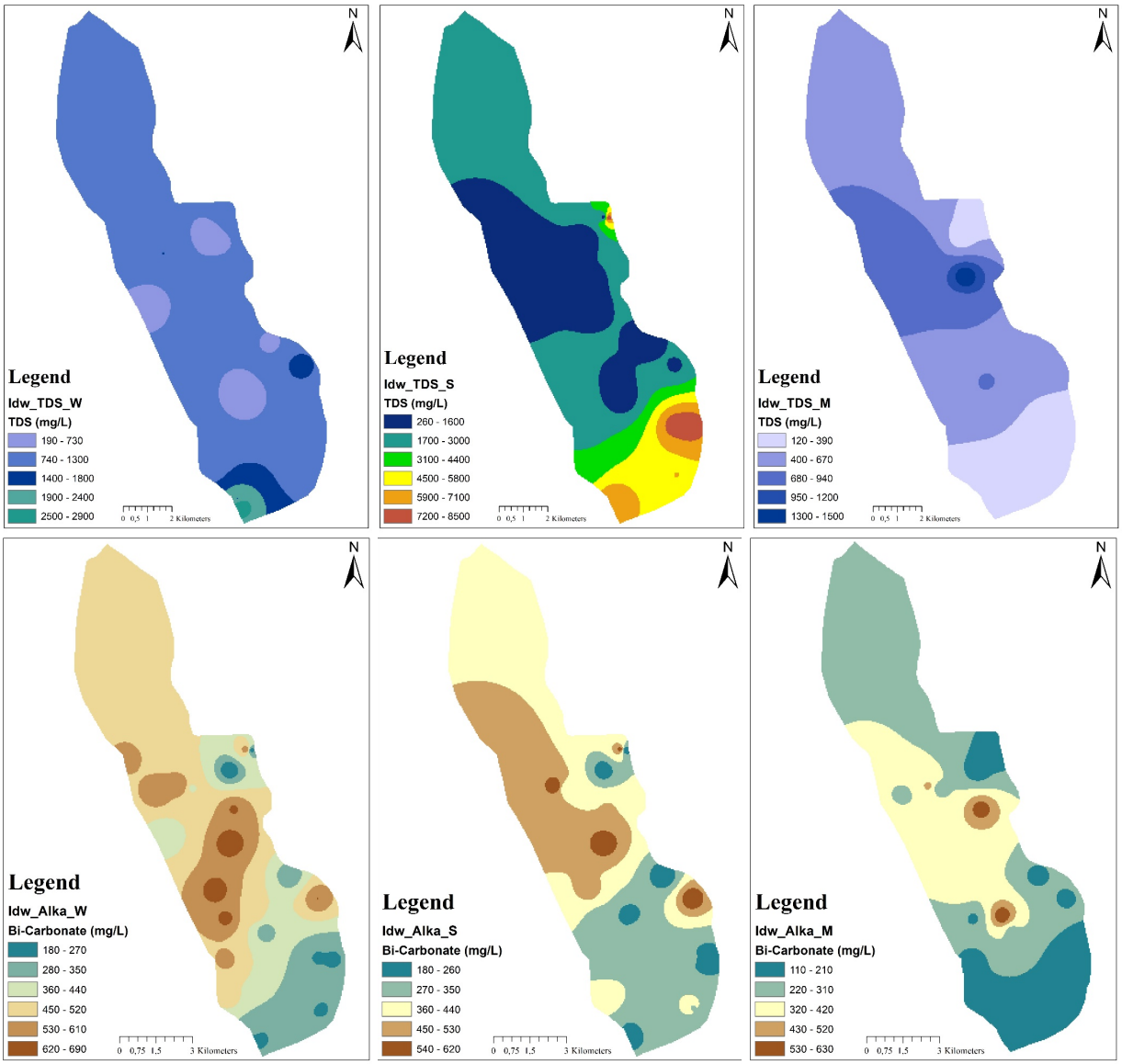


Figure 3: Spatial variability of TDS and bicarbonate in winter(left), summer(middle) and monsoon (right))

Figure 3 is a double column artwork

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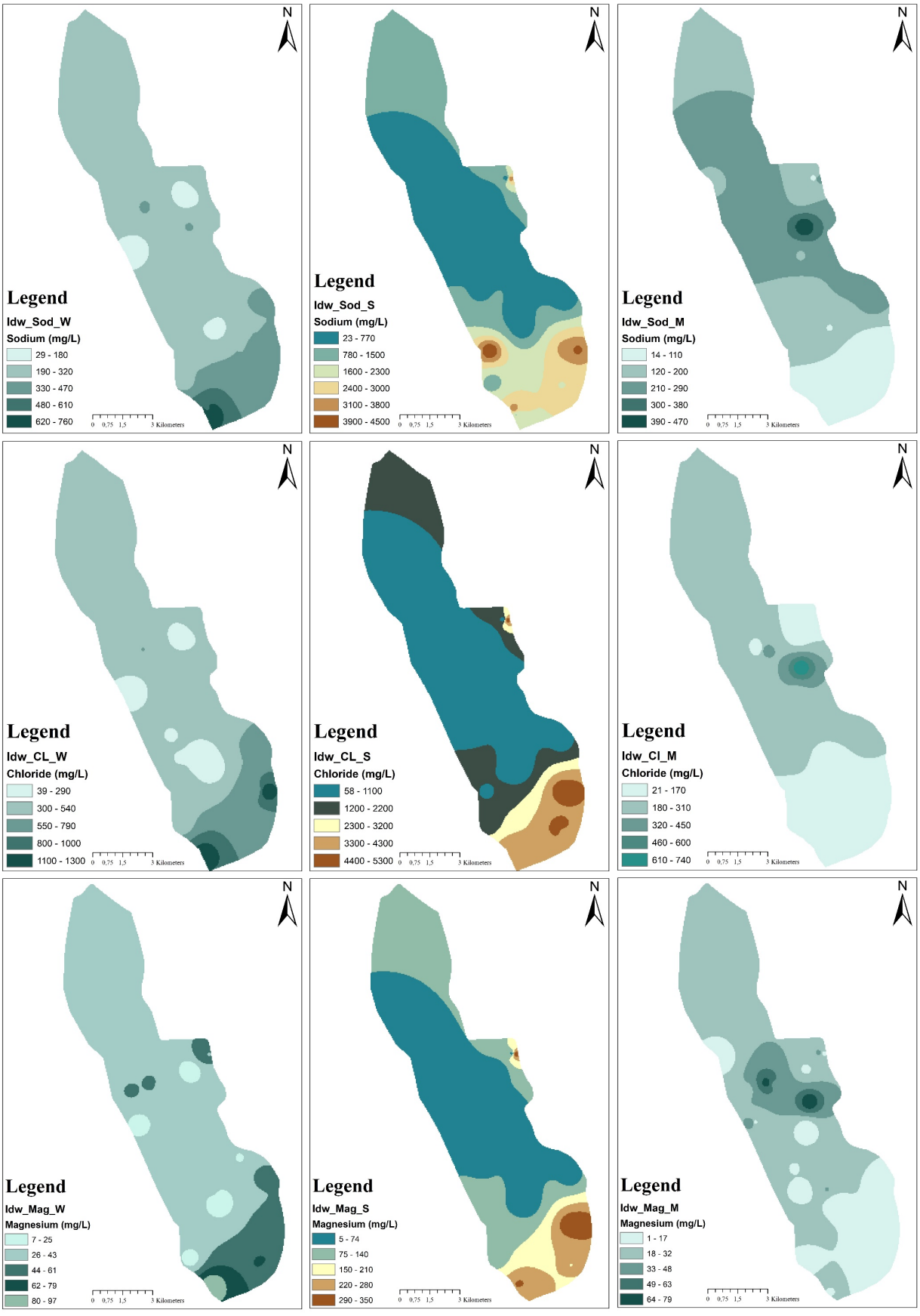


Figure 4: Spatial variation of Sodium, Chloride and Magnesium in the study area in winter (left), summer (middle) and monsoon(right))

Figure 4 is a double column artwork

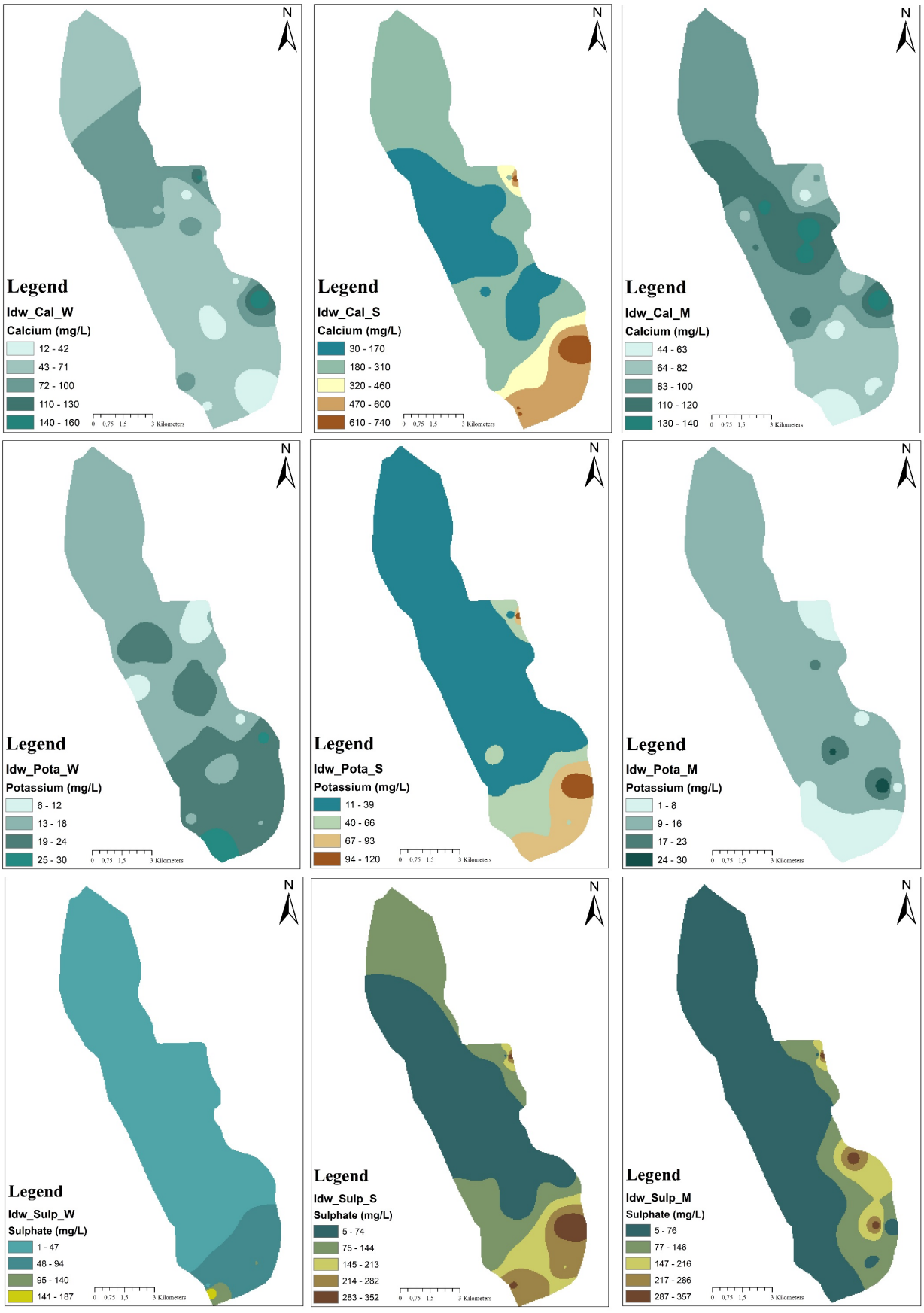


Figure 5: Spatial variation of Calcium, Potassium and Sulphate in winter (left), summer (middle) and monsoon (right

Figure 5 is a double column artwork

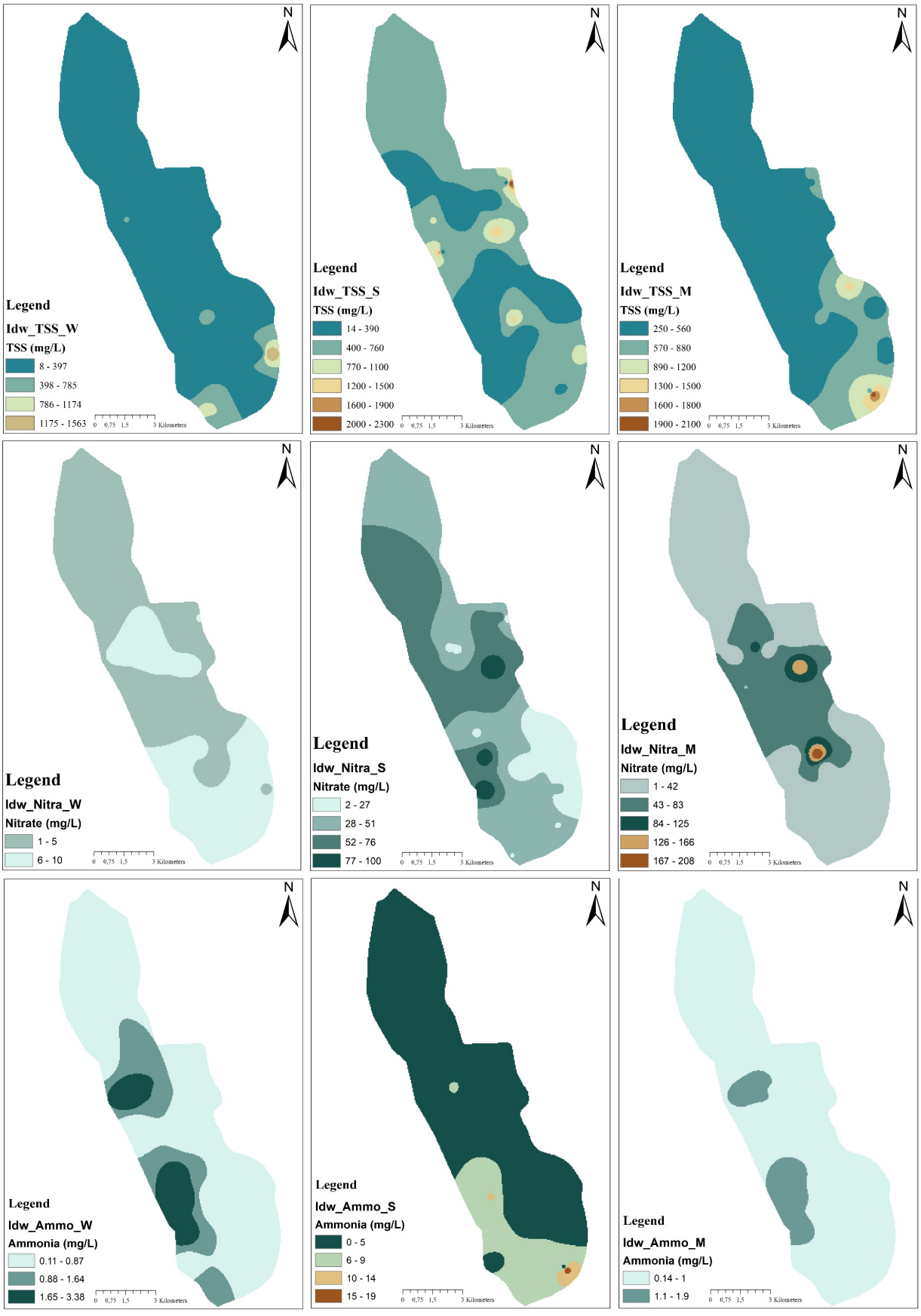


Figure 6: Spatial variability of TSS, Nitrate and Ammonia in winter (left), summer (middle) and monsoon (right)

Figure 6 is a double column artwork

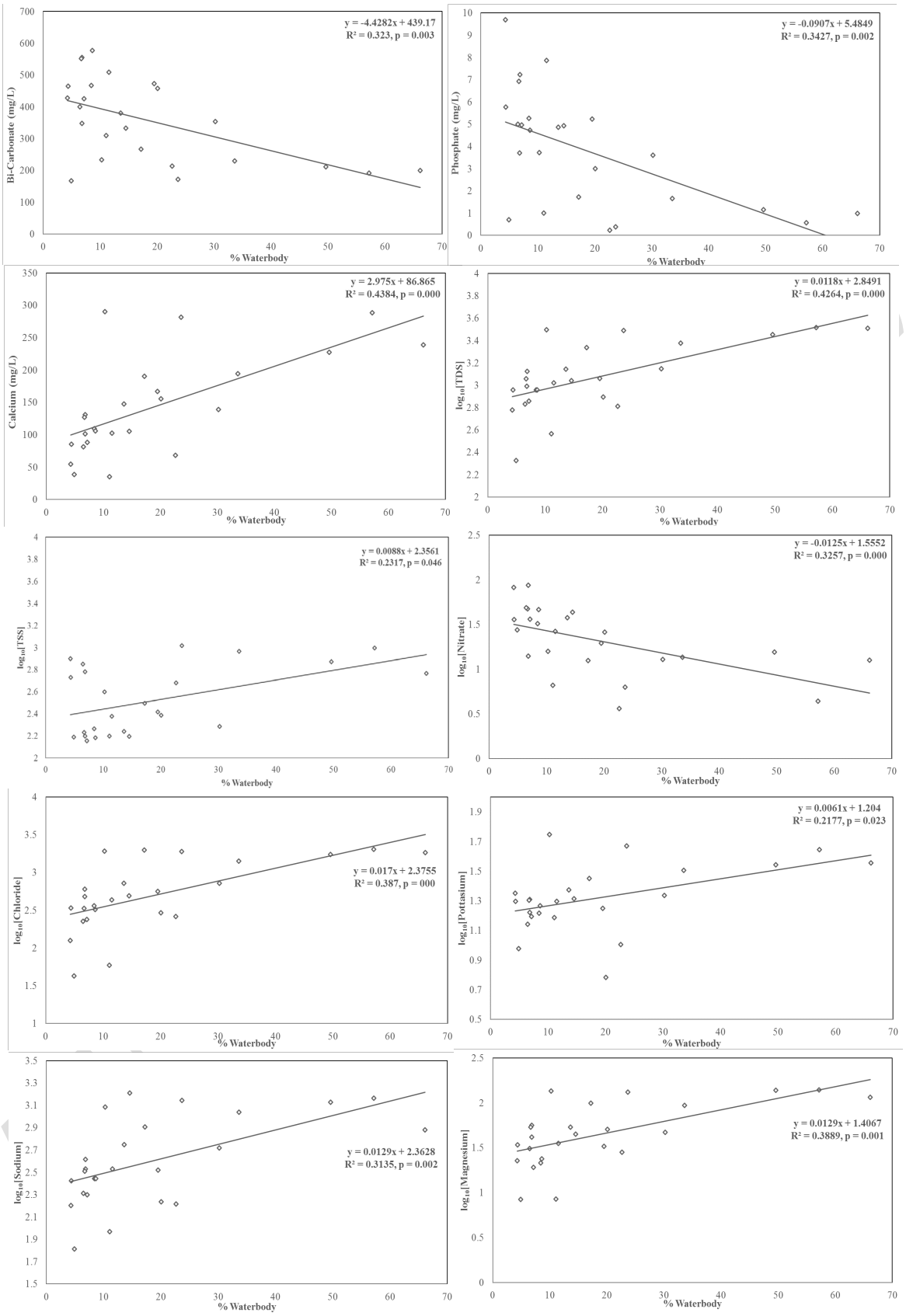


Figure 7: Scatter plot between percentage of waterbody within 500m buffer and correlated water quality parameters

Figure 7 is a double column artwork

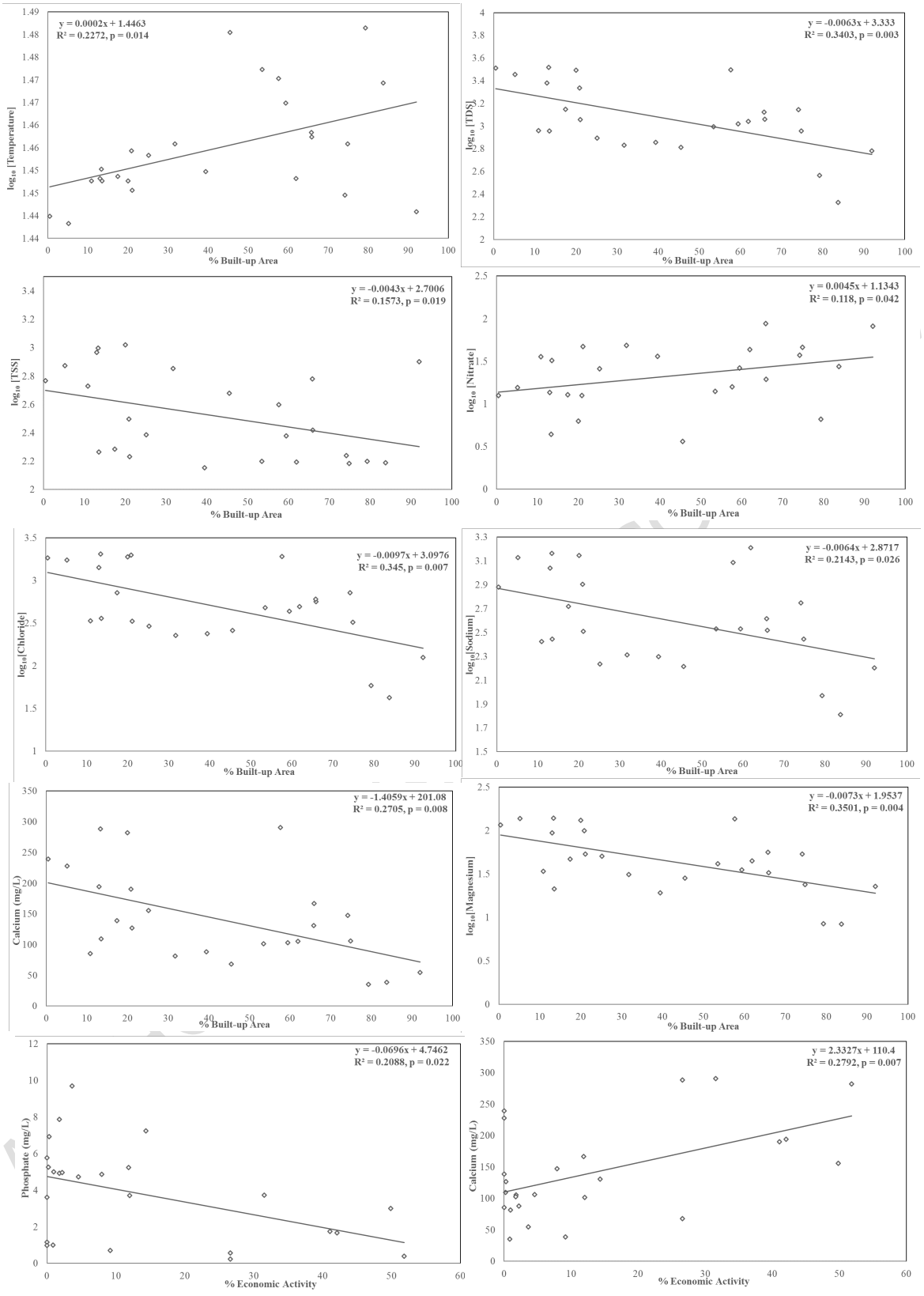


Figure 8: Scatter plot between percentage of built-up area and economic activity and correlated water quality

Figure 8 is a double column artwork

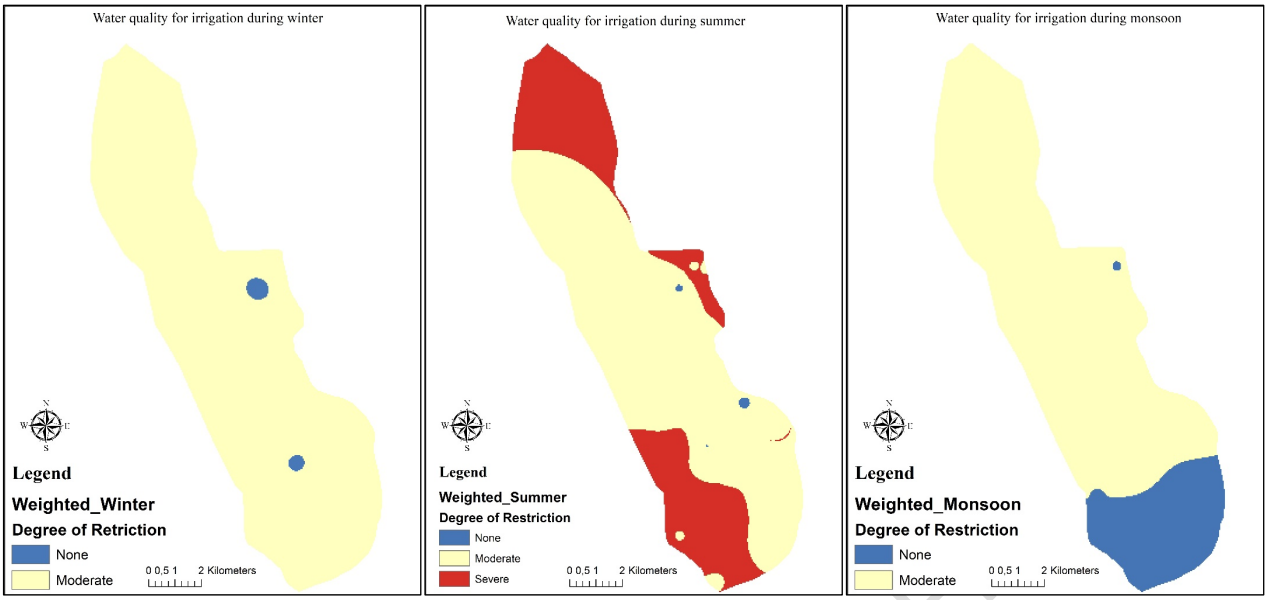


Figure 9: Degree of restriction of water use for irrigation in winter (left), summer (middle) and monsoon (right)

Figure 9 is a double column artwork

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