Quantitative impacts of population on river water quality in the Jinshui River basin of the South Qinling Mts., China

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Abstract Increasing population is generally responsible for the degraded river ecosystem. Using regression models and mathematical functions, the research quantitatively estimated the population and elevational gradient effects on river water quality during nine surveys from 2006 to 2008 in the Jinshui River basin of the South Qinling Mts., China. The total factor scores at 11 different sampling sites were calculated in factor analysis and first used as pollution index to represent the water quality levels. Population and elevational gradient both significantly linked with most water quality variables and pollution index in correlation analysis and explained 36.5–77.8 % of the total variances in regression analysis, indicating that human activities were gradually frequent with population growth and affected the input and output of pollutants in river water. On the basis of regression models and quadratic functions among population, elevational gradient, and pollution index, the population capacity of the river basin was estimated as 1815 people, and the threshold value of elevation was calculated as 1174 m. The results of multivariate linear models further confirmed that population and population distribution had direct influences on river water quality. This study will facilitate the ecosystem management for

mountainous streams and provide quantitative models for understanding and mitigating human impacts on river system.

Keywords River water quality · Population · Elevational gradient · Pollution index · Regression model · Mathematical functions · Quantifying impact

Introduction

Human activities have more or less impacts on the surrounding ecological environment, altering the nitrogen cycle in aquatic systems (Howarth et al. 1996), changing hydrological circulation (Ahn and Merwade 2014), deteriorating river water quality (Rashid and Romshoo 2013; Liu et al. 2014), etc. In a watershed scale, population growth significantly contributes to the pollutant concentrations in rivers and determines the carrying capacity of water environment to a certain extent. Thus, human activities are considered to be the highest contributing factor in water pollution of water bodies all over the world (Sirunda and Msangi 2014). Particularly for a small mountainous watershed, the impacts of human activities on water environment are more sensitive due to its vulnerability (Wohl 2006).

Rapid increase in the population is generally responsible for the degraded environment, particularly the aquatic ecosystem (Howarth et al. 1996; Rashid and Romshoo 2013; Liu et al. 2014). Rashid and Romshoo (2013) recognized the impacts of tourist numbers on seasonal variation in water quality of Lidder River in Kashmir Himalaya. Stream water quality around urban villages with high population densities was worse than that within business districts away from the urban villages in Guangzhou, China

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(Liu et al. 2014). Population density also exerted an important influence on nutrient concentrations in river systems (Caraco 1995; Howarth et al. 1996; Caraco and Cole 1999). In addition, elevational gradient may control the water chemistry of streams and rivers as well (Vitousek 1977). In the streams of the Great Smoky Mountains National Park, most water quality parameters were found to be higher in the low elevations than in the high, but nitrate concentrations increased with increasing elevation (Silsbee and Larson 1982).

Although significant human activities affecting the river water quality have been focused, less is known regarding the quantitative role in the impacts of population on water quality in rivers, particularly for natural river systems within a mountainous watershed.

The Jinshui River originates from the south slope of the Qinling Mts. of central China and is a source area of the Middle Route of South-to-North Water Transfer Project in China (Bu et al. 2010a). As a headwater stream, the Jinshui River is particularly important in controlling the water quality for the interbasin water transfer project since the most rapid uptake and transformation of pollutants occur in the smallest streams (Peterson et al. 2001; Wohl 2006). The water quality and geochemical processes of the Jinshui River have been discussed in previous articles (Bu et al. 2010b, 2015). The research selected the Jinshui River basin to quantify the population and elevational gradient effects on river water quality by regression models and mathematical functions in the South Qinling Mts., China.

The main objectives of this study are to (1) indicate the population influences on river water quality, (2) detect the impacts of elevational gradient on river water quality, and (3) quantitatively estimate the threshold values of population and elevational gradient affecting the water quality in the Jinshui River basin of the south Qinling Mts., China. This study will facilitate the ecosystem management for mountainous streams and provide quantitative models for understanding and mitigating human impacts on river system.

Materials and methods

Study area

The Jinshui River (33°16′–33°45′N, 107°40′–108°10′E) is a tributary of the Han River, located in Shaanxi Province in the south Qinling Mts., China. It drains a total area of 730 km² with a total length of 87 km, ranging in elevation from 322 to 2874 m (Fig. 1), and includes four major reaches, the Xi River, Xindianzi River, Dong River, and Lvguan River. The river is in a humid monsoon climate zone. The annual average rainfall ranges from 924 to

1244 mm, and most of the precipitation occurs from June to August. The average temperature is approximately from 11.5 to 14.5 °C, with a maximum of 21.9 °C in summer and a minimum of −0.3 °C in winter.

The Jinshui River basin lies entirely within a mountainous area with large forest land of 96.4 % of the drainage area (Bu et al. 2010b). Agricultural land covers 2.21 %, and non-agriculture land is 1.33 % of the total area. In the river basin, industrial activities are minimal. However, concentrated agricultural activities and human populations are found in the lower reaches of the river. Particularly, the Jinshui Town (Fig. 1) has a population of 9.87 thousand, or 51.4 % of the total population, and 94.1 % of agricultural land of the drainage area (Bu et al. 2010a). In the middle reaches of the river, agricultural activities and human population are scattered and moderate.

Water sampling and analytical methods

Water samples were collected in nine surveys from Oct 2006 to Nov 2008 during high-flow period (Oct 2006, Aug 2007 and Aug 2008), low-flow period (Dec 2006, Mar 2007 and Mar 2008) and mean-flow period (May 2007, Nov 2007 and Nov 2008) at 11 sampling sites in the Jinshui River basin. Of the 11 sampling sites, nine were in the mainstream of the river, while others lie in the Xi River, a main tributary of the Jinshui River (Fig. 1). To assess the impact of population on river water quality, 25 representative parameters were selected for further analysis. These variables included water temperature (Temp), pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), turbidity (Turb), 5-day biological oxygen demand (BOD₅), chemical oxygen demand (Mn) (COD_{Mn}), bicarbonate (HCO₃), total hardness (T-Hard), sulfate (SO₄), chloride (Cl), ammoniacal nitrogen (NH₄-N), nitrate nitrogen (NO₃-N), total nitrogen (TN), orthophosphate (PO₄-P), dissolved phosphorus element (DP), total phosphorus (TP), dissolved sulphur element (DS), and dissolved trace elements of potassium (K), sodium (Na), calcium (Ca), magnesium (Mg), silicon (Si), and strontium (Sr). The water sampling and analytical methods follow the standard methods and procedures (NEPB 2002), and refer to articles of Bu et al. (2010a, b).

Population data and its distribution

The people of the Jinshui River basin all live in rural areas. In this study, the population was only considered in the vicinity of the sampling sites since it had direct impacts on river water quality. The population data were obtained by field survey and verified by the local village committee. The mean total population along all the sampling sites is

Fig. 1 The location and 11 sampling sites of the Jinshui River basin in the South Qingling Mts., China

6.29 thousand (Table 1) from 2006 to 2008 during the sampling periods, with the population density of 8.6 per km².

The population data were vertically distributed (Table 1) and exponentially decreased ($R^2 = 0.856$, $p < 0.001$) when the elevational gradient increased (Fig. 2). Their relations were expressed as:

$$(pop) = 4154.8e^{-0.31(H \times 10^{-2})} \quad (1)$$

where (*pop*) is the population and *H* is elevational gradient. The higher the elevational gradient, the human activities are the less. Thus, the elevational gradient, as a variable characterizing the population distribution, was also discussed together with population data in the research.

Statistical methods

Factor analysis (FA) was used to calculate the total factor scores and identify the water quality at each sampling site in the Jinshui River basin during the sampling periods from 2006 to 2008. Before FA was performed, the water quality data were initially standardized by *z*-scale transformation to avoid misclassification because of the wide differences in data units and dimensionality (Bu et al. 2010a). Kaiser–Meyer–Olkin (KMO) and Bartlett’s sphericity tests were conducted to measure the adequacy of the sampling data for FA. Factor scores of each factor for different sampling sites were calculated based on the Anderson–Rubin method (Field 2013), showing relative water quality of one

Table 1 Mean population (from 2006 to 2008) and elevational gradient at different sampling sites in the Jinshui River basin of the South Qingling Mts., China

Sampling site	Elevational gradient (m)	Population
Site 1	1193	113
Site 2	1050	507
Site 3	892	391
Site 4	954	160
Site 5	870	356
Site 6	742	498
Site 7	729	217
Site 8	645	662
Site 9	591	711
Site 10	427	1236
Site 11	320	1443

Data sources: The population data were obtained by field survey and verified by the local village committee

Fig. 2 Relationship between population and elevational gradient in the Jinshui River basin of the South Qingling Mts., China

sampling site compared to another. The total factor scores of different sampling sites were estimated by the factor scores and eigenvalues. The formula for calculating the value was expressed as:

$$F = \sum_{i=1}^n \left(\frac{\lambda_i}{\sum_{i=1}^n \lambda_i} f_i \right) \quad (2)$$

where F is the total factor score of each sampling site, f is the factor score of each sampling site in each factor, λ is eigenvalue in each factor, and n is the number of extracted factors.

Correlations among population, elevational gradient, and water quality chemistry were tested using Pearson's correlation coefficients with statistical significances at $p < 0.01$ and $p < 0.05$ levels (2-tailed), respectively. Regressions based on the p value < 0.01 or < 0.05 were also conducted to explain the relationships among population, elevational gradient, and water quality in the river basin. For the correlation and regression analysis, the one-sample Kolmogorov–Smirnov test was used in testing the normal distribution for all variables (Bu et al. 2014). The results showed asymptotic significance (two-tailed) values (p values) ranging from 0.200 (T-Hard) to 0.989 (DP) and greater than 0.05, suggesting normal distribution. All statistics were performed using SPSS 13.0 (SPSS, Inc., USA).

Results

River water quality

In FA, the results of KMO and Bartlett's sphericity test were 0.749 and 2323.748 ($df = 300$, $p < 0.001$), respectively. The first five rotated factors with eigenvalues greater than 1 were extracted to explain about 80.47 % of the total variance in the water quality data set (Table 2). The total factor scores at 11 different sampling sites were calculated based on the factor scores and eigenvalue in each factor (Table 2) and displayed in Fig. 3. The higher the total factor score, the worse is river water quality (Bu et al. 2010b). Among these sampling sites, site 10 (Jinshui Town) has the highest

Table 2 Factor scores at the 11 sampling sites according to the factor analysis in the Jinshui River basin of the South Qingling Mts., China

Sampling site	Factor score				
	1	2	3	4	5
Site 1	−0.894	−0.169	−0.086	−0.072	0.253
Site 2	−0.454	0.018	0.054	0.001	0.570
Site 3	−0.290	0.101	0.088	0.083	−0.420
Site 4	−0.773	−0.194	−0.103	−0.043	0.274
Site 5	−0.689	0.035	0.006	−0.108	−0.202
Site 6	−0.233	0.066	0.042	−0.098	0.157
Site 7	−0.208	0.097	−0.145	−0.046	−0.591
Site 8	−0.094	0.383	−0.040	−0.310	0.278
Site 9	0.222	−0.017	−0.073	0.218	−0.277
Site 10	2.471	−0.135	0.180	0.040	−0.109
Site 11	0.976	−0.129	0.105	0.320	0.281
Eigenvalue	9.457	3.404	3.191	2.340	1.725
% of variance	37.83	13.62	12.76	9.36	6.90
Cumulative %	37.83	51.45	64.21	73.57	80.47

Fig. 3 The total factor scores at the 11 sampling sites in the Jinshui River basin of the South Qinling Mts., China (boxes represent interquartile range, whiskers highlight the range of the total factor scores, and the bold lines denote the median values on the graph)

total factor scores with mean value of 1.16, showing the worst water quality. The mean values of total factor scores at sites 8, 9, and 11 were also greater than 0 (Fig. 3), implying the water quality had deteriorated there. Site 1 had the best water quality since its total factor score was relatively low with the value of -0.45 . In the study, the total factor scores were defined as pollution index in the next analysis.

Linkage between population and river water quality

Correlation analysis showed significant relationships between population and river water quality in the Jinshui River basin during the sampling periods (Table 3). The population was positively correlated with most of water quality variables including EC, TDS, DO, Turb, COD_{Mn} , HCO_3 , T-Hard, SO_4 , Cl, DP, DS, K, Na, Ca, Mg, and Sr ($p < 0.01$ or $p < 0.05$). The linear regression models explained more water quality variables by population in the Jinshui River basin (Table 4). The population data predicted 16 variables of EC, TDS, DO, Turb, COD_{Mn} , HCO_3 , T-Hard, SO_4 , Cl, DP, DS, K, Na, Ca, Mg, and Sr ($p < 0.01$ or $p < 0.05$), and explained 43.3 % (DO) to 77.8 % (Cl) of the total variances. Pollution index and population were also significantly correlated with each other ($p < 0.01$, Table 3) and their relationship at different sampling sites in the river basin was expressed as a quadratic equation (Fig. 4a):

$$PI = 0.259[\ln(pop)]^2 - 2.642\ln(pop) + 6.324 \quad (3)$$

where PI is the pollution index and (pop) is the population.

Table 3 Pearson's correlation coefficients among population, elevational gradient, and river water quality in the Jinshui River basin of the South Qinling Mts., China

Variable	Population	Elevational gradient (m)
Temp	0.386	-0.655^*
pH	0.295	-0.585
EC	0.857^{**}	-0.798^{**}
TDS	0.858^{**}	-0.798^{**}
DO	0.658^*	-0.658^*
Turb	0.769^{**}	-0.725^*
BOD_5	0.150	0.088
COD_{Mn}	0.802^{**}	-0.879^{**}
HCO_3	0.823^{**}	-0.783^{**}
T-Hard	0.844^{**}	-0.732^{**}
SO_4	0.682^*	-0.519
Cl	0.882^{**}	-0.847^{**}
$\text{NH}_4\text{-N}$	0.409	-0.427
$\text{NO}_3\text{-N}$	0.190	-0.438
TN	-0.538	0.740^{**}
$\text{PO}_4\text{-P}$	0.569	-0.599
DP	0.728^*	-0.737^{**}
TP	0.182	-0.224
DS	0.682^*	-0.532
K	0.784^{**}	-0.824^{**}
Na	0.857^{**}	-0.789^{**}
Ca	0.858^{**}	-0.808^{**}
Mg	0.812^{**}	-0.765^{**}
Si	0.493	-0.087
Sr	0.832^{**}	-0.758^{**}
PI^a	0.891^{**}	-0.813^{**}

* $p < 0.05$ (two-tailed)

** $p < 0.01$ (two-tailed)

^a Pollution index

Linkage between elevational gradient and river water quality

The correlations between elevational gradient and water quality were significant during the sampling periods (Table 3), indicating that population distribution influenced the river water quality. In correlation analysis, elevational gradient was related to Temp, EC, TDS, DO, Turb, COD_{Mn} , HCO_3 , T-Hard, Cl, TN, DP, K, Na, Ca, Mg, and Sr ($p < 0.01$ or $p < 0.05$; Table 3). In the linear regression analysis, more water quality variables were explained by elevational gradient during the sampling periods (Table 5). The physicochemical variables of Temp, EC, TDS, DO, Turb, COD_{Mn} , HCO_3 , T-Hard, and Cl were all estimated by elevational gradient at significant level of $p < 0.01$ except for Temp, DO, and Turb at $p < 0.05$ level. Additionally, the population was the predictor for nutrient variables (TN

Table 4 Linear regression models for water quality variables and population during the sampling periods in the Jinshui River basin of the South Qinling Mts., China

Variable	Regression model	R^2	Adjusted R^2	Sig.
EC	$95.838 + 9.302(pop^a \times 10^{-2})$	0.735	0.705	<0.001
TDS	$62.473 + 6.038(pop^a \times 10^{-2})$	0.736	0.707	<0.001
DO	$8.847 + 0.995(pop^a \times 10^{-3})$	0.433	0.370	0.028
Turb	$0.254 + 2.003(pop^a \times 10^{-3})$	0.592	0.547	0.006
COD _{Mn}	$1.873 + 0.234(pop^a \times 10^{-3})$	0.644	0.604	0.003
HCO ₃	$38.404 + 6.167(pop^a \times 10^{-2})$	0.677	0.641	0.002
T-Hard	$0.518 + 0.501(pop^a \times 10^{-3})$	0.712	0.680	<0.001
SO ₄	$11.166 + 5.980(pop^a \times 10^{-3})$	0.465	0.406	0.021
Cl	$1.027 + 1.446(pop^a \times 10^{-3})$	0.778	0.753	<0.001
DP	$0.018 + 0.007(pop^a \times 10^{-3})$	0.530	0.478	0.011
DS	$4.032 + 1.206(pop^a \times 10^{-3})$	0.465	0.406	0.021
K	$0.556 + 0.351(pop^a \times 10^{-3})$	0.614	0.572	0.004
Na	$1.184 + 0.618(pop^a \times 10^{-3})$	0.734	0.704	<0.001
Ca	$13.056 + 1.582(pop^a \times 10^{-2})$	0.735	0.706	<0.001
Mg	$1.622 + 1.625(pop^a \times 10^{-3})$	0.659	0.621	0.002
Sr	$0.054 + 0.077(pop^a \times 10^{-3})$	0.692	0.657	0.002

EC is in $\mu\text{S/cm}$, Turb is in NTU, T-Hard is in mmol/l, and others are in mg/l^a Population

and DP, $p < 0.01$), as well as the dissolved trace metals of K, Na, Ca, Mg, and Sr ($p < 0.01$). Since they highly linked each other ($p < 0.01$, Table 3), a quadratic function was built up between pollution index and elevational gradient at different sampling sites in the river basin (Fig. 4b):

$$PI = 0.017(H \times 10^{-2})^2 - 0.399(H \times 10^{-2}) + 1.956 \quad (4)$$

where PI is the pollution index and H denotes the elevational gradient.

Multivariate regression models of water quality variables

The relationships among water quality variables, population, and elevational gradient were simulated by multivariate linear regression analysis using Enter method (Table 6). Population combined with elevational gradient accounted for 52.8 % (for pH) to 80.5 % (for Cl) of the total variances of water quality variables in the Jinshui River basin during the sampling seasons. Pollution index was explained 80 % of the total variances by population and its vertical distribution.

Discussion

Impacts of population on river water quality

In this study, the population at 11 sampling sites was positively contributed to the concentrations of water

quality variables in the Jinshui River basin of the South Qinling Mts., China (Tables 3, 4). The slopes of the regression models in the regression analysis were all positive (Table 4), indicating that human activities were gradually frequent with population increases and thereby affected the input and output of pollutants in river water (Li et al. 2004). Thus, the contents of pollutants expanded when population increasing.

In regression analysis between pollution index and population (Function 3), the pollution index was regarded as the explained variable and the natural logarithm of population as the explanatory variable. The graphics showed a shape of parabola ($R^2 = 0.796$, $p < 0.01$; Fig. 4a) opening upwards for $0.259 > 0$. Most points lay in the right of the parabola, explaining that the pollution index rose with the population growth. According to the properties of quadratic function, one order derivative was evaluated on both side of the function (3) and a new function was obtained as follows:

$$\frac{\partial PI}{\partial \ln(pop)} = 0.518 \ln(pop) - 2.642 \quad (5)$$

When $\frac{\partial PI}{\partial \ln(pop)} = 0$, then $\ln(pop) = 5.100$. Thus, threshold values of the function (3) were calculated. Here $pop = e^{5.100} \approx 165$, while the minimum value of pollution index ($PI_{\min}$) was -0.414 . The results explained that the river water quality decreased with population growth when other conditions were not changed. In other words, the water quality for the Jinshui River was not largely influenced by population as long as population was controlled

Fig. 4 Regression analyses **a** between pollution index and population and **b** between pollution index and elevational gradient at different sampling sites in the Jinshui River basin of the South Qinling Mts., China

under 165 people at each sampling site. Or, even if the water quality was affected by population under 165 people at each site, it could be restored through the river self-purification effects. As the population was more than 165 people at each site, however, the river water quality would be impacted by human activities and not be restored in a short term.

On the basis of the extreme value of population, the population capacity of the river basin covering the 11 sampling areas was estimated as 1815 people. Although the population density was relatively low in the Jinshui River basin, the total population of the basin was close to 5.4 times of the population capacity. Therefore, population control was still needed in the river basin in order to protect the ecological environment of the Qinling Mts., China.

Impacts of population distribution on river water quality

Most of water quality variables were negatively correlated with elevational gradient in correlation analysis (Table 3) and also defined by elevational gradient in regression analysis (Table 5), showing that population distribution had direct influence on river water quality in the Jinshui River basin of the South Qinling Mts., China. The slopes of the regression models in the regression analysis were mostly negative (Table 5), suggesting that human disturbances were reduced with elevational gradient uplifting, which caused the input and output of pollutants decrease in river water (Vitousek 1977). Water temperatures in the river decreased approximately 2.3 °C for every 1000 m increase in elevation (Table 5) since radiative warming would be more significant in the low elevations (Silsbee and Larson 1982). The pattern of decreasing Turb with increasing elevation closely paralleled that of EC, TDS, DO, COD_{Mn}, HCO₃, Cl, and DP, indicating elevational trends for less human disturbance. Additionally, low temperature in high elevations could decrease the metabolic rates and biological activity of aquatic organisms (Wetzel 2001), which caused the reduction of COD_{Mn} with increasing elevation. T-hard, K, Na, Ca, Mg, and Sr also followed elevational gradients because the low temperatures of the high elevations may slow chemical weathering rates (Gorham et al. 1979). The TN concentrations increased with distinct elevational gradients, which were attributable to the fact that nitrogen cycling within the forest system is quite large relative to outputs in streamwater (Bormann et al. 1977). Another reason might be related to forest floor and soil characteristics rather than forest composition (Vitousek 1977; Silsbee and Larson 1982).

The regression analysis between pollution index and elevational gradient (Function 4) showed a decreasing trend with elevation as was reflected by R^2 value of 0.796 ($p < 0.01$). The graphics also displayed a parabola shape opening upwards for $0.017 > 0$ (Fig. 4b) and most points lay in the left of the parabola, suggesting that the pollution index decreased with the increasing elevation. According to the properties of quadratic function, one order derivative was evaluated on both sides of the function (4), and then function (6) was obtained:

$$\frac{\partial PI}{\partial (H \times 10^{-2})} = 0.034(H \times 10^{-2}) - 0.399 \quad (6)$$

When $\frac{\partial PI}{\partial (H \times 10^{-2})} = 0$, then $H = 1174$ (m). Hence, $PI_{\min}$ was -0.385 when threshold value of elevation was 1174 m. The results indicated that the river water quality in the Jinshui River could gradually get better with the elevational gradients due to less human activities when the

Table 5 Linear regression models for water quality variables and elevational gradient during the sampling periods in the Jinshui River basin of the South Qinling Mts., China

Variable	Regression model	R^2	Adjusted R^2	Sig.
Temp	$17.027 - 2.298(H^a \times 10^{-3})$	0.429	0.365	0.029
EC	$257.063 - 0.141H^a$	0.637	0.597	0.003
TDS	$167.009 - 9.151(H^a \times 10^{-2})$	0.636	0.596	0.003
DO	$10.656 - 0.162(H^a \times 10^{-2})$	0.432	0.369	0.028
Turb	$3.753 - 0.308(H^a \times 10^{-2})$	0.525	0.473	0.012
COD _{Mn}	$2.327 - 0.418(H^a \times 10^{-3})$	0.773	0.748	<0.001
HCO ₃	$146.887 - 9.570(H^a \times 10^{-2})$	0.614	0.571	0.004
T-Hard	$1.347 - 0.708(H^a \times 10^{-3})$	0.535	0.484	<0.010
Cl	$3.585 - 0.226(H^a \times 10^{-2})$	0.717	0.686	<0.001
TN	$0.276 + 0.616(H^a \times 10^{-3})$	0.548	0.498	0.009
DP	$0.031 - 0.012(H^a \times 10^{-3})$	0.543	0.492	<0.010
K	$1.217 - 0.601(H^a \times 10^{-3})$	0.679	0.644	0.002
Na	$2.247 - 0.928(H^a \times 10^{-3})$	0.622	0.580	0.004
Ca	$40.697 - 2.430(H^a \times 10^{-2})$	0.653	0.614	0.003
Mg	$4.460 - 2.495(H^a \times 10^{-3})$	0.585	0.539	0.006
Sr	$0.186 - 0.114(H^a \times 10^{-3})$	0.574	0.527	0.007

EC is in $\mu\text{S/cm}$, Turb is in NTU, T-Hard is in mmol/l, and others are in mg/l^a Elevational gradient**Table 6** Multivariate regression models for water quality variables, population, and elevational gradient during the sampling periods in the Jinshui River basin of the South Qinling Mts., China

Variable	Regression model	R^2	Adjusted R^2	Sig.
Temp	$19.667 - 1.596(pop^b \times 10^{-3}) - 4.556(H^c \times 10^{-3})$	0.564	0.455	0.036
pH	$8.685 - 0.361(pop^b \times 10^{-3}) - 0.909(H^c \times 10^{-3})$	0.528	0.410	0.049
EC	$137.416 + 72.307(pop^b \times 10^{-3}) - 38.869(H^c \times 10^{-3})$	0.746	0.683	0.004
TDS	$88.761 + 47.289(pop^b \times 10^{-3}) - 24.576(H^c \times 10^{-3})$	0.747	0.684	0.004
Turb	$1.300 + 1.482(pop^b \times 10^{-3}) - 0.978(H^c \times 10^{-3})$	0.605	0.506	0.024
COD _{Mn}	$2.251 + 0.046(pop^b \times 10^{-3}) - 0.353(H^c \times 10^{-3})$	0.779	0.724	0.002
HCO ₃	$74.982 + 43.455(pop^b \times 10^{-3}) - 34.195(H^c \times 10^{-3})$	0.696	0.621	0.008
Cl	$1.966 + 0.978(pop^b \times 10^{-3}) - 0.878(H^c \times 10^{-3})$	0.805	0.756	0.001
T-Hard	$0.514 + 0.503(pop^b \times 10^{-3}) + 0.004(H^c \times 10^{-3})$	0.712	0.640	0.007
TN	$-0.086 + 0.219(pop^b \times 10^{-3}) + 0.925(H^c \times 10^{-3})$	0.593	0.491	0.027
DP	$0.025 + 0.003(pop^b \times 10^{-3}) - 0.007(H^c \times 10^{-3})$	0.575	0.468	0.033
Ca	$21.339 + 11.698(pop^b \times 10^{-3}) - 7.744(H^c \times 10^{-3})$	0.752	0.690	0.004
K	$1.012 + 0.124(pop^b \times 10^{-3}) - 0.426(H^c \times 10^{-3})$	0.698	0.623	0.008
Mg	$2.474 + 1.200(pop^b \times 10^{-3}) - 0.796(H^c \times 10^{-3})$	0.674	0.592	0.011
Na	$1.414 + 0.504(pop^b \times 10^{-3}) - 0.215(H^c \times 10^{-3})$	0.742	0.678	0.004
Si	$1.361 + 2.535(pop^b \times 10^{-3}) + 3.376(H^c \times 10^{-3})$	0.717	0.646	0.006
Sr	$0.078 + 0.065(pop^b \times 10^{-3}) - 0.022(H^c \times 10^{-3})$	0.697	0.621	0.008
PI ^a	$-0.246 + 0.820(pop^b \times 10^{-3}) - 0.287(H^c \times 10^{-3})$	0.800	0.750	0.002

Temp is in $^{\circ}\text{C}$, EC is in $\mu\text{S/cm}$, Turb is in NTU, T-Hard is in mmol/l, PI has no unit, and others are in mg/l^a Pollution index^b Population^c Elevational gradient

elevation was below 1174 m and other conditions unchanged. However, the water quality above the elevation of 1174 m inversely declined because of the influence of atmospheric precipitation and surface runoff in forest (Silsbee and Larson 1982).

Combined effects of population and its distribution on river water quality

The multivariate linear regression models showed that most water quality variables were significantly predicted

by population and elevational gradient (Table 6). Pollution index of river water was also linearly expressed by population and its vertical distribution. Their relationships suggested population and its distribution put pressures on the river water quality in the river basin (Juma et al. 2014). As the population grows, the need of more natural resources, such as agriculture, industry, and household demand, also continues to increase in the river basin. Additionally, the natural resources will be first consumed in lower elevations when people centralize. However, the over-consumption of resources will negatively impact on the river ecosystem and exceed the river capacity, ultimately leading to degradation of river water quality (Caraco and Cole 1999). Consequently, controlling the population growth and its vertical distribution will be an effective approach to mitigate human influences on the mountainous river ecosystem in the future.

Conclusions

The results of the research quantitatively explained the impacts of population on river water quality by nine surveys in the Jinshui River basin of the South Qinling Mts., China. Pollution indices at 11 different sampling sites ranged from 1.16 to −0.45 calculated by factor scores in FA, representing that the river water quality was from low to high. Population significantly positively linked with most water quality variables and pollution index in correlation analysis and explained 43.3–77.8 % of the total variances in regression analysis, indicating that human activities were gradually frequent with population growth and affected the input and output of pollutants in river water. According to the quadratic function between pollution index and population, the population capacity of the river basin was estimated as 1815 people. Elevational gradient was also negatively correlated with most water quality variables in correlation analysis and defined them in regression analysis, suggesting that population distribution had direct influence on river water quality due to less human activities in high elevation. The threshold value of elevation was calculated as 1174 m by using the regression model between pollution index and elevational gradient. Finally, the combined effects of population and elevational gradient were analyzed by multivariate linear models, further confirming that the population and its vertical distribution directly put pressures on the river water quality.

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Compliance with ethical standards

Conflict of interest The authors declare that we have no conflict of interest.

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