Original Article

Ecogeomorphological Condition and Hydrological Indicators of the Self-purification Capacity of Rivers: A Case Study of Siminehrood River in Northwestern Iran

Afagh Kazemi, Mohammad Hossein Rezaei Moghaddam[1], Saeed Khezri

Department of Geomorphology, Faculty of Natural Resources, University of Kurdistan, Sanandaj, Iran, [1]Department of Geomorphology, Faculty of Planning and Environmental Sciences, University of Tabriz, Tabriz, Iran

Abstract

Aims: The steady development of human communities and the spread of industrial activities are major contributors to environmental pollution, especially the contamination of water resources. Population growth and thus the acceleration of municipal, industrial, and agricultural wastewater release have adversely affected these inestimable resources and restricted their accessibility. This work attempts to identify the ecogeomorphological condition of rivers in drainage basins emphasizing the Siminehrood River in Northwestern Iran. The purpose is to study all nonpoint source (PS) and PS pollutions and circumstances that weaken and intensify the pollution rate and self-purification capacity of rivers, especially in the Siminehrood River. **Materials and Methods:** All data and statistics were collected and their seasonal average was calculated. Maps and variables associated with the physical properties of drainage basins were then extracted through ArcGIS. The Schuler diagram was plotted through Chemistry software for all stations and each season to assess the type and chemical quality of the river's drinking water. HEC-RAS model, HEC-GEORAS extension, and ArcGIS were employed for simulation of river flow and calculation and determination of water surface profiles and other hydraulic characteristics of flow including water depth, water flow rate, stream shear stress, and stream power. **Results:** According to the analyses and results, the improper ecogeomorphological condition of rivers and their low self-purification capacity are directly correlated with the mean river water depth, water flow rate, slope of the river basin, and environmental differences. **Conclusions:** Within the study area, the highest environmental instability and the least self-purification capacity were observed downstream of the sub-basin in which the mean and maximum depth of water were, respectively, 3.10 m and 8.803 m. Insignificant water flow rate (0.86 m/s on average) and slope of <4% in the area have stagnated water flow in most areas and consequently declined the content of dissolved oxygen and the quality of water. Conclusively, this sub-basin can be reported as a region with an improper ecogeomorphological condition.

Keywords: Ecogeomorphology, hydrological indicators, self-purification, Siminehrood River

Introduction

Eco-geomorphology is an interdisciplinary approach to the study of river systems by integrating hydrology, fluvial geomorphology, and ecology considering different spatial and temporal perspectives. In fluvial ecogeomorphology, the ecological, geomorphological, and hydrological components of river systems reciprocally influence each other in terms of multiple spatial and temporal scales.[1] Hydrology controls the chemical characteristics of water, channel geomorphology, and habitat (fauna) availability. The importance of flow change and variability is known as a critical factor in the conservation of river geomorphology and its ecological quality.[2] Natural fluvial processes are accordingly critical to the formation and conservation of natural habitats, aquatic ecosystems, and river banks. Furthermore, understanding the reciprocal interactions and feedback between river ecology, hydrology, and geomorphology is necessary for the

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Address for correspondence: Dr. Afagh Kazemi, Department of Geomorphology, Faculty of Natural Resources, University of Kurdistan, Sanandaj, Iran.
E-mail: kazemi.uok2010@yahoo.com

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management, restoration, and regulation of rivers.[3] Water quality and self-purification capacity of rivers are important components that entail comprehensive ecogeomorphological and systematic perspectives. Self-purification is the capacity and potential of the river to eliminate contaminants and purify streaming water. There are limited results of basic and applied studies available for water resource managers to understand the ecogeomorphological condition of drainage basins. Therefore, by emphasizing the Siminehrood River and analyzing its self-purification capacity and given the great importance of rivers to supply drinking water and agricultural and industrial demands, we attempt to propose a model for reaching the short- and long-term goals of river management.

Several studies have concentrated on the self-purification capacity of rivers. Spellman and Drinan investigated the ecological interactions and various conditions of living in fluvial environments and the capacity of the stream to self-purify and refine.[4] In their study of chemical and microbiological parameters in freshwater and sediments, Ferronato *et al*. evaluated the pollution risk of the Reno River Basin, located in Northern Italy, and concluded that streams in mountainous areas have good quality while the quality at all other stations is moderate. The decline in water quality in these areas is a result of entering pollutants such as drainage of sewage and also industrial and agricultural pollution that leads to losing the self-purification capacity.[5] Galvis *et al*., by examining the self-purification capacity of the Coca River, found that pollution caused by municipal wastewater severely diminishes the rate of DO and consequently the self-purification capacity of a river, in particular when discharge and river flow velocity increases after rainfall.[6] Porzionato *et al*. studied pollutant accumulation, self-purification capacity of the river, and its influence on suburban areas and revealed that river water acts as a treatment plant on water routes ending on the boundaries of large cities, meaning that sewage and industrial waste are discharged into the river from upstream to downstream and then accumulate along the river and consolidate with river sediments. Such waters have considerable self-purification capacity because of sedimentation and absorption processes. Pollutants accumulated in sediments are gradually sustained due to anaerobic processes and thereby prevent contaminants from entering into municipal areas.[7] Kingsley evaluated the factors affecting the self-purification capacity of river Kaduna in Nigeria. The results revealed that water velocity affects the spatial distribution of dissolved oxygen, meaning that increasing water velocity shortens the time for oxygen release and results in oxygen deficiency. Furthermore, as the water depth increases, the volume of oxygen released by phytoplankton decreases.[8] Studies conducted in Iran on the self-purification capacity of rivers:

Hoseyni and Hoseyni investigated changes in the self-purification capacity of Karun River by the QUAL2KW model and reported that comparing the changes of the self-purification capacity of Karun River in both years shows that the problem of increasing EC component and water salinity has not been fixed after 5 years. Furthermore, raising the BOD of the water and the inability of the river to self-purify will be future problems of this river.[9] Wenai *et al*. concluded that the self-purification capacity of Abbas Abad River in Hamadan (Iran) in mountainous areas is higher in the first interval than the second interval due to proper aeration. Furthermore, the highest self-purification capacity in the whole river is related to the BOD index and the lowest to COD and NO3 indices, respectively, in the first and second intervals.[10] Moghimi Nezad *et al*. studied seasonal variations of the self-purification capacity of the Karun River and concluded that this river has the lowest purification capacity in winter and the highest self-purification capacity in February for pathogens due to the application of nitrate fertilizers for plant growth and pollutants entry into the river.[11]

According to the research performed by these authors, none of the researches conducted in Iran has investigated comprehensive ecogeomorphology and hydrologic factors affecting the self-purification capacity of the river. However, it is visible in global studies that only part of our work has been performed while hydrologic factors affecting the self-purification capacity of the river have been limitedly studied (e.g., Kingsley, 2016, which considers two factors of water velocity and water depth or Galvis *et al*., 2014, which examines the effects of water flow and water velocity). The purpose is, therefore, to fill the existing gaps wherever possible, identify the ecogeomorphological condition of the river basins and all nonpoint source (NPS) and point source (PS) pollutions, and the self-purification capacity of rivers emphasizing the Siminehrood River.

Geographical location and features of the study area

The study area is a drainage basin of the Siminehrood River in northwestern (NW) Iran, having a geodetic longitude of 45°30’22″E to 46°25’1″E and latitude of 36°10’35″N to 37°12’53″N. The total study area is 3803 km^2. In terms of administrative dividing, the drainage basin is largely located in Mahabad and Bukan counties, with a limited area that falls in Sardasht, Baneh, Saqez, and Miandoab counties. According to the National Iranian Watershed Division Plan, the study area is part of the drainage basin of Urmia Lake (code: 3031) with three sub-basins including (1) Siminehrood River, upstream of the conjunction of Galolan and Tataho rivers (Siminehrood source; code: 30313); (2) Siminehrood River, from Hajiabad to the conjunction of Galolan and Tataho rivers (middle Siminehrood River; code: 30312); and (3) Siminehrood River from the estuary to where the river enters Hajiabad plain (riffle of the Siminehrood River; code: 30311) [Figure 1].

In topography, the drainage basin consists of three mountainous, foothill, and alluvial areas. The mountainous area of the region is located at elevations of 1729 m to 2559 m and slopes over 11°. In these elevations, there are deep steep valleys formed by the action of the river. At the foothill of the nearly high and extended elevations of the study, there are alluvial deposits (alluvium) that are formed by the erosion of upstream formations. This

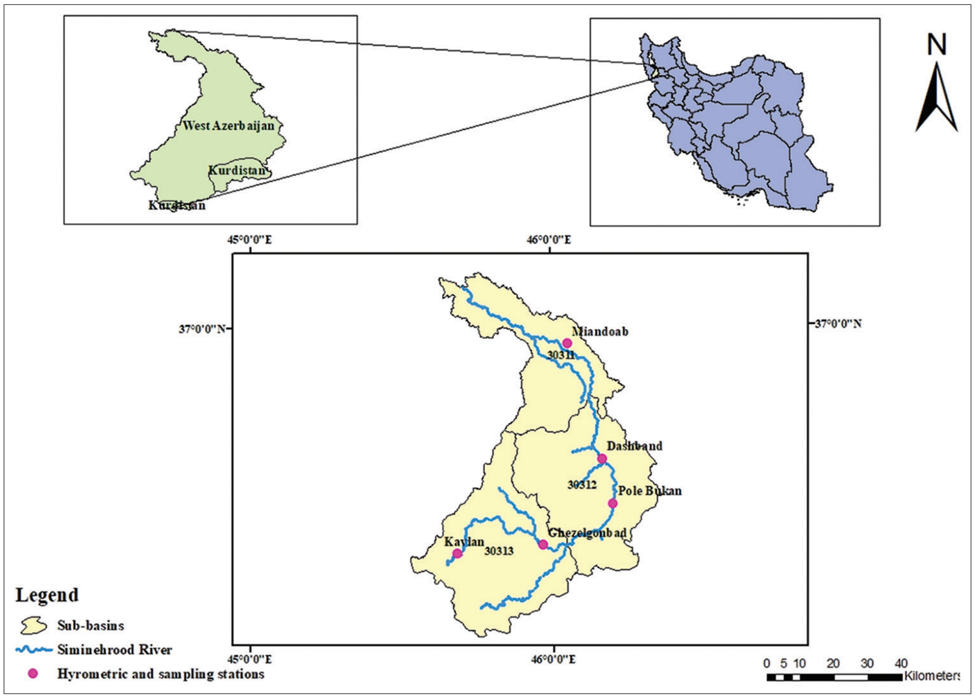

Figure 1: Study area (Siminehrood River basin)

area is topographically located in the elevations of 1393 m to 1728 m and slopes of 4°-11°. These foothills consist mainly of gravel and sand, while the particles become finer downstream of the foothills. The alluvial plain covers an area of 1125.2 km^2 on the elevations of 1249 m to 1392 m that corresponds to the Siminehrood River route and occupies most of the study area. The slope in this area ranges from 0° to 4°. This area starts from the middle part of the region and extends north. Bukan, Simineh, and Miandoab counties are located in the study area. There are new alluvial deposits at the boundaries of the Siminehrood River and in the plain area. Most of the wells in this area have been excavated in these sediments. Alluvial sediments consist of gravel, sand, silt, clay, and loamy soils [Figures 2 and 3].

The study area is located downstream of the Hamedan-Urmia zone (of Iran's geological divisions) which form the northern part of the Sanandaj-Sirjan zone. Siminehrood is one of the major rivers of the Urmia Lake basin and flows west of the Zarinehrood Basin. The mean long-term discharge downstream of the Siminehrood River is on average 11.8 m^3/s annually at the Miandoab station. The first branches of the Siminehrood originate from the south and east slopes of Mount Neyestan, at the elevation of 2410 m, 22 km NW of Sardasht. In Siminehrood basin, of about 3803 km^2, 960.9 km^2 (around 25.26%) are irrigated lands, which are on the route and border of the river, and about 1093.7 km^2 (around 28.75%) are dryland cultivation areas, which are the low-elevation neighboring areas [Figure 4].

Materials and Methods

Understanding the ecogeomorphological condition of the drainage basin is required for accurate assessment of river water quality and its self-purification capacity. Thus, all statistics and data related to NPS and PS pollutions in the study area were collected following information obtained from industries and mines, environmental protection, and agricultural jihad organization of West Azerbaijan province.

Furthermore, data of five hydrometric stations of the Siminehrood River drainage basin on physical, chemical, and hydrological variables such as electrical conductivity (EC; microsiemens/cm (µS/cm), total soluble solids (TDS; mg/l), sodium adsorption ratio, total hardness (TH; mg/l), calcium carbonate, chlorine (Cl), sulfate (So4), bicarbonate (Hco3), calcium (Ca), magnesium (Mg), sodium (Na) (all in meq/l), temperature, discharge, and sediment were obtained from the regional water authority of the West Azerbaijan province. Then, the seasonal average of the data obtained for each station was calculated using Excel. Maps and variables related to the physical properties of the drainage basin were extracted through ArcGIS. The changes in these parameters in different seasons and at each station were studied separately to study the effects of hydrogeomorphological factors on changes in water quality variables. Finally, the Schuler diagram was plotted through the Chemistry software for each station and in each season to evaluate the type and chemical quality of river drinking water. The foremost qualitative criteria to classify drinking water using Schuler diagrams were the content of solute in the main water solution containing anions and cations, the total dry matter, and the TH of water sources (mg/l) [Table 1].[12] In this diagram, the concentration of the parameters is plotted on the vertical columns and then the points are connected, and the analysis results are displayed as lines. Samples with higher TDS are mainly in the upper part of the diagram and those with fewer TDS are in the lower part.[13]

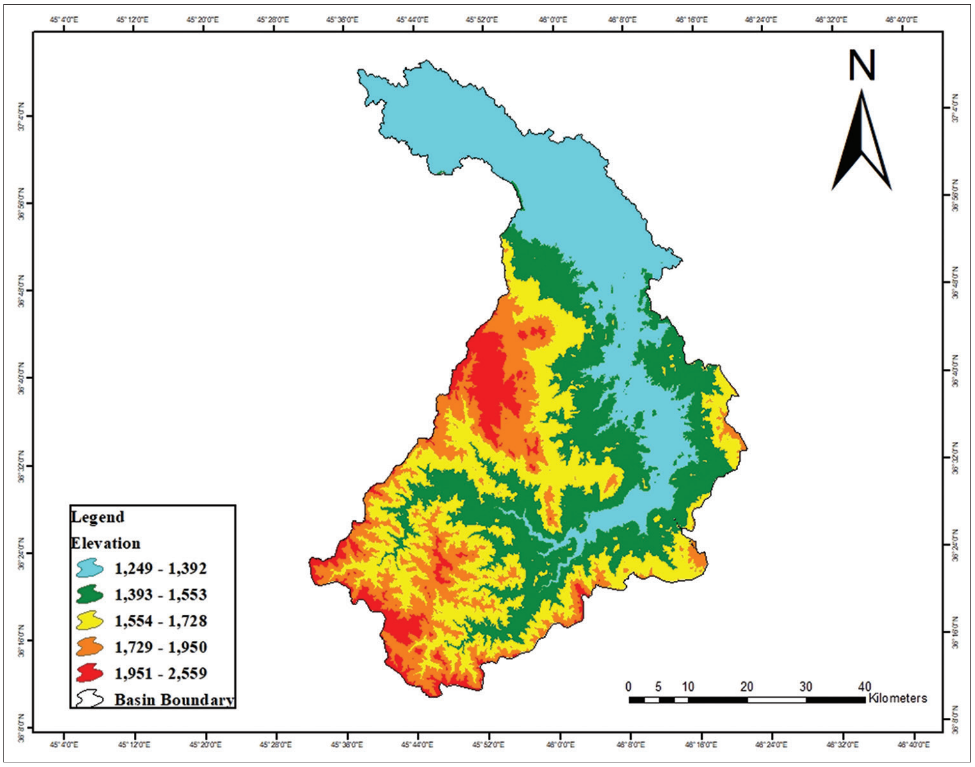

Figure 2: Siminehrood River basin altitude map

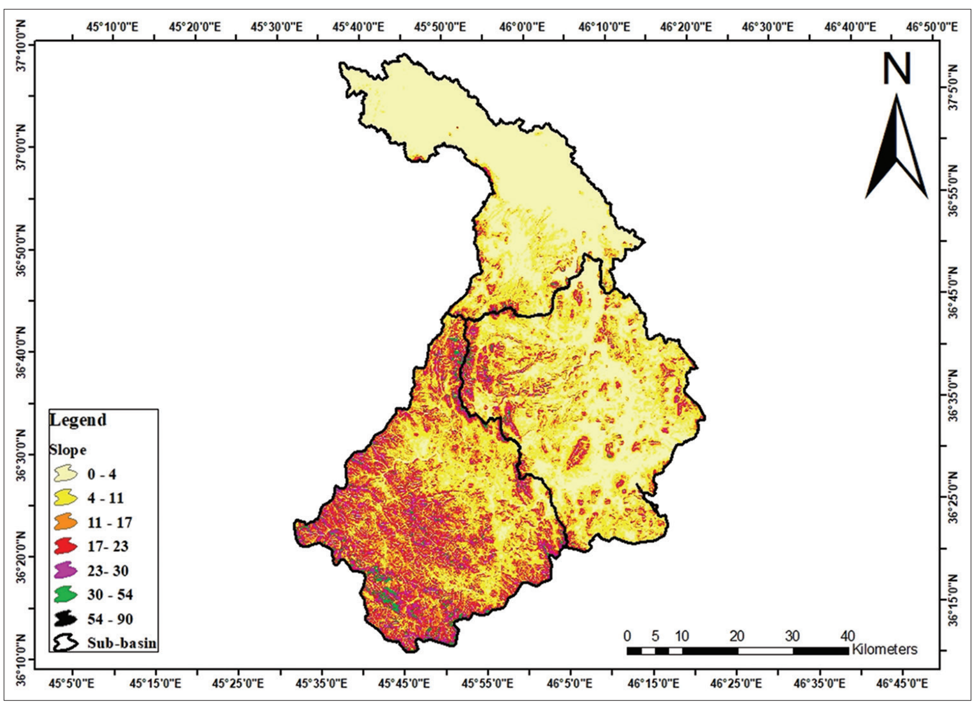

Figure 3: Siminehrood River basin slope map

The next step was to calculate hydrological indices (e.g., water depth, water flow rate, stream shear stress, and stream power), and investigate their role in weakening or enhancing pollution and self-purification capacity of the river. HEC-RAS model, HEC-GEORAS extension, and ArcGIS were used to simulate river flow and calculate and determine water surface profiles and other hydraulic flow characteristics (e.g., water depth, water flow rate, stream shear stress, and stream power). One hundred and four sheets of the topographic map (with the 1:2000 scale) were used. Four hundred and nine cross-sections were created

Table 1: Classification of water type based on the Schuler diagram

Water type	SO_4	CL	Na + K	TH	TDS
Good and fully tasteless	<140	<180	<115	<250	<500
Drinkable and slightly tasty	140-300	180-360	115-235	250-500	500-1000
Slightly unsuitable for drinking	300-580	360-720	235-460	500-1000	1000-2000
Inappropriate or unpleasant taste	580-1180	720-1400	460-900	1000-2000	2000-4000
Inappropriate or quite unpleasant taste	1180-2300	1400-2900	900-1850	2000-4000	4000-8000
Nondrinkable	>2300	>2900	>1850	>4000	>8000

TH: Total hardness, TDS: Total soluble solids, SO_4: Sulfate, CL: Chlorine, Na: Sodium

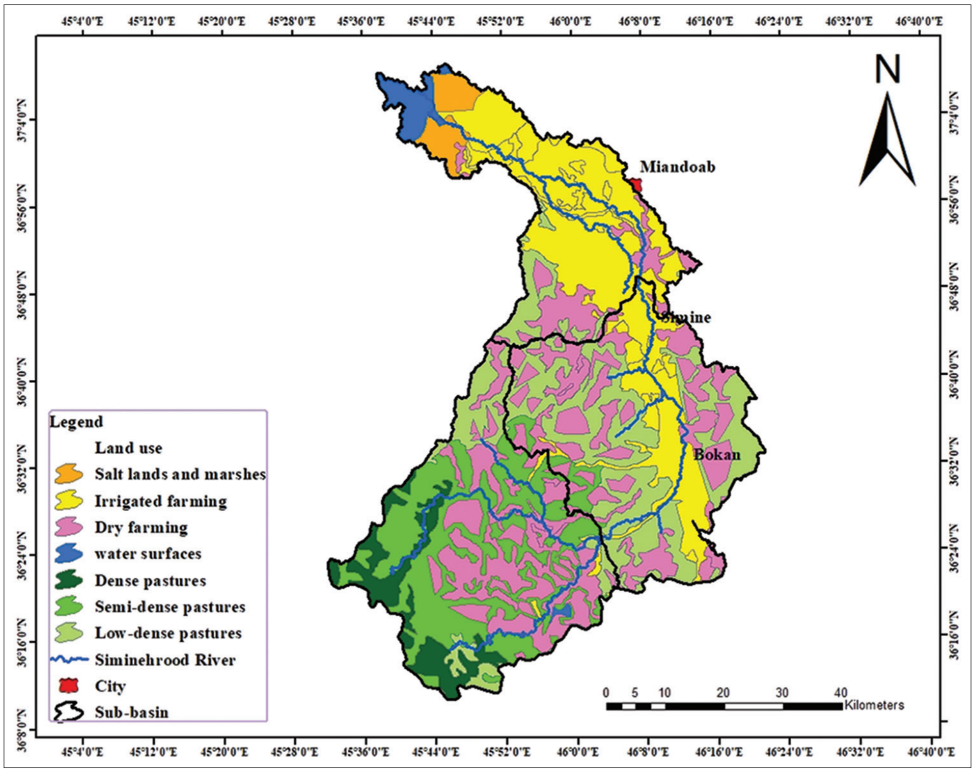

Figure 4: Land use and vegetation map of the Siminehrood River basin

across the river in ArcGIS by the HEC-GEORAS extension. The riverbanks that were originally plotted in Google Earth software to enhance the accuracy of the work entered into the HEC-GEORAS extension and digitized. Therefore, the data layers of the centerline, sidelines, and cross-sections were developed as a preprocessing of the HEC-RAS software and were called into this software. Furthermore, other geometrical and hydrological characteristics of the river flow including boundary conditions of the study area, river flow type, flow regime with different regimes, and Manning's roughness coefficient were completed and entered into HEC-RAS model. SMADA software and hydrometric data of the Polebukan and Miandoab station upstream and downstream of the river were used to the estimation of peak discharges for different return periods. The Log-Pearson type 3 distribution indicating the best curve fitting for the above statistics, and the Weibull prediction method were used for data. Finally, the outputs were returned to ArcGIS after running the HEC-RAS model. In this work, flood zoning with a 1.5-year return period (bankfull discharge) was the basis of calculations. To study hydrological indices' role in changing the self-purification capacity of the river, the mean, highest and lowest values of water depth, water flow rate, shear stress, and stream power were determined and analyzed for each of the sub-basins by HEC-RAS model. As a geomorphological concept, stream power is the amount of energy a river has to move or displace sediments, rocks, or woods.[14-16]

Boundary shear stress is defined as the onset of the movement of sedimentary particles by water flow in the bed of the river.[17] The resistance or variability of the rivers depends on the resistance of each point around the cross-section bed against the shear stress caused by the flow.[18]

Results

Regarding the ecological condition of the area and the types of NPS and PS pollutions in the Siminehrood River basin, it can be stated that the river has no industrial pollutants from the city of Bukan to upstream areas according to the data collected and the results obtained. There are only some human-made pollutants including an active iron ore mine (and two other inactive mines) in the Kooleh Boz branch and two aquaculture centers in the area. The first and foremost human-made pollutants include Bukan's wastewater that directly (and recently after treatment) enters into the river. Hence, it can be asserted that the water resources of these areas are threatened with no potential industrial pollutants. There are also formations with the potential of introducing heavy metals in the water in the upstream and mountainous areas and formations with a probability of the creation of saline water in the central and downstream regions. Furthermore, formations with the potential to produce suspended fine sediments and carbonate-rich formations are irregularly distributed within the region. Most of the industrial, aquaculture, and farming activities are concentrated in the middle and downstream sub-basins due to the presence of major population sites. In this region, the main population sites are located on the peripheral of the rivers. The Siminehrood River flows through the center of Bukan and Simineh cities and by the Miandoab border. Industrial sites are also crowded as a result of population rise around these sites and the boundaries of the river. According to the data gathered, water resources in this area are at risk of contamination of numerous pollutants from industries, mines, aquacultures, and farming activities [Figure 5].

The results of the HEC-RAS model on processes governing the river channel such as erosion and sedimentation processes and flood occurrence and also factors affecting the change of river self-purification capacity show that lateral erosion is limited and flood plain is less extended in upstream sub-basin and mountainous areas of the region due to lithological resistance. River discharge and water velocity are high and mainly vertical erosive processes and river bed degradations are dominated. Erosion is also severe in the middle of the basin, and the river carries its sedimentary load downstream with a maximum velocity of 3.447 m/s and maximum power equal to 558.631 w/m^2. In this sub-basin, the width of the flood plain has increased due to lower slope and height than the upstream sub-basin, so that the mean water surface width in this sub-basin reaches 70.76 m. In the downstream sub-basin, the width of the flood plain reaches its maximum value rather than the whole basin, so that the mean width of the water level in this sub-basin is 284.85 m. In this sub-basin, a decrease in slope results in decreased water flow rate (0.86 m/s on average), decreased stream power (with a maximum power of 214.83 w/m^2), and consequently decreased in shear stress (with the maximum amount of 162.084 N/m^2 in the middle sub-basin and 78.072 N/m^2 in the downstream sub-basin). Therefore, under these conditions, the erosive processes in this sub-basin have stopped and replaced by sedimentation processes [Table 2 and Figures 6-9].

Discussion

From the ecogeomorphological perspective, each of the contaminants, regardless of their aspect in the study area, differs in terms of environmental and hydrological impacts, absorption power by land formations and river beds, as well

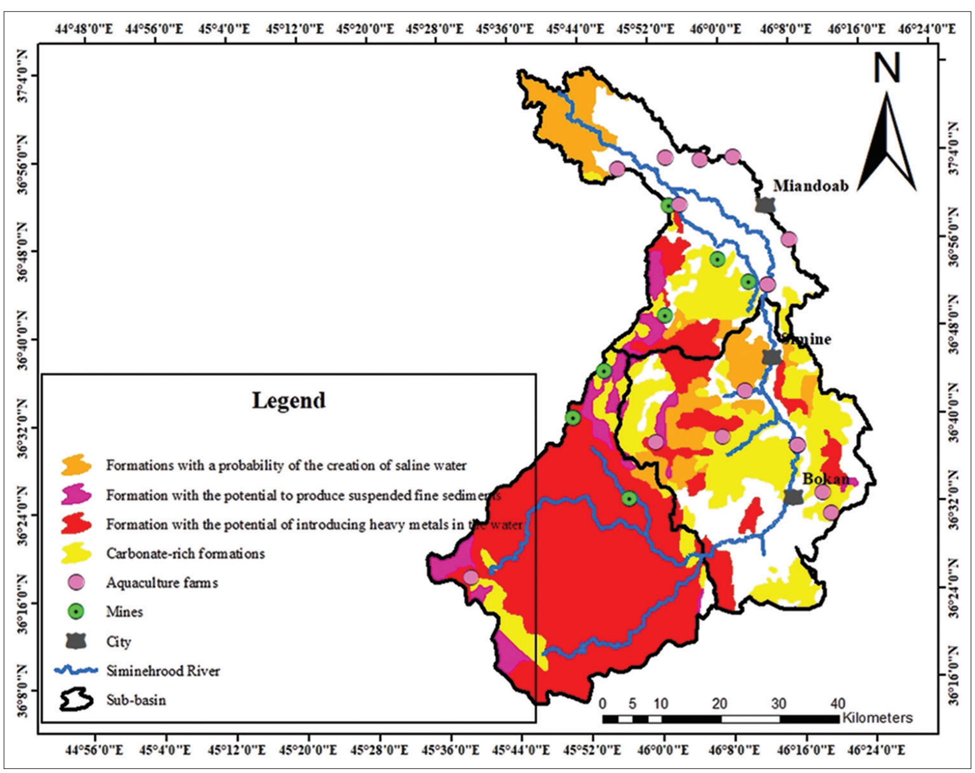

Figure 5: The spatial location of pollutant sources in the Siminehrood River basin

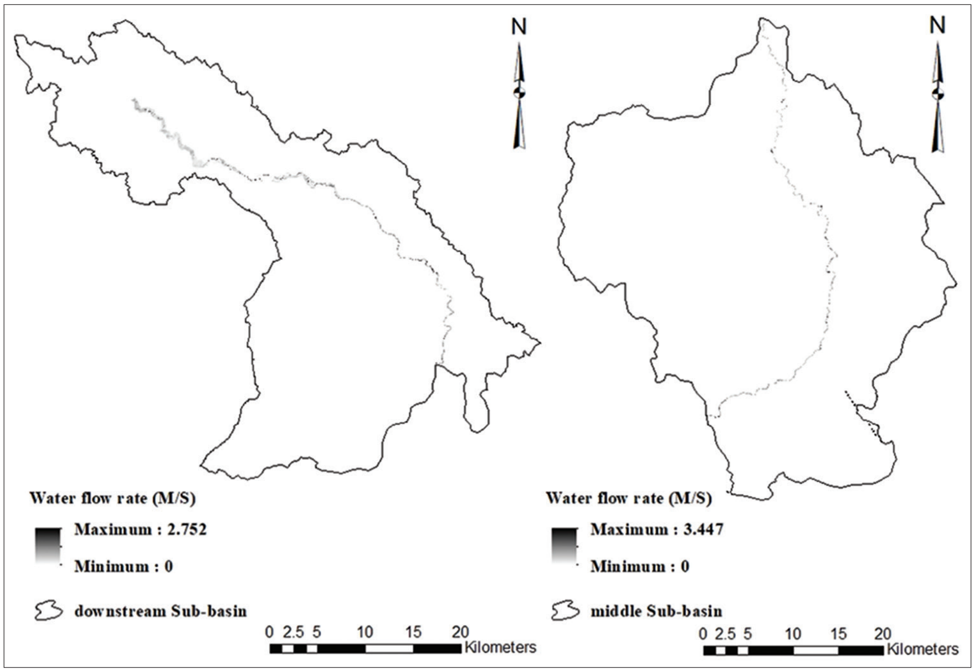

Figure 6: Water flow rate map of the Siminehrood sub-basins for floods with a 1.5-year return period

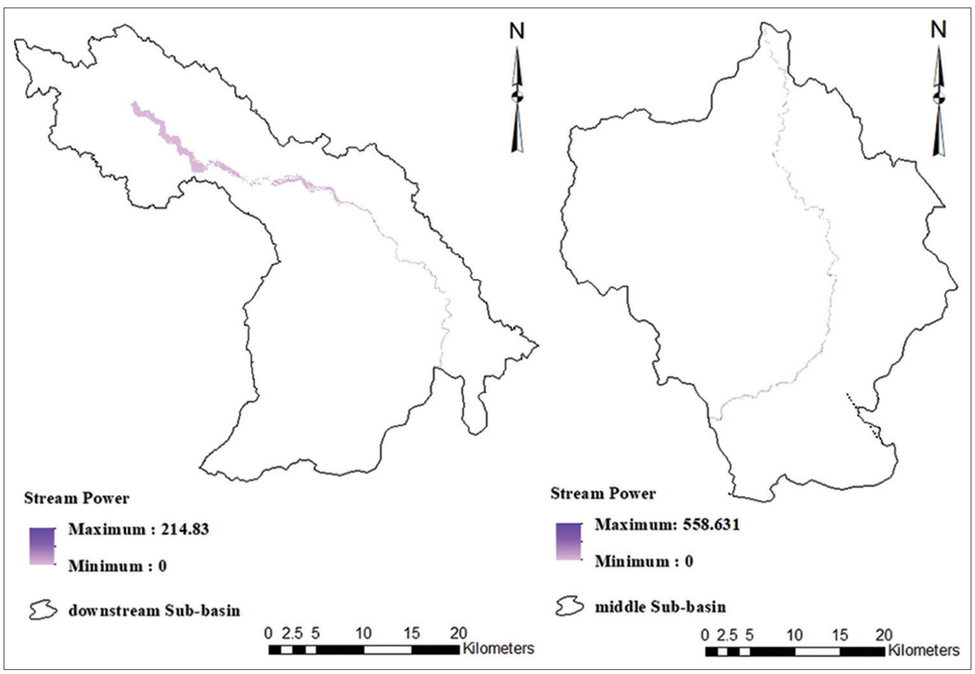

Figure 7: Stream power map of the Siminehrood sub-basins for floods with a 1.5-year return period

as natural purification and disposal in sub-basins. Because their hosting environments are diverse in each sub-basin and yet their tolerable pollution levels depend on different temporal and spatial factors, type and severity of inlet pollution and also environmental conditions. Therefore, the self-purification capacity of the river differs in each of the sub-basins due to different geomorphologic and hydrological factors such as the topography of the land (elevation and slope), hydrogeomorphological factors such as discharge rate, sediment and slope of the river, banks and formations of the region, stream velocity, and power and the shear stress of the river. The erosion is very severe in the upstream sub-basin due to the high slope, higher rainfall, and rangeland and dryland vegetation, and the land washing cause sediment transport to the surface waters. Furthermore, there is a high potential for contamination by heavy metals due to the existence of upstream formations. Groundwater and surface water resources may be contaminated by such metals through sediments.

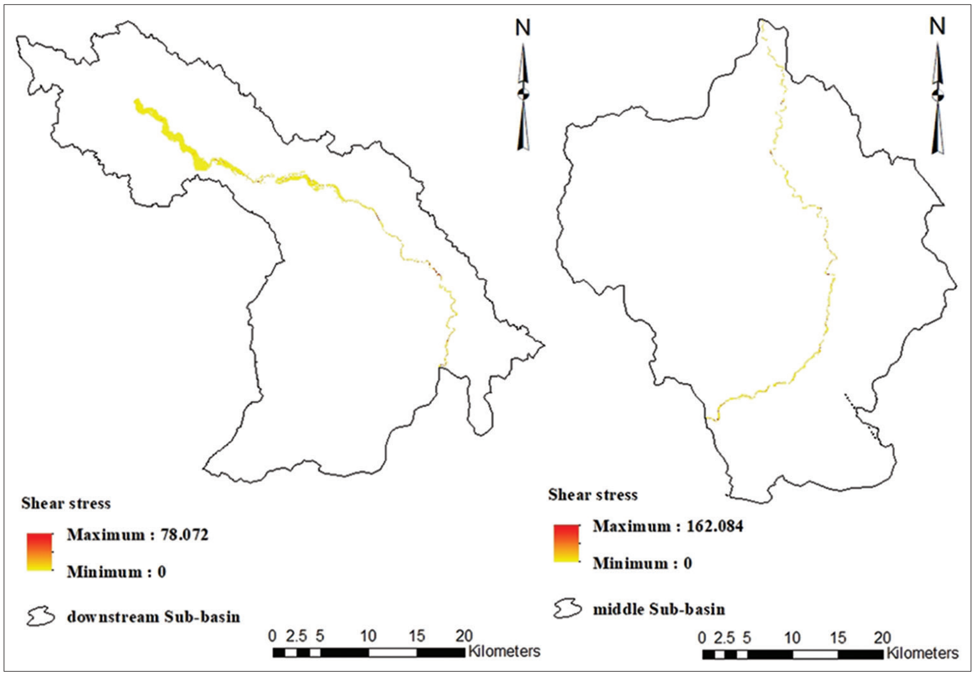

Figure 8: Shear stress map of the Siminehrood sub-basins for floods with a 1.5-year return period

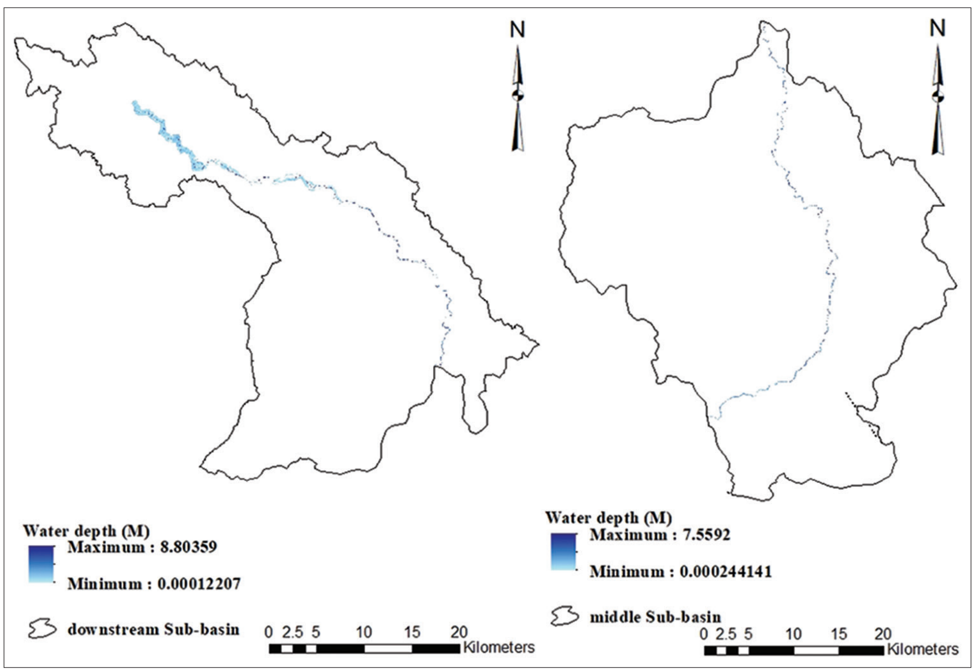

Figure 9: Water depth map of the Siminehrood sub-basins for floods with a 1.5-year return period

However, as a result of factors such as high water discharge, steep slope, and high stream velocity, the self-purification of the river is high in this region and the quality of the river water is good in all seasons according to Schuler diagram.

In the central sub-basin, the land remains its valley shape and erosion is severe in most areas, but the river can carry the sedimentary load, and there is also land washing and transportation of natural pollutants (formations) toward end sub-basin.

In the end sub-basin, the volume of contamination is high and out of river acceptance capacity due to low slope, the concentration of rural sites, development of agricultural and livestock activities, and the existence of numerous industries that drain their effluent into water. Furthermore, the river is not capable of transporting and discharging sediments, and the response to this phenomenon is reflected as sedimentation. As sediment load increases, plants cannot grow and are buried, resulting in sediment-caused suffocation. Thus, the river loses

Table 2: Characteristics of the sub-basins of the Siminehrood during the 1.5-year return period (channel's bankfull discharge)

Reach	The mean of water flow rate (m/s)	The mean width of the water level (m)	The mean of depth of water (m)
Middle sub-basin	07/1	76/70	63/2
Downstream sub-basin	86/0	85/284	10/3

self-purification capacity in this sub-basin and is ecologically unstable. The existence of Urmia Lake downstream of the basin has severely affected the quality of the groundwater in the downstream area. According to the data obtained, the groundwater is affected by saline lake water to downstream of Miandoab, around 20 km far from Urmia Lake.

Conclusions

According to the results, the improper ecogeomorphological condition of the rivers and their low self-purification capacity and also environmental differences are directly related to the mean river water depth, water flow rate, and river basin slope. Downstream of the study area has the highest environmental instability and the least self-purification capacity, with a mean and maximum depth of water of 3.10 m and 8.803 m, respectively, which is the highest water depth than the whole basin. Very low water flow rate (0.86 m/s on average) and slope of less than 4% of the area lead water flow to be stagnant in most areas, resulting in declined dissolved oxygen and low water quality. This sub-basin can be classified as a region with a poor ecogeomorphological condition. Consequently, on a smaller scale, the water quality of the Kavlan station in the upstream in May can be viewed as the most optimal spatial and temporal intervals with maximum self-purification capacity. Furthermore, Miandoab station in summer is considered the most critical temporal and spatial intervals due to maximum solubles and EC after reduction of river slope and discharge, where increased loads caused minimum self-purification capacity of the river.

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Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Thoms MC, Parsons M. Eco-geomorphology: An interdisciplinary approach to river science. Proc Int Symp Held Alice Springs Aust IAHS Publ 2002;276:113-9.
2. Gilvear DJ, Heal KV, Stephen A. Hydrology and the ecological quality of Scottish river ecosystems. Sci Total Environ 2002;294:131-59.
3. Rinaldi M, Wyzga B, Dufour S, Bertoldi W, Gurnell A. River processes and implications for fluvial ecogeomorphology: A European perspective. In: Treatise on Geomorphology, Vol 12, Ecogeomorphology. San Diego: Academic Press; 2013. p. 37-52.
4. Spellman FR, Drinan J. Stream Ecology & Self-Purification an Introduction. 2nd ed. American: CRC Press, Technomic Publishing Company, Inc; 1996.
5. Ferronato CH, Modesto M, Stefanini I, Vianello G, Biavati B, Antisari LV. Chemical and microbiological parameters in fresh water and sediments to evaluate the pollution risk in the Reno River watershed (North Italy). J Water Resour Prot 2013;5:458-68.
6. Galvis A, Hurtado IC, Martnez-Cano C, Urrego JG. "Dynamic Condition Approach to Study the Self-Purification Capacity of Colombian Water Bodies Case: Cauca River And Salvajina Dam". In: International Conference on Hydroinformatics by an authorized administrator of City University of New York (CUNY). New York:Academic Works; 2014.
7. Porzionato N, Mantiñan M, Bussi E, Grinberg S, Gutierrez R, Curutchet G. Accumulation of pollutants, self-purification and impact on peripheral Urban Areas: A case study in shantytowns in Argentina. Int J Environ Ecol Eng 2015;9:5.
8. Kingsley P. Evaluation of the Factors Affecting the Self-Purification Capacity of River Kaduna, Nigeria. Zaria: Department of Chemical Engineering, Faculty of Engineering, Ahmadu Bello University; 2016.
9. Hoseyni P, Hoseyni Y. Changes in the self-purification capacity of the Karun River in 2008 and 2014 using the QUAL2KW model in Ahvaz. Amirkabir J Civil Eng 2017;49:1.
10. Wenai A, Marofi S, Azari A. Self-purification of the Hamedan Abbas Abad River, in the mountain reach. J Environ Stud 2017;43:1.
11. Moghimi Nezad S, Ebrahimi K, Kerachian R. Investigation of seasonal self-purification variations of Karun River, Iran. Amirkabir J Civil Eng 2018;49:1.
12. Thomas NV. Global Water Quality Standards. United States:Ground Water; 1996.
13. Hounslow AW. Water Quality Data Analysis and Interpretation. USA:Lewis publishers, CKC press, LLC; 1995. p. 378.
14. Song S, Schmalz B, Fohrer N. Simulation and comparison of stream power in-channel and on the floodplain in a German Lowland Area. J Hydrol Hydromechanics 2014;62:133-44.
15. Natural Resources Conservation Service. Stream Restoration Design (National Engineering Handbook 654). USA: United States Department Agriculture; 2008.
16. Barker DM, Lawler DM, Knight DW, Morris DG, Davies HN, Stewart EJ. Longitudinal distributions of river flood power: The Combined Automated Flood, Elevation And Stream power (CAFES) methodology. Earth Surf Processes Landf 2009;34:280-90.
17. Ismaili R, Hoseynzadeh M. Studying the phenomena forming longitudinal obstacles in mountainous rivers; a case study of North Alborz, Lavijrood drainage basin. Phy Geogr Res 2010;71:5.
18. Ghaffari G, Solaimani K, Mosaedi A. Changes in the morphology of the stream bank using GIS (Babolrood; Mazandaran). Geogr Res 2006;57:4.