

## Assessment of Spatial Heterogeneity of Landscape of the Subarnarekha River Basin, India

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### ABSTRACT

The study of landscape patterns and prevailing ecological processes in a riverine environment is significant for the sustainable management of natural resources. To study the landscape ecology in terms of identification and quantification of landscape patterns and ecological processes in a manner of spatial and temporal heterogeneity has been performed with the application of remote sensing and GIS as well as interpreting water quality data. A systematic scale-independent approach and organization of the landscape ecological indicators like the forest, water, land use, and human community are combined in landscape ecological study. Estimations of changes in landscape ecological indicators and their trends have been performed by using a combination of geospatial and statistical techniques. The spatial pattern of source and sink landscapes was measured using relative elevation, slope gradient, and relative flow length, and maps were prepared from the DEM. The data about surface water quality were collected from the outlets of the river basin and analysed to identify the pollution scenario with relation to source and sink landscape categories. The location-weighted landscape contrast index (LWLI) has been applied to study the impact of landscape type on ecological processes. Lorenz curves and GINI co-efficient of 11 landscape units were prepared by normalizing the landscape spatial elements to determine the configuration of source and sink landscapes. The overall calculated LWLI of the basin is more than zero which revealed that the NPS has the potential impact on the landscape ecology of the Subarnarekha Basin.

**Key words:** Landscape Structure, Source And Sink Landscapes, Non-Point Source Pollution(NPS), Lorenz Curve, Location-Weighted Landscape contrast Index.

### INTRODUCTION

Landscape ecology is the study of the spatial pattern of landscapes and the ecological consequences of those spatial patterns. Landscape ecology is to understand the reciprocal relationship between spatial patterns and ecological processes (Turner 2001, 2005, Wiens and Milne 1989. and Wiens and Moss 2005, Wu and Hobbs 2007). Landscape ecology is also the study of the pattern and interaction between ecosystems within a region of interest, and the way the interactions affect ecological processes, especially the unique effects of spatial multiformity on these interplays (Forman, R.T.T. (Ed.). 1995, Clark 2010). Though there is no specific spatial extent that defines a unique landscape, most landscape ecologists are interested in large-area units ranging from a few square kilometers to the entire globe. There are possibilities of occurrences of different ecosystem types occurring as patches within the large landscape unit. For example, in a riverine landscape, the patches might be different agricultural fields, woodlands, grassland, buildings, lakes, etc.

Landscape ecology seeks to describe the dynamic relationships between ecological patterns and processes across spatial scales, from a plot or forest-stand level to watersheds, from local regions to eco section, or globally. Landscape ecology is significant for landscape ecologists to study the effect of human activity on regional ecosystems, and to explore the relationship between landscape patterns and ecological processes (Sanderson and Harri 2000., Domer et al. 2002, Li and Wu 2004, Johnson et al. 2004).

The goal of the study is to understand and describe the pattern of landscape structure; how this structure influences the movement of organisms, material, or energy across the landscape; and how and why landscape structure changes over time. Landscapes and the ecological processes they support are inherently complex systems, in that they have large numbers of heterogeneous components that interact in multiple ways, and exhibit scale dependence, non-linear dynamics, and emergent properties. The emergent properties of landscapes encompass a broad range of processes that influence biodiversity and

human environments (Newman et al. 2019). Landscape structures are being changed through natural geological or biological processes but presently human activities are the main influencing factor for the change. Although landscape ecology is a relatively new scientific discipline since the 1980s landscape ecologists have begun to understand how to characterize landscape structure, how landscape structure influences ecological processes, and how landscape structure changes (Kratz et al. 1994). Human activities like agricultural practice, industrialization, urbanization, mining activities, etc. are the most influencing factor to deteriorate the landscape ecological process in a riverine landscape. A wide range of human activities may cause the discharge of pollutants into water environments, resulting in eutrophication of the water bodies and deterioration of water quality in rivers (Bu et al. 2014, Liu et al. 2018). The surface water quality of Indian river basins is highly influenced by intensive agricultural activities as farmers use huge fertilizers and pesticides for more production. The effluent from riverside urban centers and industrial structures also makes the situation worse. The concept of source and sink landscape is very much applicable to riverine landscape ecological study. Linking landscape patterns and ecological processes has become a challenge for landscape ecologists. "Source" and "sink" are common concepts (Chen et al. 2008).

The sustainable conservation of land and water resources is directly related to landscape ecology. Presently, the applications of Remote Sensing and Geographical Information systems (GIS) to assess the status of the landscape ecology of a river basin are intensively used on a regional as well as local scale. Various techniques and methods have been applied to study the status of landscape ecology worldwide. Statistical analyses such as Lorenz curve analysis, correlation analysis, multivariate regression, and conventional linear regression can be used to analyze the effects of landscape patterns on river water pollution (Yu et al. 2016, Wu and Lu 2019, Xu et al. 2019). In this paper, multi-temporal remote sensing images as essential data sets, and various statistical methods are applied to identify the relation between landscape patterns and ecological processes. The main task of this study is the

classification of multitemporal remotely sensed images and the preparation of hydrological attributes to delineate the source and sink landscapes. So the objectives of this study were twofold: 1) To study the general spatial patterns and process dynamics of landscape ecological characteristics of the river basin and 2) To evaluate the relations between landscapes spatial characteristics and non-point source of pollution (NPS) with the application of location weighted landscape index. The water quality, land-use change, spatial distribution of source and sink landscape related to landscape elements, and location-weighted landscape contrast index (LWLI) were applied to measure the spatial distribution of the source and sink landscape of the Subarnarekha river basin.

## STUDY AREA

The Subarnarekha river basin encompasses approximately 27220.75 km<sup>2</sup> and 395 km long and about 30% of the total population is a tribal population and the society is depending on agricultural activities and natural resources like forest, river water, minerals, etc. (Fig. 1). This basin is also belonging to a rainfed region, about 80% of the total annual rainfall is occurred in four months (June-September) and the rest of the year is dry. The average water potential of the river is about 12370 mcm and the utilized surface water resource is 6800 mcm (CWC, Ghatshila). The Subarnarekha River is one of the most significant interstate rivers that flows through Jharkhand, Odisha, and West Bengal, with a flow length of about 450km from its source at Nagri village, Ranchi to meeting point Kirtania port of Balasore, Bay of Bengal. Sankha, Sanjoy, Karkari, Kharkai, Kanchi, Kharsothi, Garru, Raru, and Dulung are the main tributaries of the Subarnarekha. The river provides water to the community for domestic, irrigation, and industrial purposes and holds rich terrestrial and aquatic biodiversity of flora and fauna. The availability of huge mineral resources gives priority to the establishment of various industries in the vicinity of the river bank. But unscientific mining, agricultural practices, industrial management system, overexploitation of land and water resources, and human-made infrastructures degraded the landscape ecology of the entire basin.

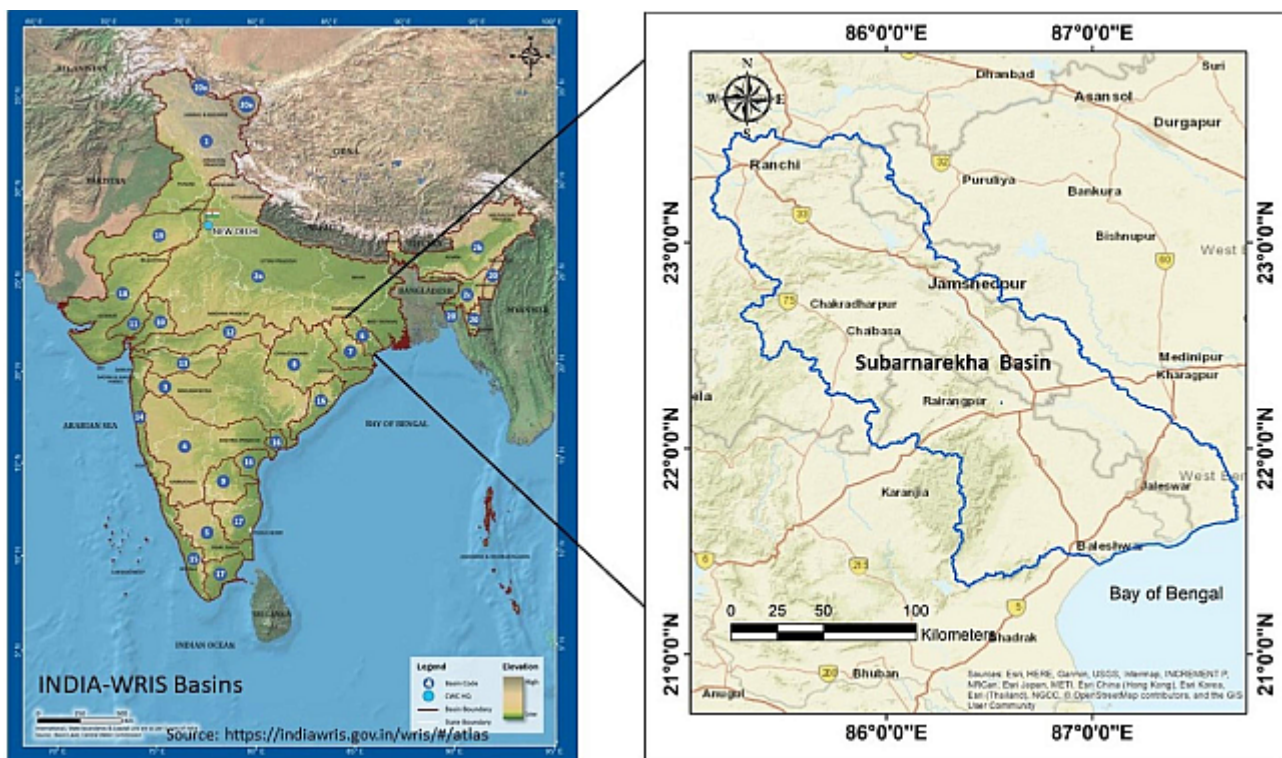


Figure 1. Location of the Subarnarekha River Basin, India

## MATERIAL AND METHODS

The study of the landscape ecology of the Subarnarekha river basin has been undertaken through the intensive reviewing of works of literature, measurement, and analysis of landscape features and their interrelationships. Data and maps about topography, water, and population were collected from various Government sources like the Survey of India, the Geological Survey of India, reports of Central Water Commission and Central Ground Water Board, Ranchi, etc. Free Landsat satellite imageries and IRS Cartosat elevation raster data were downloaded from the website <https://earthexplorer.usgs.gov> and <https://bhuvan.nrsc.gov.in>. The LANDSAT imageries for the year 2020 covering the whole catchment (Path no 139 and 140, Row no 44 and 45) were radiometrically corrected using ERDAS imagine, and the land-use and land-cover (LULC) were constructed applying a supervised classification algorithm (maximum likelihood) in ArcGIS 10.4 platform, 11 land-use and land-cover categories were delineated including rural residential land, urban residential land, dense forest, open forest, Grassland, etc.

For the abstraction of sub-catchments and monitoring of nitrogen and phosphorus in outlets a digital elevation model (DEM) of the terrain's surface was created from Cartosat DEM and the slope was abstracted. With the help of the ArcGIS platform, the catchment boundary was abstracted using Arc Hydro Tools, and sub-catchments were selected as sample regions for monitoring nitrogen and phosphorus nutrients. The spatial pattern of source and sink landscapes was measured using relative elevation, slope gradient, and relative flow length, and maps were prepared from the DEM within the ArcGIS environment.

To determine the configuration of source and sink landscapes in the basin Lorenz curves were prepared by normalizing the landscape spatial elements of the total catchment to the range of [0, 1] by the method of min-max normalization. The formula used was:

$$\text{Normalized value} = (\text{value\_min})/(\text{max-min}),$$

where min and max are minimum and maximum values of the data array, and then reclassified into 20 equal zones and converted into a vector map. The reclassified vector map of each element, source, and sink landscape type was superimposed using the

spatial intersect tool in ArcGIS, with further work done by calculating the area of each landscape type within the GIS platform. Finally, the accumulated area percentages were calculated according to the area arrangement to construct the Lorenz curves of these landscape elements for each source and sink landscape type.

The study of the landscape ecology of the Subarnarekha basin was based on the formula developed by Chen et al.(2009) which is a scale-independent approach. According to Chen et al. (2009) and Chongwei et al. (2020) the location-weighted landscape contrast index is depicted as the landscape pattern of the watershed towards the outlet and was treated to the point-based measurement of nutrient losses or soil erosion and is used to study the landscape pattern evaluation based on source-sink ecological processes. It was developed with the frameworks of the Lorenz curve and the GINI coefficient. Two following equations were formulated to calculate LWLI:

$$LWLI = \left[ \sum_{i=1}^m Sr_i \times Wt_i \times SrP_i + \left[ \sum_{i=1}^m Sr_i \times Wt_i \times SrP_i + \sum_{j=1}^n Sk_j \times Wt_j \times SrP_j \right] \right] \dots\dots\dots Eqs.1$$

$$LWLI = LWLI''_{distance} \times LWLI''_{elevation} \div LWLI''_{slope} \dots\dots\dots Eqs. 2$$

where  $Sr_i$  and  $Sk_j$  refer to the areas of the  $i$ th “source” and  $j$ th “sink” landscapes unit;  $Wt_i$  and  $Wt_j$  are the weights for the “source” and “sink” landscapes unit;  $SrP_i$  and  $SrP_j$  refer to the percentages of the  $i$ -source and  $j$ -type landscapes unit; and  $m$  and  $n$  are the numbers of “source” and “sink” landscape types, respectively.  $LWLI''_{distance}$ ,  $LWLI''_{elevation}$ , and  $LWLI''_{slope}$  are the values of LWLI concerning the distance, relative elevation, and slope gradient, respectively (Chen et al. 2009, Chongwei Li et al. 2020). The categorization of source and sink landscapes was done based on the knowledge and pieces of information about the pollution scenarios of different parts of the Subarnarekha basin gained from literature reviewing and govt. reports. The landscape was categorized into cropland, rural settlements, urban areas, mining, and industrial area, and barren land as “source” landscapes while dense forest, open forest, grassland, waterbody, plantation, and sandy area as “sink” landscapes. The weight of each land-use type can be determined by comparing

its contribution to the processes. The weights of “sink” landscapes are determined by comparing their role in nutrient retention according to the field measurements and expert knowledge (Table 1). Considering the impact of landscape types on the ecological process, and the values of relative elevation, relative distance, and slope gradient from landscape units to outlets, the location-weighted landscape index (LWLI) was applied to measure the spatial distribution of source and sink landscape (Fig. 2) (Chen et al. 2009).

Table 1. Weights given on landscape units

Landscape units		Weight
Source Landscape	Mining & industrial area	1
	Urban area	1
	Rural settlement	0.8
	Barren Land	0.6
	Cropland	0.5
Sink Landscape	Dense Forest	1
	Open Forest	0.8
	Water Bodies	0.6
	Grassland	0.5
	Plantation	0.4
	Sandy Area	0.3

**RESULTS AND DISCUSSION**

The landscape ecology of the basin is affected by both the natural and human activities throughout the Subarnarekha basin. The changing land use and land cover categories revealed a decrease in the dense forest from 7.66 to 5.36 % between 2005 and 2018 (Pramanik and Roy Chowdhury 2018). The decrease in the open forest was also from 26.49% to 20.87 % respectively. The reason behind this was rapid deforestation in the area which removed the vegetation cover from the land as forest wood was used for fulfilling household requirements like cooking and heating, cultivation and construction of built-up land. An increase in the human and cattle populations has put remarkable pressure on the forests, impacting their regeneration and growth capability. An increment in the total area of built-up land was found from 1296.14 km<sup>2</sup> (4.76 %) to 5089 km<sup>2</sup> (18.69%) during the years 2005 and 2018 due

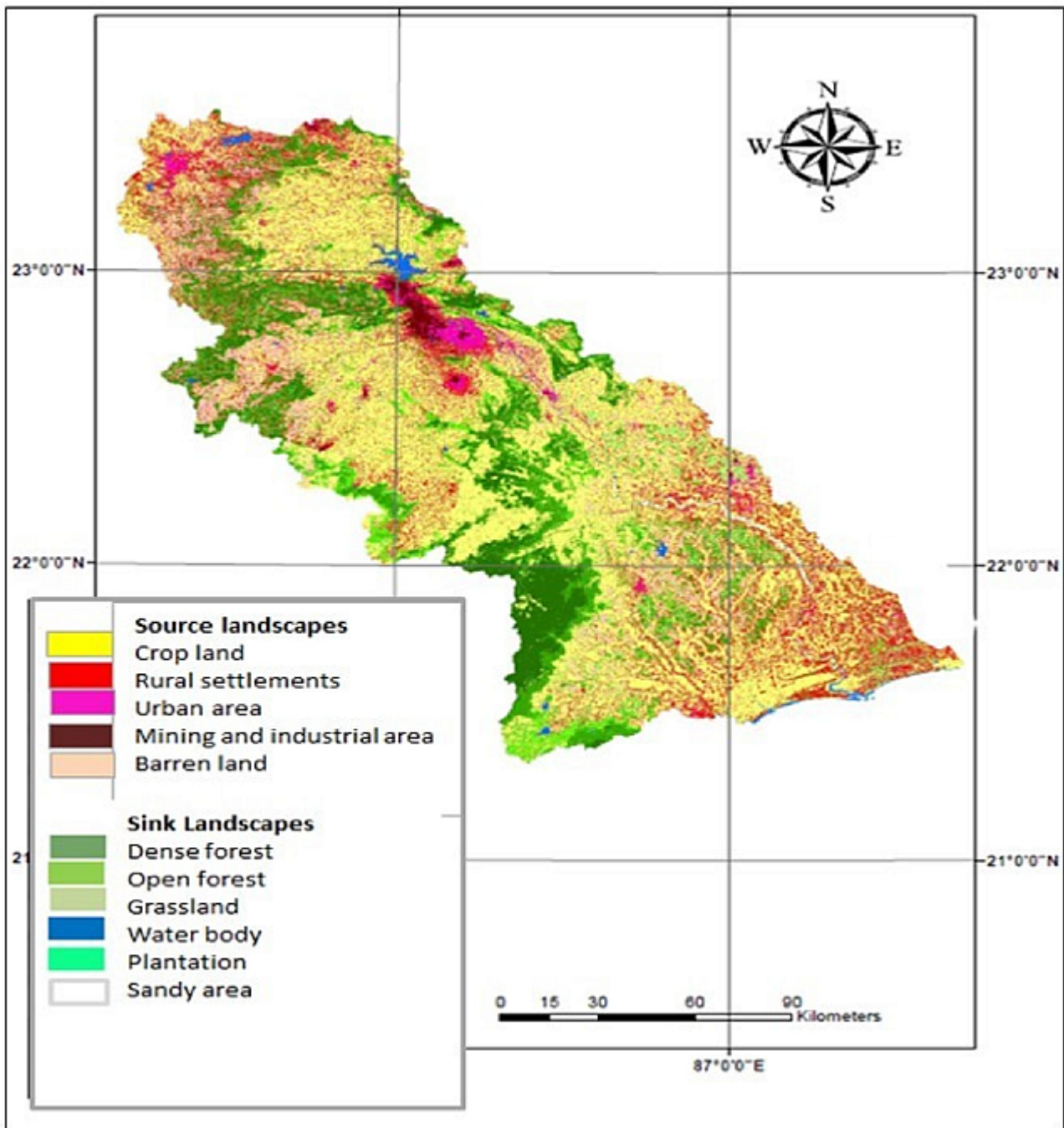


Figure 2. Source and Sink landscapes of the Subarnarekha basin

to several new housing schemes, commercial, services, institutional and recreational pursuits that have been developed in and around the area in the past decades. The percentage of the population classified as rural is 88.21% and urban is 11.79% in the entire basin.

According to the census 2011 total population of the basin is 7844635. Between 1991 and 2001 the growth rate is about 23.36 while in the next decade

2001-2011 it declined to 20.79. It has been identified that the pressure of population is maximum in the upper catchment of the river basin (Ranchi and Purbi Singhbhum zone) where most of the conversion of landscape units and pollution of the river course from source to end has happened. Habitat destruction and fragmentation have plagued some of the major ecosystems in the basin which also give a negative impact on the natural development of the ecosystem

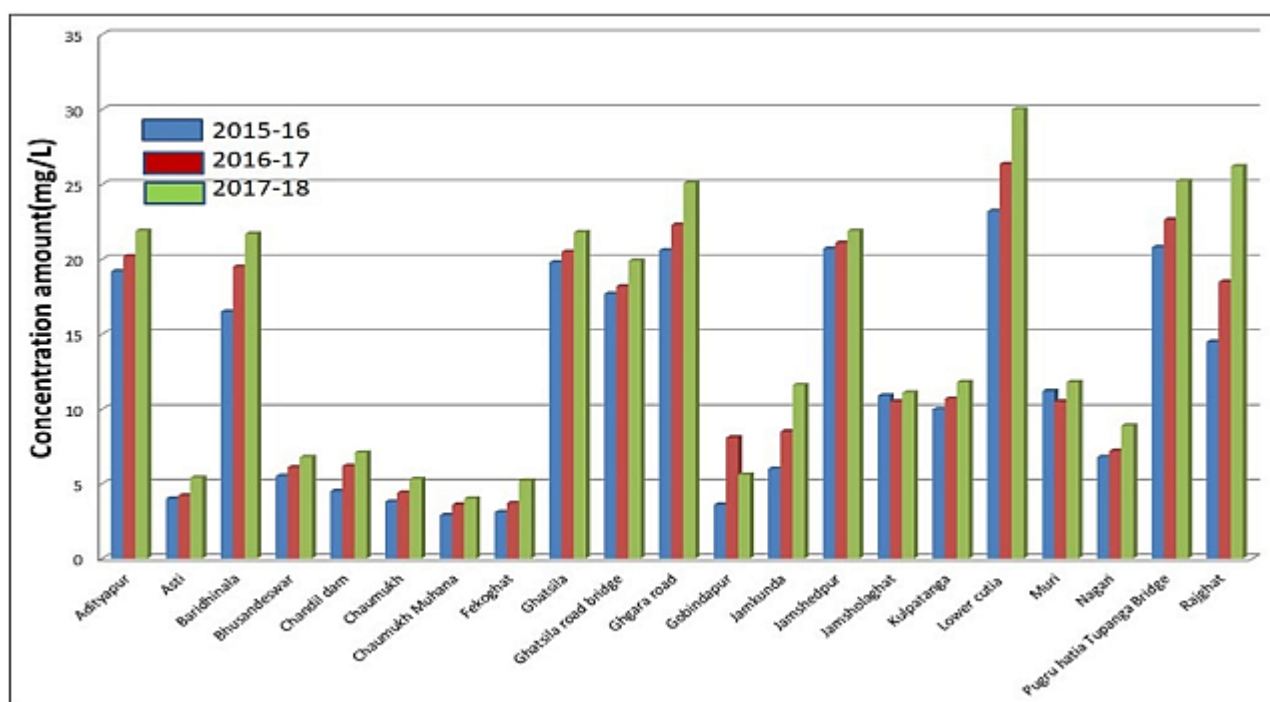


Figure 3. The concentration of total nitrate ( $\text{NO}_3$ ) in surface runoff

and make changes in the succession of the natural environment. The analysis of the quality of surface water of the Subarnarekha river basin in several published research works revealed the presence of toxic heavy metals in a higher concentration than the accepted limits in many outlet stations along the river path. The Subarnarekha river in the Jharkhand region of Ghatsila has been so heavily contaminated by various kinds of organic and inorganic wastes that, if the situation is not controlled, it'll grow eutrophication. The fact that this could have a negative impact on the river's biodiversity and serious consequences for the human population (Mishra et al. 2019). The concentration of total nitrate ( $\text{NO}_3$ ) and total phosphorus (TP) in surface runoff of different observing outlet stations were analysed for the period 2015-2016, 2016-2017, and 2017-2018 (Figs. 3, 4). The nitrate concentration in the surface water is low (0-18 mg/l) but as a result of agricultural runoff, refuse dump runoff, or contamination with human or animal wastes it can rise. The concentration often fluctuates with the season and may increase when the river is fed by nitrate-rich aquifers (WHO 2011). The nitrate concentration of the river water of 9 sample stations (Adityapur, Jamshedpur, Ghgara road, Ghatsila, Rajghat, Lower Chutia, Pugru Hatia

Tupanga Bridge, etc.) out of 21 sample stations is high (18.22 to 30.02 mg/l). The reason behind this high concentration is due to the mixing of sewer water into the river water, as it contains more nitrate than agricultural runoff. These stations are near urban centers and the concentration and increasing rate of nitrate revealed the impact of urbanization. The nitrate content of the river water at the agricultural background sample stations is showing low concentration due to agricultural and fertilizer runoff and the sample stations which are near the urban centers or industrial areas are showing high nitrate content and is due to sewer water pouring into the river. Extensive freshwater pollution was carried through the disposal of industrial sewage and waste as these contain high amounts of phosphate. Though phosphate possesses problems in surface waters, its presence is necessary for the biological degradation of wastewater. Phosphorus is an essential nutrient for the growth of organisms and helps the primary productivity of water (Karim and Panda 2014, Clinton and Pratt 2003).

The concentration of phosphorus in the river outlets' was found to be in the range of 0.85-1.50 ppm and 0.95-1.25 ppm, respectively. This has serious consequences for the deterioration of river

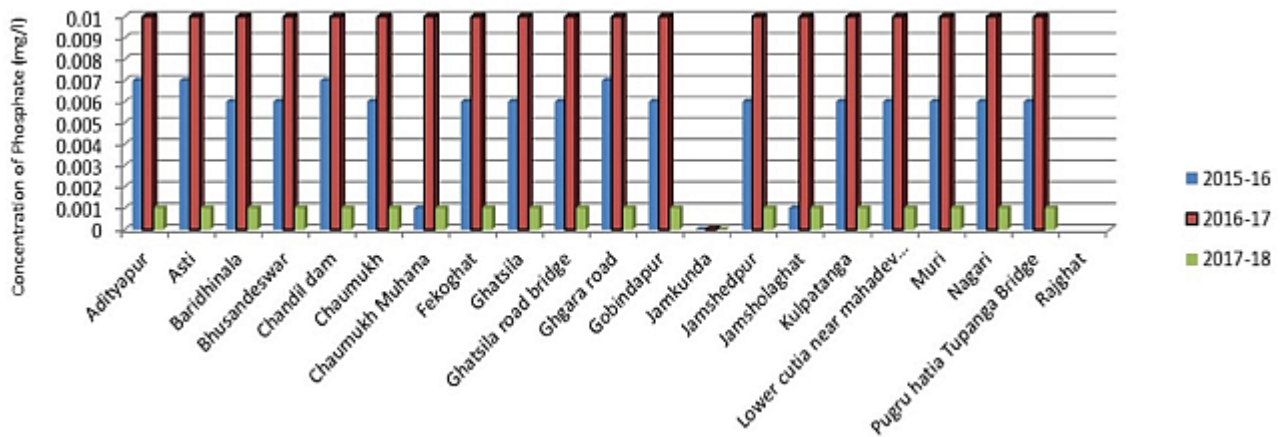


Figure 4. The concentration of total phosphorus (TP) in surface runoff

ecology and the structure of the river landscape. Eutrophication and thick growth of weed grass are found in the river water. It has been found that rainwater and floods further increase a load of phosphates and nitrates in the river by leaching fertilizers from nearby agricultural lands and the cremation ground on the riverside.

Taking the river basin's outlets as a point of reference, the spatial pattern of the source and sink landscapes may be determined by comparing it to landscape variables such as distance, relative height, and slope gradient. To calculate the accumulated area percentage of various landscapes related to relative elevation, relative flow length, and slope gradient, the spatial distribution of source and sink landscape was compared with the outlet of the catchment, the Lorenz curves for various source and sink landscape types were then constructed (Fig. 5).

The Lorenz curve constructed for relative elevation can reflect the distribution degree of source and sink landscape in the vertical direction. The dense forest, whose Lorenz curve of relative elevation was near the balance line, showed the highest relevance. As a result, the dense forest was evenly distributed throughout each elevation zone, and the potential effects of slope cultivation on NPS pollution were dispersed over the whole catchment. The distribution of sources and sinks in the flow direction is shown by the Lorenz curves related to relative flow length (Fig. 5). As is seen in the respective distributions of source and sink landscapes related to relative flow length are mostly concentrated. Just because of that, the value of the relative flow length of the source and sink landscapes

primarily falls within the intermediate zones of the relative flow length. All slope gradient curves for all source and sink landscapes are concave, in contrast to the Lorenz curves of relative elevation and relative flow length. Forest land has the lowest slope gradient curve sections, which can effectively limit pollution loss and preserve nutrients, according to sink landscape data. Because ponds, main canals, etc. are primarily dispersed in low-lying areas, which have the advantage of collecting precipitation and runoff, the slope gradient of water conservation was also low.

The GINI co-efficient of the 11 source and sink landscapes has indicated the heterogeneities in the spatial pattern of landscape structures. The GINI coefficient is ranging from 0.24 to 0.87. A larger GINI co-efficient value of landscape categories refers to more substantial effects of a landscape index or land use type on water quality. It increases as the strength of the stratified heterogeneity rises. The percentage of human-altered land cover types in a watershed (e.g., agriculture, urban and non-forested cover types) is positively related to N, P, alkalinity, and total dissolved solids in surface waters (Johnson et al. 1997). Total N inputs to a basin are correlated positively with the percentage of agriculture and urban land-use types and negatively with the percentage of the forest. By calculating the LWLI value, the effect of landscape patterns in different watersheds can be differentiated. A Watershed, as a complex landscape with multiple potential sources or sinks of Nitrate ( $\text{NO}_3$ ) and Phosphate (P), may contribute more to the nutrient loading when they have a higher LWLI value. The overall calculated

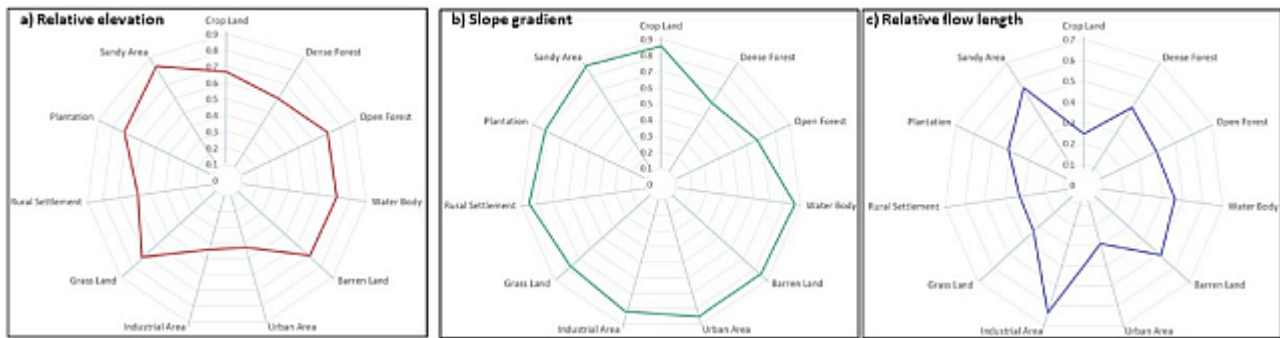


Figure 5. Distribution characteristics of the source and sink landscape related to normalized relative elevation, slope, and flow length of the river basin

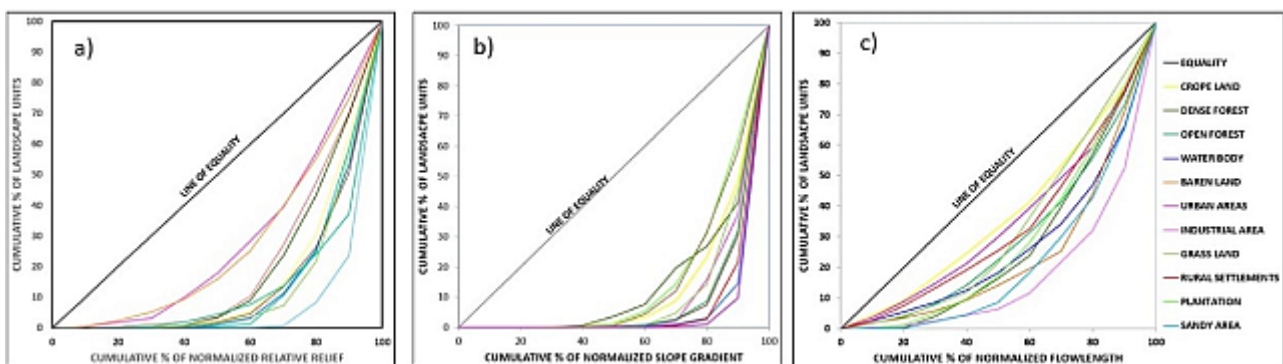


Figure 6. The GINI co-efficient of source landscape related to landscape elements

LWLI of the basin is 0.7335994 which revealed that the NPS has the potential impact on the landscape ecology of the Subarnarekha Basin.

### Distribution characteristics of source and sink landscape related to slope gradient

There will be more pollutants exported from catchments with a high risk of NPS pollution when  $LWLI > 0$ , which indicates that the source landscape contributes more to NPS pollution of the outflow than the sink landscape (Wang et al. 2018). Karmakar et al. (2008) and Roy Chowdhury and Pramanik (2018) has mentioned in their study that the species diversity of the basin was continuously declining due to surface water pollution and changing LULC. So the LWLI is an important scale-independent index to study the landscape ecology of the Subarnarekha river basin.

### CONCLUSIONS

According to the source-sink concept in the NPS pollution process, the ecological function, field

measurement, and expert knowledge were used to differentiate the source and sink landscape of the Subarnarekha river basin. Throughout this study, it has been found that nutrient loads in surface water were increased by landscape patterns in the river basin with higher LWLI values. These results highlight the importance of spatial arrangement of land-use types in a watershed when estimating the non-point source pollutant loads. It also implies that landscape pattern modification is a potential way to control nutrient losses given that the same proportion of land-use types in a watershed is fixed. A higher GINI co-efficient value refers to more substantial effects of a landscape index or land use type on water quality. It increases as the strength of the stratified heterogeneity rises. An increase in agricultural and mining activities leads to the conversion of the landscape ecology of the basin. Habitat loss and fragmentation due to forest cutting, forest fire, urbanization, and mining activities. Population pressure is responsible for the degradation of landscape ecology. The forests within the basin are in a poor state of maintenance and required rigorous

protective measures. Appropriate land and water resource management, massive afforestation, and corrective land-use planning are essential to abate water pollution, control soil erosion, and enhance the forest cover area of the basin. For mitigating pollution, proper remedial measures should be adopted in the towns and the industrial units responsible for polluting the surface water and groundwater systems. The need for stringent control of the quality of the industrial, mining, and domestic wastewater effluents discharged into the river is the utmost important aspect. The nutrient loading in the surface water body can be mitigated by landscape design and planning. The spatial distribution characteristics of the source and sink landscape associated with relative elevation, relative flow length, and slope gradient inside the Subarnarekha basin were analysed and measured by the distribution pattern and area of the Lorenz curve used in this study. For a more accurate identification of source and sink landscape spatial characteristics in small catchments, it is practical to take into account additional landscape parameters.

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## REFERENCES

- Bu, H., Meng, W., Zhang, Y. and Wan, J. 2014. **Relationships between land use patterns and water quality in the Taizi River basin, China.** Ecological Indicators, 41, 187-197. <https://doi.org/10.1016/j.ecolind.2014.02.003>
- Chen, L.D., Fu, B.J. and Zhao, W.W. 2008. Source-sink landscape theory and its ecological significance. *Frontiers in Biology*, 3(2), 131-136. <https://doi.org/10.1007/s11515-008-0026-x>
- Chen, L., Tian, H., Fu, B. and Zhao, X. 2009. Development of a new index for integrating landscape patterns with ecological processes at watershed scale. *Chinese Geographical Science*, 19(1), 37-45.
- Clark, W. (Ed.). 2010. Principles of landscape ecology. *Nature Education Knowledge*, 3(10), 34. <https://www.nature.com/scitable/knowledge/library/principles-of-landscape-ecology-13260702/>
- Clinton, C. and Pratt, K. 2003. Phosphorus effects on surface water quality and phosphorus development. In: *Western Nutrient Management Conference, 2003. Vol. 5.* Salt Lake City, UT. [Online] URL: <https://ucanr.edu/sites/nm/files/76602>
- Domer, B., Lertzman, K. and Fall, J. 2002. Landscape pattern in topographically complex landscapes: issues and techniques for analysis *Landscape Ecology*, 17(7), 729-743.
- Forman, R.T.T. (Ed.). 1995. *Land Mosaics: The Ecology of Landscapes and Regions.* New York: Cambridge University Press. xx+605pages.
- Johnson, C.J., Boyce, M.S., Mulders, R., Gunn, A., Gau, R.J., Cluff, H.D. and Case, R.L. 2004. Quantifying patch distribution at multiple spatial scales: applications to wildlife-habitat models. *Landscape Ecology*, 19(8), 869-882. <https://doi:10.1007/s10980-004-0246-7>
- Johnson, L., Richards, C., Host, G. and Arthur, J. 1997. Landscape influences on water chemistry in Midwestern stream ecosystems. *Freshwater Biology, Land Use and Water Quality*, 37, 193-208.
- Karim, A. and Panda, R.B. 2014. Assessment of water quality of Subarnarekha River in Balasore region, Odisha, India. *Current World Environment*, 9(2), 437-446. <https://www.cwejournal.org/pdf/vol9no2>.
- Karmakar, A.K., Das, A. and Banerjee, P.K. 2008. Fish Fauna of Subarnarekha River. *Records of Zoological Survey of India, Occasional Paper No. 283*, 57 pages.
- Kratz, T.K., Magnuson, J.J., Frost, T.M. and Benson, B.J. 1994. Landscape Position, Scaling, and the Spatial and Temporal. Pp. 217-230. In: *Biological Monitoring of Aquatic Systems*, CRC Press.
- Li, C., Zhang, H., Hao, Y. and Zhang, M. 2016. Characterizing the heterogeneous correlations between the landscape patterns and seasonal variations of total nitrogen and total phosphorus in a peri-urban watershed. *Environmental Science and Pollution Research*, 27, 34067-34077. <https://doi.org/10.1007/s11356-020-09441-5>
- Li, H.B. and Wu, J.G. 2004. Use and misuse of landscape indices. *Landscape Ecology*, 19(4), 389-399.
- Liu, J., Shen, Z. and Chen, L. 2018. Assessing how spatial variations of land use pattern affect water quality across a typical urbanized watershed in Beijing, China. *Landscape and Urban Planning*, 176, 51-63
- Mishra, S., Singh, R. and Kumar, B. 2019. Analysis of early signs of eutrophication in Subarnarekha River at Ghatsila, Jharkhand. *International Journal of Engineering Applied Sciences and Technology*, 4(7), 108-112
- Newman, E.A., Kennedy, M.C., Falk, D.A. and McKenzie, D. 2019. Scaling and complexity in landscape ecology. *Frontiers in Ecology and Evolution*, 7, art293. <https://doi.org/10.3389/fevo.2019.00293>
- Pramanik, S. and Roy Chowdhury, S. 2018. Need for sustainable management of natural landscape in the

- Subarnarekha Basin. pp. 595-619. In: Basu, M., Gupta, A.D., Mondal, B.K., Dutta, R.K. and Bhattacharyya, D. (Eds.) Geo-environmental Issues of the New Millennium, Deys Publishing, Kolkata.
- Sanderson, J. and Harri, L.D. (Eds). 2000. Landscape Ecology: A Top-Down Approach. Boca Raton, FL: Lewis Publishers. USA 246pages.
- Turner, M.G. (Ed.). 2001. Landscape Ecology in Theory and Practice: Pattern and Process. 2<sup>nd</sup> edition. New York: Springer. xx+467pages. [https://doi.org/10.1007/978-1-4939-2794-4\\_1](https://doi.org/10.1007/978-1-4939-2794-4_1).
- Turner, M.G. 2005. Landscape ecology in North America: past, present, and future. Ecology, 86, 1967-1974
- Wang, J-L., Ni, J-P., Cheng, C-L., Xie, D.T., Shao, J-A., Chen, F-X. and Lie, P. 2018. Source-sink landscape spatial characteristics and effect on non-point source pollution in a small catchment of the Three Gorge Reservoir Region. Journal of Mountain Science, 15(2), 327-339. <https://doi.org/10.1007/s11629-017-4417-9>
- Wiens, J.A. and Milne, B.T. 1989. Scaling of "landscape" in landscape ecology, or, landscape ecology from a beetle's perspective. Landscape Ecology, 3(2), 87-96.
- Wiens J. and Moss M. 2005. Issues and perspectives in landscape ecology. Cambridge University Press, Cambridge. <https://doi.org/10.1017/CBO9780511614415>
- World Health Organization (WHO). 2011. Nitrate and Nitrite in Drinking-water Background document for development of WHO Guidelines for Drinking-water Quality. WHO/SDE/WSH/07.01/16/Rev/1. 31 pages
- Wu, J.H. and Lu, J. 2019. Landscape patterns regulate non-point source nutrient pollution in an agricultural watershed. Science of Total Environment, 669, 377-388. <https://doi.org/10.1016/j.scitotenv.2019.03.014>
- Xu, G., Ren, X., Yang, Z., Long, H. and Xiao, J. 2019. Influence of landscape structures on water quality at multiple temporal and spatial scales: a case study of Wujiang river watershed in Guizhou. Water-Sui, 11(1), 159.
- Yu, X., Duffy, C.J., Rousseau, A.N., Bhatt, G., Álvarez, A.P. and Charron, D. 2016. Open science in practice: learning integrated modeling of coupled surface-subsurface flow processes from scratch. Earth and Space Science, 3(5), 190-206 . <https://doi.org/10.1002/2015EA000155>

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