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Study of landscape evolution in North Koel River Basin, Jharkhand, India: tectonic and structural implications based on hypsometric analysis

Arora AMAN[1,*], Manish PANDEY[2], Abhra SINGH[1], Masood A. SIDDIQUI[1]

[1] Department of Geography, Faculty of Natural Sciences, JMI University, New Delhi-110025
[2] School of Environmental Sciences, JNU, New Delhi-110067
* *Corresponding author*: aman.july07@gmail.com

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Abstract

Hypsometry is widely used for inferring tectonic effects and erosion status of landscapes. Tectonics, structural inhomogeneity, lithologic differences, and climatic variations lead to topographic undulations discerned into discrepancies in the values. Hypsometric index (and curve), indicative of frequency distribution of proportional elevation with the respective proportional area, is used as a tool to describe characteristics of landscape morphology, lithological variability, and degree of fluvial dissection. Many workers have used to infer comparison of rates of erosion with tectonic uplift rates. However, there are many other factors reported to influence topographic undulations other than tectonics which lead to a variety of hypsometries. Morphotectonic index, hypsometric integral, calculated using digital elevation models (DEMs) in GIS environment has been widely used for inferring tectonic effects, status of erosion, and structural controls. The present study is conducted in the North Koel River basin. This river rises in the Ranchi plateau and joins the Son River a few miles north-west of Haidarnagar, is the right bank tributary of the Son River. Along its entire course of flow, North Koel river (260 km) flows through plateau region mostly formed of metamorphic rocks. Hence, structural control seems to be the primary control on the landscape evolution of this sub-basin. In this study, hypsometric integral (and curve) has been calculated for third order and upper order streams to look whether this morphotectonic index shows any sign of tectonic, structural, or lithologic control on the landscape evolution in the North Koel River basin.

Keywords: *Hypsometric integral, Morphotectonic, GIS, North Koel River*

Rezumat. Studiu privind evoluția peisajului în bazinul raului Koel de Nord, Jharkhand, India: implicații tectonice și structurale bazate pe analiza hipsometrică

Hispometria este larg utilizată în indicarea efectelor tectonice și a stadiului de eroziune al reliefului. Tectonica, neomogenitatea structurală, diferențele litologice și variațiile climatice duc la undulații topografice marcate în discrepanțe ale valorilor. Indicele hipometric (și curba), care indică distribuția frecvenței altitudinii proporționale cu aria proporțională corespunzătoare, este folosit ca instrument pentru a descrie caracteristicile morfologiei peisajului, variabilitatea litologică și gradul de disecție fluvială. Mulți muncitori au folosit-o pentru a deduce compararea ratelor de eroziune cu ratele tectonice de ridicare. Cu toate acestea, există mulți alți factori care au influențat undulațiile topografice, altele decât tectonica, care au dus la o varietate a hipsometriilor. Indicele morfotectonic, integrala hipsometrică, calculat folosind modele altimetrice digitale (DEM) în mediul SIG, a fost folosit pe scară largă pentru a deduce efectele tectonice, starea eroziunii și controalele structurale. Prezentul studiu este făcut pentru bazinul hidrografic al râului Koel de Nord. Acest râu izvorăște din platoul Ranchi și unește cu râul Son, aflat la câțiva kilometri nord-vest de Haidarnagar, fiind afluent de dreapta al râului Son. De-a lungul întregului său curs, râul Koel de Nord (260 km) curge prin regiunea de platou formată mai ales din roci metamorfice. Prin urmare, controlul structural pare a fi controlul primar privind evoluția peisajului din acest sub-bazin. În acest studiu, a fost calculată integrala (și curba) hipsometrică pentru cursurile de ordinul trei și cele de ordin superior pentru a vedea dacă acest indice morfotectonic indică vreun semn de înfluență tectonică, structurală sau litologică asupra evoluției peisajului din bazinul râului Koel de Nord.

Cuvinte-cheie: *integrala hipsometrică, morfometrie, SIG, râul Koel de Nord*

Introduction

The geomorphology of Jharkhand state is characterized by a big number of tectonically origin rivers networks passing through the hills and valleys. The rock types are metamorphic which are less prone to soil erosion in rainy season. The North Koel River rises on the Ranchi plateau and enters Palamau division, below Netarhat near Rud. After flowing nearly due west for about 32 kilometres (20 mi), it turns north at an almost complete right angle through a gorge at Kutku, and flows through the centre of the district until it falls into the Son a few miles north-west of Haidarnagar. River basins are the important elements of the fluvial landforms and a large quantity of study has focused on their geometric behaviors and characteristics, which contain the topology of the stream networks and quantitative analysis of drainage texture, pattern, shape, and relief characteristics (Abrahams1984; Huggett and Cheesman 2002).

The region is rich in various natural resources; most parts of the areas remain not accessible due to the mountainous nature of the land. Conservation of land and water resources is an important aspect of basin management. A drainage basin is an area from where all precipitation flows to a particular water body, such as tributary stream, river or sea and it can be considered as an important geomorphic unit. Therefore, analysis of the basin contributes to understand the landform evolution through successive stages of geological time, fluvial process, lithologic character and hydrological behavior of a basin as well as tectonic activity of a region.

Hypsometry of a region provides measurement of land elevation sea level. A hypsometric curve is essentially a graph that illustrates the proportion of land area that exists at various elevations by plotting relative area against relative height. Strahler (1952) and Schumm (1956) utilized hypsometric (or area-altitude) analysis to differentiate between eroded lands at different stages in their evolution. This kind of study involves calculating the percentage of drainage basin area above each of a series of given altitudes.

Hypsometric analysis is a useful method to identify the stage of a drainage basin in the present cycle of erosion and evaluates the erosional condition of a basin, and also populates the denudational processes over a region. Besides erosional condition of landform evolution, the influence of activity and lithological factors controlling on landform evolution can be calculated from hypsometric examination (Lifton and Chase, 1992; Moglen and Bras, 1995; Willgoose and Hancock, 1998; Hurtrez and Lucazeau, 1999; Chen et al., 2003; Huang and Niemann, 2006). Thus, hypsometric investigation can be used as an estimator of erosional condition of a drainage basin and prioritize them for taking up soil and water conservation measures, which is the prerequisite for planning and management of the basin. Geographic information system (GIS) and digital elevation model (DEM) have played a vital role in in drainage basin analysis (Rai et. al. 2014; Rai et.al. 2016 & Rai et.al. 2017). Therefore, GIS technique is used as an appropriate tool for hypsometric examination. The objective of this study to look whether the morphotectonic index, hypsometric integral (and curve), calculated for third order and upper order streams, shows any sign of tectonic, structural, or lithologic control on the landscape evolution in the North Koel River basin.

Characteristics of the Study Area

The North Koel River, which rises in the Ranchi plateau and joins the Son River a few miles north-west of Haidarnagar. It is the right bank tributary of the Son River. Along its entire course of flow, North Koel river (260 km) flows through plateau region mostly formed of metamorphic rocks. Hence, structural control seems to be the primary control on the landscape evolution of this sub-basin. The study area stretches between 23°00' N, 83°30' E to 24°30' N, 85°00 E. The total area of the study area is 11418 sq. km. The maximum elevation is 1177 m while minimum elevation of the basin is 122 m.

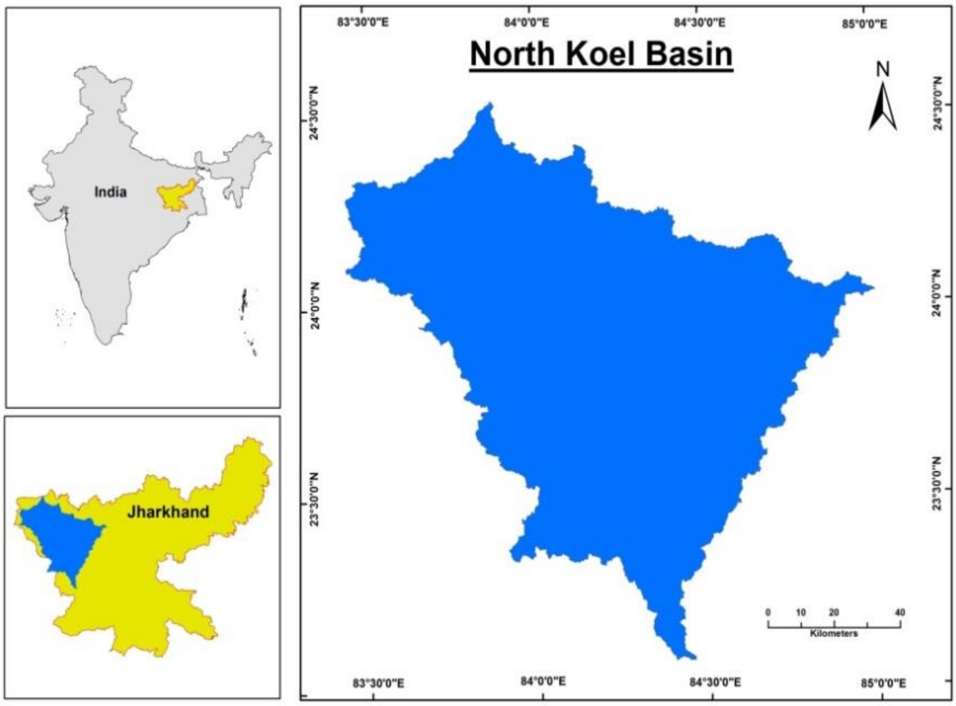

Fig. 1: Location Map of the Study Area

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Materials and Methods

This study analyzes the Hypsometric Integral in the North Koel basin using Shuttle Radar Topography Mission (SRTM) satellite data- Digital Elevation Model (DEM) of 30 m resolution shown in Figure No. 02. ArcGIS hydrology and spatial analysis tools have been used for the study. For the hypsometry integral MS excel has been used to plot the diagram of calculated statistics. Map layouts have been generated in the ArcGIS Desktop. The complete process flow diagram is illustrated in Figure 3a & 3b. The hypsometric curves for the North Koel basin and its sub-basins were prepared based on Strahler (1952) method. Hypsometric integrals of all sub-basins have been calculated using empirical formula proposed by Pike and Wilson (1971).

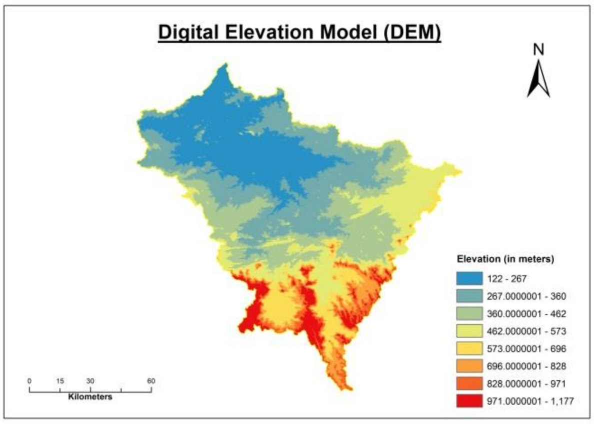

Fig. 2: Digital Elevation Map of the Study Area

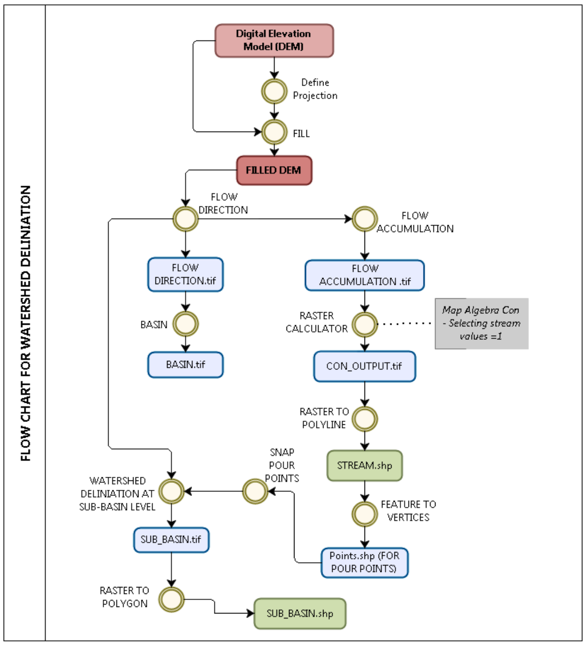

Fig. 3a: Process Flow for delineation of Watershed

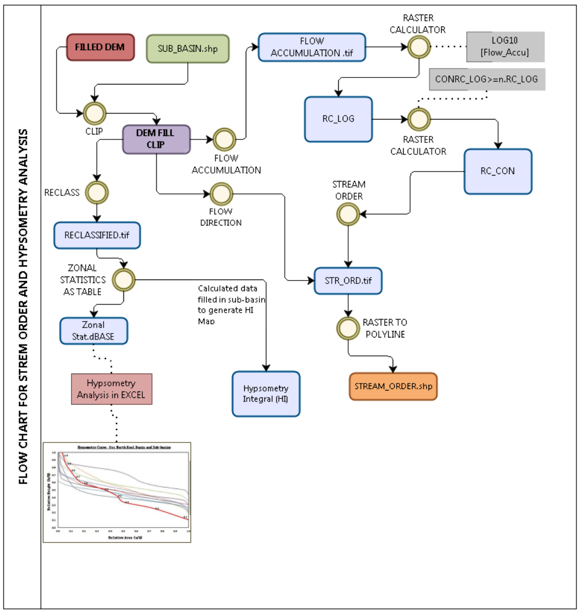

Fig. 3b: Process Flow for Hypsometry

The complete methodology has been divided in two parts for better understanding of the methods utilized in the study. In the first part, figure no. 03a, watershed delineation (fig. 4) has been done while in the other part results have been calculated (fig. 3b).

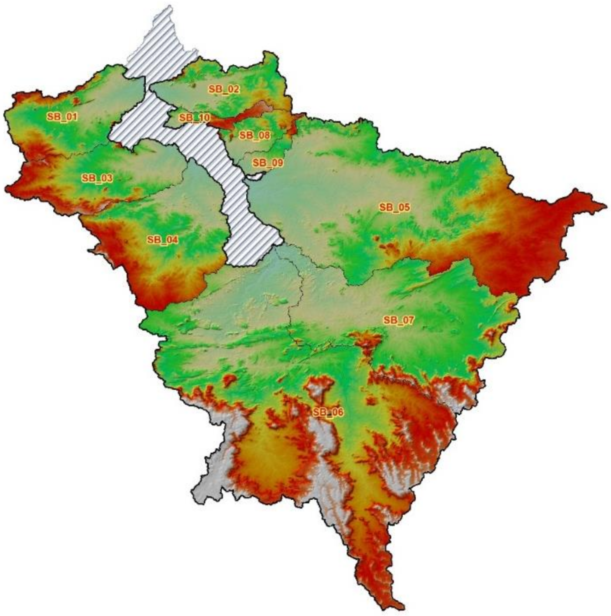

Fig. 4: Delineated ten watersheds of the study area

The stream order morphometry (fig. 5) shows the stream order structures and their total length and share in the basin shown in Table 1.

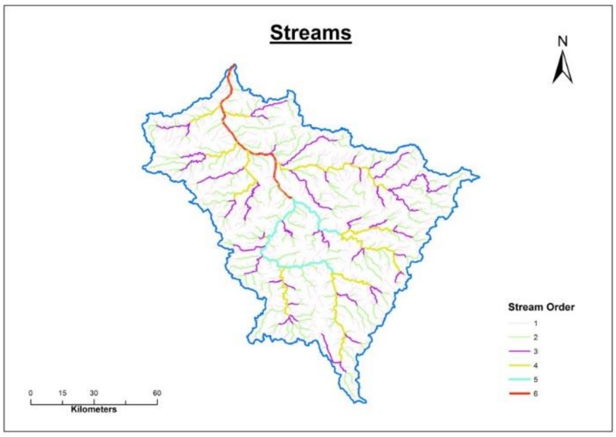

Fig. 5: Stream Order of the Study Area

Table 1: Stream Order Morphometry

Stream Order	Total Length (km.)	% age Share
1	2902.54	51.20
2	1462.87	25.80
3	687.27	12.12
4	397.27	7.01
5	125.49	2.21
6	93.58	1.65

The total Stream length is 5669.01 km up to 6^{th} order of the streams. Generally, the total length of stream segments decrease as the stream order increase. It can be inferred from the table no. 01 that the total length of stream segments is maximum (2902.54 km) in first order streams and decreases as the stream order increases.

Results and Discussion

Hypsometry can be evaluated through the hypsometric curve and hypsometric integral. The shapes of the hypsometric curve and the values of hypsometric integral are important elements in the landform analysis. These can be explained in terms of degree of landscape dissection and relative landform age. The hypsometric curves and hypsometric integral values of the North Koel basin and its sub-basins are discussed below.

Hypsometric curve

The hypsometric curve defines the distribution of elevations across an area of land, which has been used to estimate the evolutionary status of landforms. It is related to the volume of the soil mass in the basin and the amount of erosion that had done in a basin against the remaining mass (Hurtrez et al., 1999, Ahmed F. et al., 2016). Hypsometric curves are related to geomorphic and tectonic evolution of the basins in terms of their arrangements and developments (Schumm, 1956; Strahler, 1964; Leopold et al., 1964; Hurtrez et al., 1999). A useful characteristic of the hypsometric curve is that drainage basins of different sizes can be matched with each other because area and elevation are plotted as functions of the total of both variables. Strahler (1952) has classified three types of landforms on the basis of shapes of the hypsometric curve, denoting the three typical stages, (i) young (ii) mature and (iii) old stages. Convex shaped curves are associated with young stage of basin, indicate that the area is slightly eroded and not eroded much, mature stage is resemble to S shaped curves being concave upwards at higher elevations and convex downwards at lower elevations characterized by moderately eroded regions and old stage of basin is related to concave shaped curves indicate highly eroded and deeply dissected landscapes (Ahmed et al., 2016).

Plotting of hypsometric curves

In the study hypsometry analysis has been performed at basin level as well as at sub basin level for better and detailed outcome. Table no. 02 explains the elevation and area details for the North Koel Basin.

Table 2: Hypsometry Calculation of the North Koel Basin

Elevation Interval (m)	Area Proportion (q. km)	Area Accumulate (sq. km)	Area Accumulation (%)	Proportion of Height	Proportion of Area
122-300	3049.66	11418.01	100.00	**0.1**	**1.0**
300-400	2635.78	8368.35	73.29	**0.3**	**0.7**
400-500	608.46	5732.57	50.21	**0.3**	**0.5**
500-600	1176.23	5124.11	44.88	**0.4**	**0.4**
600-700	1822.50	3947.88	34.58	**0.5**	**0.3**
700-800	668.99	2125.38	18.61	**0.6**	**0.2**
800-900	410.36	1456.39	12.76	**0.7**	**0.1**
900-1000	372.38	1046.03	9.16	**0.8**	**0.1**
1000-1100	294.11	673.65	5.90	**0.8**	**0.1**
1100-1177	379.54	379.54	3.32	**1.0**	**0.0**

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Hypsometry curves were also generated for ten sub basins, figure no. 04, of the study area. Figure no. 08 is showing the curves for all sub basins and also the main basin curve is included in the same figure for better illustration and understanding of the North Koel basin. The 'S' shape curves at sub-basin level are also showing the same diminishing trend which was generated in figures 6 & 7.

The diminishing trends for sub-basins and main basin show that the rivers in the basin are at their old stage. From the curves it can be depicted that the hills of the study area got eroded at large scale and continuously it is getting at base level.

For comparison study two kinds of hypsometry curves have been generated for the whole basin, first curve (fig. 6) generated on the basis of area proportion (in %) and the second one, figure no. 06, made on the basis area proportion ratio. Both curves show same diminishing trend for the whole basin.

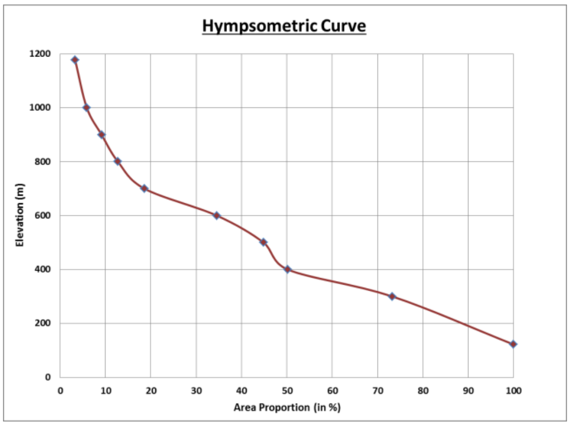

Fig. 6: Hypsometry Curve (Area Proportion %)

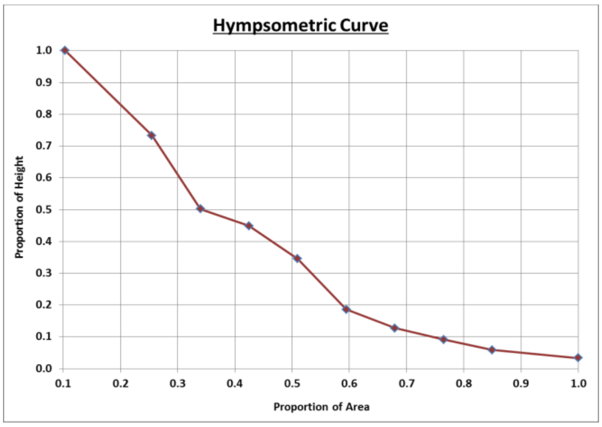

Fig. 7: Hypsometry Curve (Area Proportion Ratio)

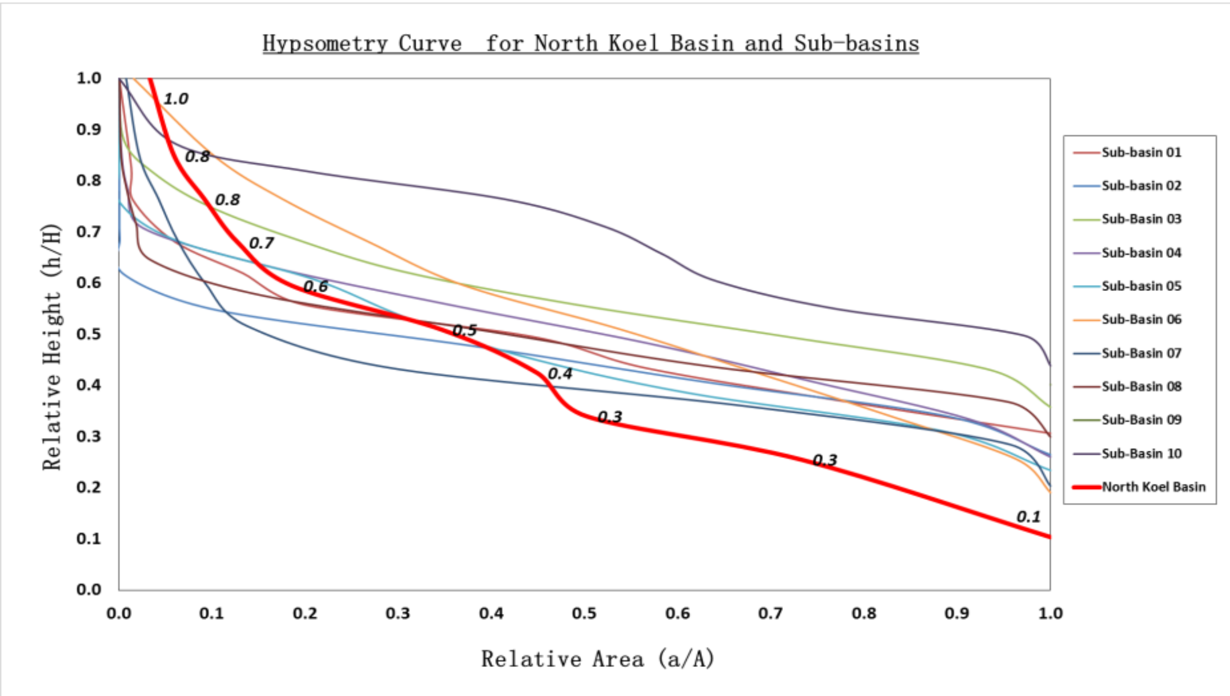

Fig. 8: Hypsometry Curves (Area Proportion Ratio) for Sub-basins

Estimation of hypsometric integral

Integration of the hypsometric curve gives the hypsometric integral (HI), which is equivalent to the elevation-relief ratio (E) as proposed by Pike and Wilson (1971). Mathematically, it is defined as

$$E \approx H_{si} = \frac{Elev_{mean} - Elev_{min}}{Elev_{max} - Elev_{min}}$$

Where,

E_{mean} = Mean elevation value (from summary statistics for watershed raster; not median)

E_{max} = Maximum elevation value

E_{min} = Minimum elevation value (outlet)

In simple word, the HI is just the mean incision of a basin (E_{mean} – E_{min}) divided by the basin's relief (E_{max} – E_{min}).

The hypsometric integral value is defined by basin geometry, relief and area of drainage basin (Lifton and Chase, 1992; Masek et al., 1994; Hurtrez et al., 1999; Chen et al., 2003). Hypsometric integral is inversely correlated with the total relief, slope steepness, drainage density and channel gradients (Strahler; 1952). The geologic stages of development of landforms and erosional condition of the basins are calculated by hypsometric integral. High value of hypsometric integral specifies the youthful stage of less eroded areas and decreases as the landscape is denuded towards the maturity and then old stages. The HI is articulated as a percentage and is an indicator of the excess of the present volume as compared to the original volume of the basin (Ritter et al., 2002). The hypsometric integral is also a sign of the 'cycle of erosion' (Strahler, 1952; Garg, 1983). The cycle of erosion is demarcated as the total time required for reduction of a land topological unit to the base level i.e. the bottom level. This entire period of the cycle of erosion can be grouped into three categories, each representing the three distinctive stages of the geomorphic cycle, viz. (i) the monadnock stage if HI ≤ 0.35, in which the basin is fully alleviated; (ii) the equilibrium or mature stage if 0.35 ≤ HI ≤ 0.60, in which the basin development has attained steady state condition and (iii) the inequilibrium or young stage if HI ≥ 0.60, where the basin is highly susceptible to erosion and is under development (Strahler, 1952).

The hypsometrical integral (HI) analysis for the study area shows that the current stage of the basin is in its old stage. Table no. 03 describes HI for all ten sub basins of the study area. In eight sub basins the HI value comes below 0.35 which represent the old stage for the basin while two sub basins show middle maturity stage have 0.42 and 0.45 HI value.

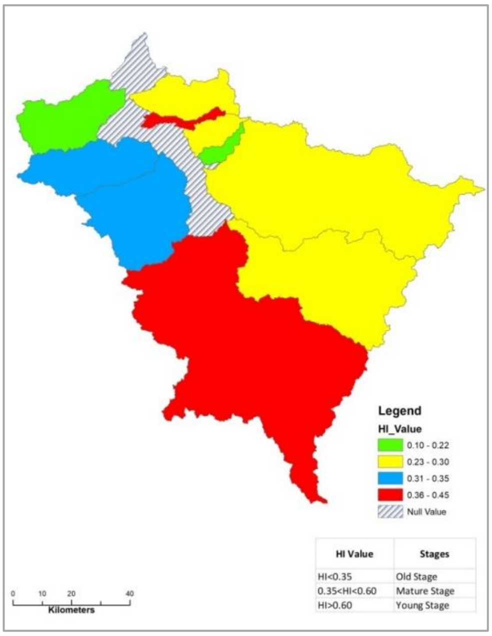

Fig. 9: Hypsometric Integral for the study area

Table 3: Hypsometry Integral at Sub-basin level of the North Koel Basin

Sub-Basin Name	Area (sq. km)	Max Elevation (m)	Min Elevation (m)	Mean Elevation (m)	Hypsometric Integral (HI)	Geological Stage
SB_01	399.53	567	150.0	242.7	0.22	Old Stage
SB_02	560.17	486	149.0	251	0.30	Old Stage
SB_03	621.83	467	167.0	268	0.34	Old Stage
SB_04	935.25	665	173.0	334	0.33	Old Stage
SB_05	2574.00	807	189.0	369	0.29	Old Stage
SB_06	3602.00	1177	224.0	624	0.42	Middle Maturity
SB_07	1584.31	1086	221.0	455.4	0.27	Old Stage
SB_08	164.07	574	172.0	278	0.26	Old Stage
SB_09	81.45	453	182.0	242	0.22	Old Stage
SB_10	84.20	374	164.0	258.2	0.45	Middle Maturity

Conclusion

From the analysis it can be concluded that; the North Koel River is a main tributary of Son River and comprises of dendritic and parallel streams with the average altitude of 400 m. Hypsometric curves for main basin as well as for sub-basins show the 'S' shape curves, indicates old or tending to old age of the basin. Also, the Hypsometric Integral analysis shows eight sub-basins are in old stage while remaining two sub-basins are in middle maturity stage. The basin has dissected landforms, and eroding continuously, prove the same. It has been also inferred that the basin has more lithological control than tectonic or structural controls.

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Application of wireless sensor networks in flood detection and river pollution monitoring

Đorđe LUKIĆ[1]*, Bogdan LUKIĆ[2]*

[1] School of Electrical Engineering University of Belgrade, Belgrade, Serbia
[2] Faculty of Geography University of Belgrade, Belgrade, Serbia
* *Corresponding author*: djordje.lukic92@gmail.com

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Abstract

In this paper, we propose a system for river monitoring based on wireless sensor network (WSN) technology. This system consists of sensor nodes that periodically measure several environmental parameters such as flow rate, water level, rainfall and pollution level. Each type of sensor node has two threshold values and measured data is compared with them at the end of the reporting interval.
Based on the current situation in WSN and measured data velocity sensors can use three different frequencies of reporting. Simulation of river monitoring system is done using Matlab software tool and the results of river maintenance during one WSN life cycle are presented. Two possible hierarchical system architectures are considered and their performance is compared. The optimal system architecture for this WSN application is discussed based on the obtained results.

Keywords: *environmental management, flood detection, river pollution, wireless sensor networks*

Rezumat. Utilizarea rețelelor de senzori wireless în detectarea inundațiilor și monitorizarea poluării fluviale

În această lucrare propunem un sistem de monitorizare a râurilor pe baza rețelelor de senzori wireless (tehnologiei WSN). Sistemul constă din noduri de senzori care măsoară periodic mai mulți parametri, cum ar fi debitul, nivelul apei, precipitațiile și nivelul de poluare. Fiecare tip de nod are două valori de prag și datele măsurate sunt comparate cu acestea la sfârșitul intervalului de raportare.
Pe baza situației actuale din WSN și a vitezei de măsurare, senzorii pot utiliza trei frecvențe diferite de raportare. Simularea sistemului de monitorizare a râurilor este realizată folosind un instrument software Matlab și sunt prezentate rezultatele analizei pe parcursul unui ciclu de viață WSN. Sunt luate în considerare două posibile arhitecturi ierarhice de sistem, iar performanța acestora este comparată. Arhitectura optimă a sistemului pentru această aplicație WSN este discutată pe baza rezultatelor obținute.

Cuvinte-cheie: *managementul mediului, detectarea inundațiilor, poluarea râurilor, rețelele de senzori wireless*

Introduction

In many industrial, scientific and medical applications, there is a need for intense and extensive data collection from the physical environment for monitoring purposes. In Serbia, about 13% of the territory (1.6 million ha) is endangered by floods and more than 2.08 million ha must be protected from floods of external and internal waters. It is necessary to drain the existing 2.67 million ha (Gavrilović, 1975; Serbian Ministry of Agriculture, Forestry and Water Management, 2001; Dragićević et al., 2009; Đorđević, 2009). Although significant protection systems have been built from the decades-long flood struggle, some of the erosion and torrential types can endanger about 90% of the territory.

Significant improvements regarding the sustainable use, protection and development of water resources in the Republic of Serbia have been made with the establishment of Water Management Information System of Serbia. The synchronization with relevant EU documents has been made, in particular with Directive 2007/60/EC of the European Parliament and the Council of the European Union from 23rd October 2007 on the assessment and management of flood risks (EFD 2007/60/EC) and with SOFPAS (*Study of Flood Prone Areas in Serbia*) project (*Indikativna mapa područja rizika od poplava*, 2016; Đorđević, 2017).

However, legacy systems for river monitoring based on complex sensor devices that use point-to-point communication for sending data did not provide the necessary flexibility, scalability and they required high operational and maintenance cost. Further development of communication technologies has enabled the application of wireless sensor networks (WSN) (Dargie & Poellabauer, 2011).

WSN applications are based on usage of small, low-cost and multi-functional sensor platforms. These platforms have the ability to form ad-hoc wireless networks in the area of interest, communicate with each other and deliver collected data to the end user. A river monitoring schemes based on WSN technology have been already studied in (Morias et al., 2005; Seal et al., 2012; Ahmad et al., 2013; Pasi & Bhave, 2015).

The rest of the paper is organized as follows. In the second section, the WSN architecture and its principles of work are defined. The third section contains description of the proposed simulated model for river monitoring. The main part of this paper is explained in the fourth section, where the simulation results are presented. Based on the obtained results, conclusions are pointed out in the fifth section.