

Quantitative Analysis of Drainage System of the Kathmandu Valley

— Krishna Prasad Paudel*

Introduction

Surface features are the product of combined and intricate relationships of various processes associated with different major aspects such as atmosphere, hydrosphere, lithosphere and biosphere. Thus land forms have an imprint of complex variables and their interactions. That is why, spatial differentiation of surface features over the globe is quite common where these different aspects of the earth's surface are operating and influencing heterogeneously.

Nepal contains a wide range of terrain in which 75 percent of land is covered by hills and mountains with high degree of complexities and the remaining 25 percent is covered by plains and lowlands (actual Tarai and Inner Tarai) with less heterogeneity. The large area under complex hills and mountainous topographic features makes a lot of impacts upon the natural environment bringing about the potential environmental degradation. Deforestation, soil erosion, landslide, siltation, flood havoc, etc. are the forms of potential environmental degradation, which are common catastrophies over the country for last few years. This sort of catastrophe is already becoming common all over the globe, where terrain is improperly used by dense mass of population, i. e. human and animal. Therefore, the present study of terrain would focus on its national planning aspects which ultimately assists to control the environmental hazards. For this purpose, it might be necessary to know about the complex variables and their interactions of terrain,

There are various approaches concerned with the evaluation of land forms. Among them the systematic approach is one of the most important

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ones. Under this approach morphometric analysis is one of the recent techniques, which is generally derived by geographers after the surface hydrologist R. E. Horton.¹

Some geographers, like A. N. Strahler and G. H. Dury have given more emphasis to the scrutiny of landforms by mathematical symbolization. Strahler noted that:

“Geomorphology will achieve its fullest development only when the forms and processes are related in terms of dynamic systems and the transformation of mass and energy are considered as function of time. A drainage system whether of water or ice within the geographical confines of a watershed represents such a dynamic system. The component unit of the geomorphology is drainage basin and analysis of basin form has proved a remarkably fertile approach to the general problem of quantitative description of landscape”.²

G. H. Dury has further emphasised that:

“Morphometry specially in geomorphology is the measurement and mathematical analysis of the configuration of the earth's surface and of the shape and dimensions of its landforms”³

Thus, for morphometric analysis, more emphasis is being given to the quantitative description. Keeping these views in mind, drainage system of the Kathmandu Valley is purposively selected for the present study and attempts have been made for evaluation of the terrain within drainage basins.

Objective of the Study

The objective of the study is to explore the characteristics of the drainage system of the Kathmandu Valley on the basis of Horton's devices and to show its geomorphic significance for the physical planning of the Kathmandu Valley.

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1. R. E. Horton, “Erosional development of streams and their drainage basins; Hydro-physical approach to quantitative morphology,” *Bulletin of the Geological Society of America*, Vol. 56 (1945) PP. 275-370.
 2. A. N. Strahler, “Dynamic basin of Geomorphology,” *Bulletin of the Geological Society of America*, Vol. (1952) PP. 923-937.
 3. G. H. Dury, *Essay in Geomorphology*, (London, Heinaman Educational Books. Ltd.) P. 235.

Methodology:

Morphometric analysis of terrain is enhanced by the mathematical values of drainage properties of the selected area. Therefore for the fulfillment of the objective, the study is exclusively based on primary data, obtained from the Topo Sheet Map on the Scale 1: 50, 000. The whole properties of drainage network have been taken for analysis. For the fulfillment of the above stated objectives the following elements of basic geometrical properties of drainage system of the Kathmandu Valley have been explored according to the devices formulated by R. E. Horton and developed by A. N. Strahler. The properties are as follows:

- i. Order and Number of Streams,
- ii. Length of the Stream,
- iii. Drainage Basin Area,
- iv. Drainage Density and
- v. Drainage Texture.

The characteristics of drainage system of the Kathmandu Valley has been explored from the basic geometrical properties of different sub basins and the different values of such properties according to Hortonian method. Finally, the geomorphic significance of the drainage system is derived through the theoretical way of description on the basis of the trend of local variation of the result of different properties and observation.

The Study Area

The Kathmandu Valley is a part of the central Nepal, a synclinal trough enclosed between two contiguous anticlinal flexures extending from 27° 32' 34" north to 27° 49' 11" north. The valley is roughly elliptical in outline with about 15 km. along east-west axis having a maximum width of 22 km. About 110 km. long perimeter of the valley is defined by the ridge-line which forms the limits of its watershed. In south the boundary has been marked near the Katuwaldaha, from where the river Bagmati makes its outlet and leaves the valley. In the present study, the study area has been confined a little above than the Katuwaldaha, along with the contourline 1229 m., covering an area of 642. 588 km² (fig. 1).

This valley is a tectonic basin, which, in its east-west alignment follows the dominant Himalayan structural trend. There is a group of confluent valleys in central part with surrounding high dividing spurs. Therefore, the central part of the valley is flatish and from which mountains rise rather steeply on all sides. The elevation of the valley varies from about 1219 m. to 2700 m. The large area of the central part of the valley is confined within a low gradient homogeneous plain and the narrow marginal surrounding rim has steep slope having with heterogeneous rugged topography affected by various processes of surface geomorphology on different geological structures (fig 2).

The Kathmandu Valley contains different tributary sub-basins. There are ten important tributary basins of trunk river Bagmati, with more than fourth-order segments. The Nakhu, Khodu (Khodku) and Godavary from Phulehoki range, the Hanumante and Manohara from Nagarkot, the Bagmati and Dhobi from Shivapuri, the Bisnumati from Shivapuri-Nagarjun, and the Balkhu and Bosan from Chandragiri have originated having with numerous tributaries and the trunk river Bagmati.

These all streams have dendritic pattern in higher altitude confluencing towards the central valley depression having with centripetal pattern.

Land use of the valley is changing variably from place to place. Much of the lowland valley floor is being used for human settlement as well as for agricultural purposes and the upland rugged mountain is under the forest covers and fallow land (fig. 3). Out of 642, 588 km² area within the watershed of the valley 60 percent is under the agricultural use and human settlement, and the remaining 40 percent is under forest, fallow land, grassland, water-bodies and waste land.

Characteristics of drainage systems

1. Order and number of streams

From the drainage net-work map (fig. 1) it is apparent that, there are 1916 big and small channel segments in total, of which 1758 belongs to ten different sub-basins and the remaining 158 segments flow directly to the trunk channel. The trunk channel of the valley is the sixth-order stream. The total length of the trunk channel within the study area is about 19.07 km.

The numbers and orders of drainage system of the Kathmandu valley are given in Table 1. The mean bifurcation ratio of the valley is 4.367. This ratio of stream order varies from basin to basin and in different order of same stream segment (Table 2 & Fig 4). Among the ten different tributary sub-basins the highest mean bifurcation ratio is 5.284 in the Bagmati and the lowest is 3.168 in the Khodu. The standard deviation of the mean bifurcation ratio of tributary sub-basins is 0.61. Although the mean bifurcation ratio of sub-basins have a great variation of the relationship between orders and numbers of the segments, a geometric progression confirms a mathematical model as a negative exponential function (fig 5). This regression coefficient strongly followed the theoretical notion of streams order and number relationship formulated by Horton.⁴

ii. Length of the Streams

It is observed that the Kathmandu Valley contains altogether 1916 streams. The trunk stream of this basin is sixth-order, but its entire length has not been measured upto the final point, because the valley has been arbitrarily delineated just near the Katuwaldaha. Therefore, first five orders have taken into consideration.

The length of the streams is given in Table-1. The mean length of the stream orders of the valley failed to follow the original Horton's analogy⁵. This is not exactly in geometric ratio but the increase has been found generally a positive direction (fig 6). The cumulative value of stream orders strongly falls on more progressive order than what Horton's original statement is. Thus Strahler's verse⁶ about length ratio more reliably fitted in the Kathmandu Valley. The mean length ratio of tributary sub-basin of the valley have also a great variation, where the standard deviation of the mean ratio is 0.56. The highest mean length ratio is in the Khodu 4.264, and the lowest is in Bisnumati 1.714.

4. "The numbers of stream segments of successively lower orders in a given basin tend to form a geometric series beginning with a single segment of the highest order and increasing according to a constant bifurcation ratio."
5. "The mean length of stream segments increases by a ratio of roughly three times with each increases in stream order. This proportion of length tends to be approximately constant for a given drainage system."
6. "The cumulative mean length of stream segments of successive orders tend to form a geometric series beginning with the mean length of the first-order segments and increasing according to a constant length ratio."

iii. Drainage Basin Area

The study of basin areas concerns with the relationship between mean area of a basin of a given order and the order itself. The total area within watershed confine of the valley is 642,588 km² drained by a sixth-order trunk channel having a total number of 1916 different orders channel segments. The mean basin area under different channel segments is 0,335 km², but the variation varies largely among the different orders. The mean basin area of the first-order is 0.201 Km², increasing of a ratio of 3.876 in first-order to second-order, 5.101 in second-order to third-order, 4.771 in third order to fourth-order and 3.653 in fourth-order to fifth-order (Table 1). In this present study, purposively the whole length as well as basin area under sixth-order trunk channel has not been taken, therefore only upto fifth-order basin is explored. The basin area also followed the progressive increase with the increment of stream orders (fig 7) as Horton's theoretical notion⁷. There is a strong positive correlation between length ratio and basin area ratio of the stream segments.

iv. Drainage Density

The Kathmandu Valley contains about 1916 stream segments having a total length of about 1294, 126 km. within the area of 642, 588 km². The average drainage density of the valley is 2 014 km/km² (Table 2). The valley comprises ten major sub-basins of fourth and greater than fourth order stream channel where the figures of drainage density largely varsin individual tributary sub-basins. The highest density of 4.403 km/ km², is in The Bosan which is the fourth-order stream covering the area of about 7. 64 km² and is located at the north-eastern piedmont of Chandragiri hill. The Bosan is followed by the Balkhu with 3.805 km/km², Nakhu with 2.651 km/km². Godavary with 2.353 km/km², Khodu with 2,099 km/km², Monohara with 2.033 km/km², Hanumante with 1.918 km/km², Dhobi with 1.943 km/km², km/km², Bagmati with 1.902 km/km², and Bisnumati with 1,793 km/km². The mean deviation of the drainage density of the sub-basins of the valley is 0.572 and The coefficient of deviation is 0.281.

V. The Drainage Texture

The drainage texture is one of the important criteria from which it may be easy to find out the nature of topography whether it is highly dissected or

7. "The mean basin areas of successive stream orders tend to form a geometric series beginning with mean area of first-order basins and increasing according to a constant area ratio."

not.⁸ There are different techniques applied by different scholars to find out the drainage texture. A.N. Strahler has made four categories of textures on the basis of drainage density. The categories made by Strahler are as following:⁹

Average drainage density (km/km ²)	Texture of Topography
1.86 - 2.48	Coarse
7.44 - 9.92	Medium
18.6 - 24.8	Fine
124 - 186	Ultrafine.

On the basis of Strahler's category, the topography of the Kathmandu Valley falls on the coarse texture. But in the case of the Balkhu and the Bosan tributary sub-basins, the texture of topography is tending towards medium texture (Table 2).

K.G. Smith has formulated a texture ratio (T) on the basis of the number of crenulations (N) in the basin contour having the maximum number of crenulations divided by the perimeter (P) of the basin. Symbolically;

$$T = \frac{N}{P}$$

On the basis of this texture ratio, he has made three main categories of the texture of topography,¹⁰ as given below.

Texture ratio	Texture category
≥ 4	Coarse
4-10	medium
7-10	fine

According to Smith's category, the topography of the Kathmandu Valley falls on the medium texture whereas the topography of individual tributary sub-basins fall on coarse texture (Table 2). The texture ratio has been shown

8. P. N. Pradhan "A Study of drainage system of the Rapti Valley," *The Himalayan Review*, Vol. 12 (1980) PP. 19-31.

9. A. N. Strahler: *Physical Geography*, Fourth ed., John Willey and Sons Inc. 1975) P. 469.

10. Peter Haggett and Richard J. Charley, "Network Analysis in Geography (London, Edward Arnold, Ltd, 1969) p. 77, citing K. G. Smith "Standards for grading texture of erosional topography" *American Journal of Science*, Vol. 248, (1950), PP 655-68

to bear a fair relationship to measure the values of drainage density.¹¹ But in the case of the Kathmandu valley the observed value of drainage density and texture ratio have fair differences or the correlation coefficient between these two values have just 0.21.

The highest texture ratio among the tributary sub-basins is observed in the Bisnumati, which has the texture ratio of 3.0, and Nakhu, Godavari, Balkhu and Bosan is 2.88, 2.67, 2.45 and 2.08 respectively, and the rest of the remaining have less than 2.0. The very interesting case is in the Bisnumati, where the observed drainage density is the lowest among the sub-basins, but the texture ratio is the maximum.

Significance of drainage properties:

Although much of the earth surfaces consist of landforms produced in the cycle of denudation in a humid climate, well-developed drainage systems characterized the vast areas of the continent.¹² Therefore, it is essential to devote some attention to the study of drainage system of the basin areas to evaluate the geomorphic conditions for the framework of physical or environmental planning of landscape. In fact a drainage system is a dynamic confine where different processes operate intricately and intensity of those processes can measure and predict for a particular physiographic condition.

The above result of the different properties of drainage system of the Kathmandu valley generally followed the theoretical hydraulic laws of R. E. Horton and A. N. Strahler. But the values of different properties have some variable nature which seems to be caused by the spatial variation of different affecting factors such as physiography, climate, vegetation cover, nature of rocks, landuse, as well as the development stage of the stream segments. The physiography alone strongly affects on the drainage properties, where nearly half of the total area within watershed falls on very gentle valley floor between the contourline of 1,200 m. and 1,400 m. having a few stream courses. Only the remaining half of the watershed belongs to heterogeneous mountain topography upto the elevation of 2,700 m. Due to contradictory physiographic conditions, the average value of the most properties follows the normal order rather than extreme. But in particular the variation is very high even in single sub-basin.

11. *Ibid.*

12. A. N. Strahler, *Op. cit* footnote, 9, P. 440

The first order stream segments are the energetic part of the dynamic system¹³, which are mostly belonging to the heterogeneous and steep surrounding mountain of the valley. There are 1445 first-order stream segments (the number includes only the fingertip single blue line marked in Toposheet Map, except intermittent channel) out of 1916 total stream segments of the valley having a mean basin area of 0.261 km². About 45 percent of the total basin area of the valley is drained by these channel segments. Due to steep and heterogeneous surface configuration having with numerous energetic fingertip channel over the mountain rim of the valley, different denudational processes over there must be very active. The low land valley floor contains about a half of the total area of watershed with very close adjustment to local baselevel, therefore the vertical deepening of the stream channel is impossible. On the other side, the valley floor has very few trunk channels with very low gradient. Therefore, the deposition work of streams seems active over the lower part, resulting into the braided conditions of several tributaries. Thus the valley floor is still suffering from a heavy mass of siltation and flood havoc every year. Since last few years, deforestations as well as encroachment activities of local people for agricultural purposes are rapidly expanding towards the surrounding mountain rim. A part of Chandragiri and Phulchauki still suffers from quarrying. These sorts of activities cause a rapid flow of soil from hillside to the valley floor through the stream channel. For the control of such potential processes of the valley, physiographic planners as well as hydraulic engineer should give their attention towards the numerous energetic first-order stream segments and their basin areas to control their active denudational processes.

13. R. P. C. Morgan, "Observations on factors affecting the behaviour of a first-order stream," *Institute of British Geographers Transaction*, No. 56, London, 1972.

TABLE-1
CHARACTERISTICS OF DRAINAGE SYSTEM OF THE KATHMANDU VALLEY

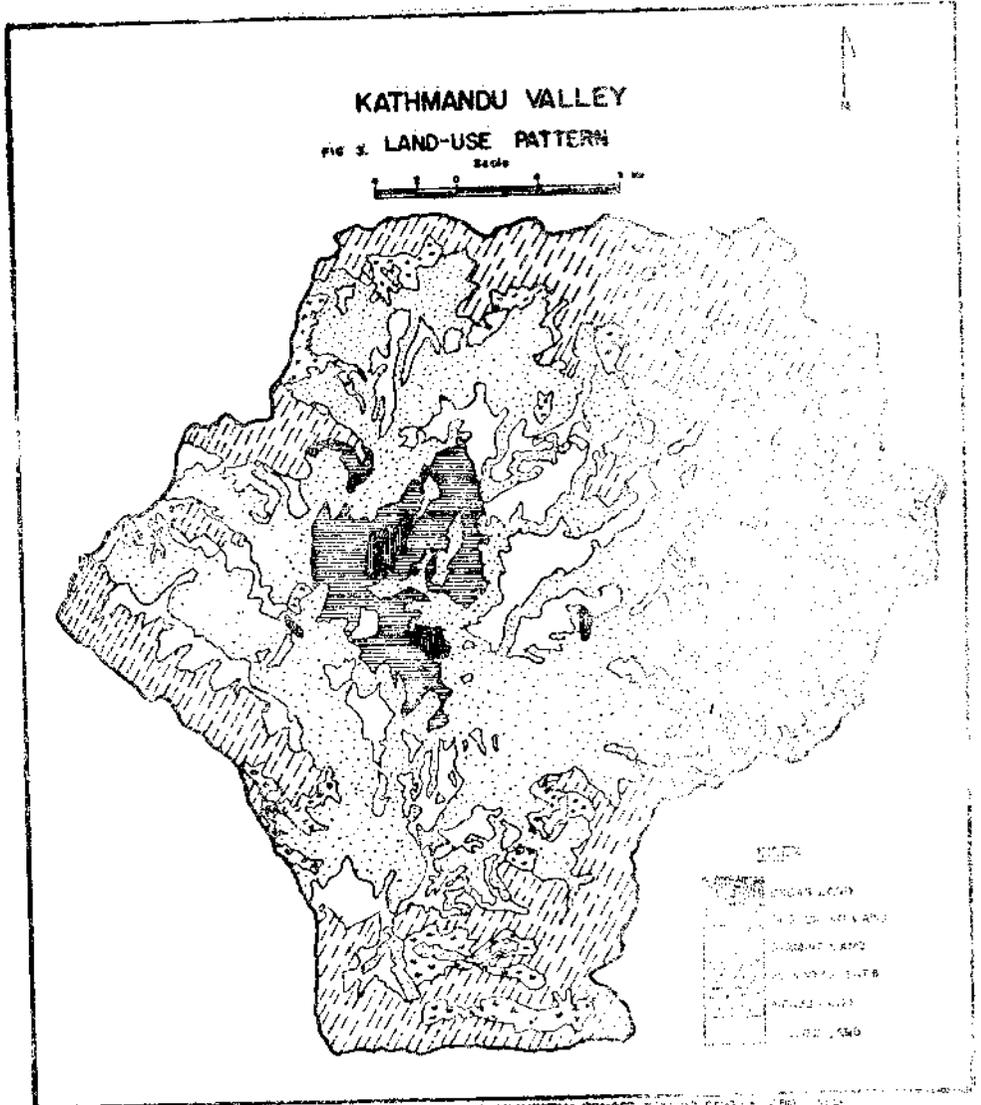
Stream Order	Number of Segments	Bifurcation Ratio	Length of the segments	Mean length of the Segments		Cumulative Mean length of the Segments (km)	Mean Length Ratio	Mean Basin Area		Mean Basin Area Ratio
				(km)	(km)			(km ²)	(km ²)	
U	Nu	Rb	Lu	Lu	C Lu	Rl	Au	Ra		
1	1445	3.981	723.37	0.501	0.501	1.501	0.201	3.876		
2	305	4.595	272.94	0.752	1.253	2.281	0.779	5.101		
3	79	3.591	135.46	1.715	2.968	2.456	3.974	4.771		
4	22	3.667	92.67	4.212	7.18	2.004	18.96	3.653		
5	6	6.0	50.65	8.442	15.662	2.255	69.26	9.278		
6	1		19.07*	19.07	34.662		642.588*			
Total	6		1294.12							
Average	1916	4.367	0.675	2.099	5.336					

*Not complete

TABLE-2
CHARACTERISTICS OF DRAINAGE SYSTEMS OF KATHMANDU VALLEY BY SUB-BASIN

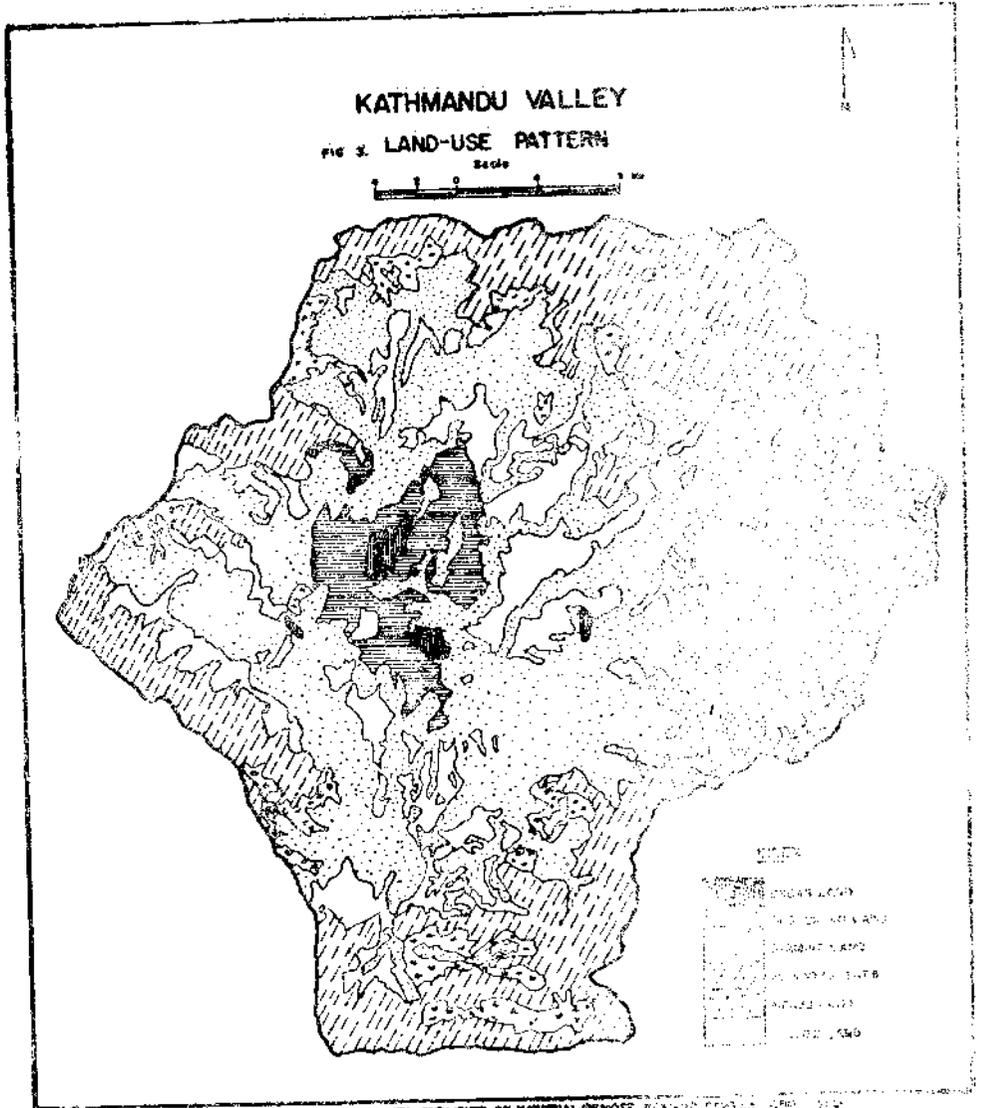
Name of Basin	Order No.	No. of Stream segments	Mean bifurcation Ratio	Total length of the segments (km)	Mean length of the segments (km)	Mean length Ratio	Total Basin Area (km ²)	Mean Basin Area Ratio	Drainage Density (km/km ²)	Drainage Texture (N/P)
	U	Nu	Rb	Lu	Lu	RL	Au	Ra	Dd	T
1. Nakhu	5th	296	4.378	153.983	0.520	2.471	58.089	4.580	2.651	2.88
2. Khodu	5th	113	3.168	73.886	0.654	4.264	35.192	3.808	2.099	1.42
3. Godavari	5th	200	3.536	112.585	0.563	3.177	47.860	4.739	2.353	2.67
4. Hanumante	5th	261	3.756	186.871	0.716	1.984	97.443	5.429	1.918	1.93
5. Monohara	5th	258	4.031	151.705	0.588	2.248	74.644	4.629	2.033	1.94
6. Bagmati	4th	175	5.284	140.28	0.802	4.138	73.756	6.590	1.902	1.9
7. Dhobi	4th	80	3.948	64.109	0.801	4.035	32.998	5.427	1.943	1.24
8. Bishumati	5th	213	3.557	182.173	0.855	1.714	101.622	4.538	1.793	3.8
9. Balkhu	4th	115	4.5	95.43	0.828	2.733	25.026	5.112	3.805	2.45
10. Bosan	4th	47	3.259	33.642	0.716	2.098	7.648	3.675	4.405	2.08
TOTAL KATHMA- NDU VALLEY*	6th	1916	4.367	1294.13	0.675	2.099	642.588	5.336	2.014	4.48

*Including interbasin areas and small stream segments directly joined with trunk stream.

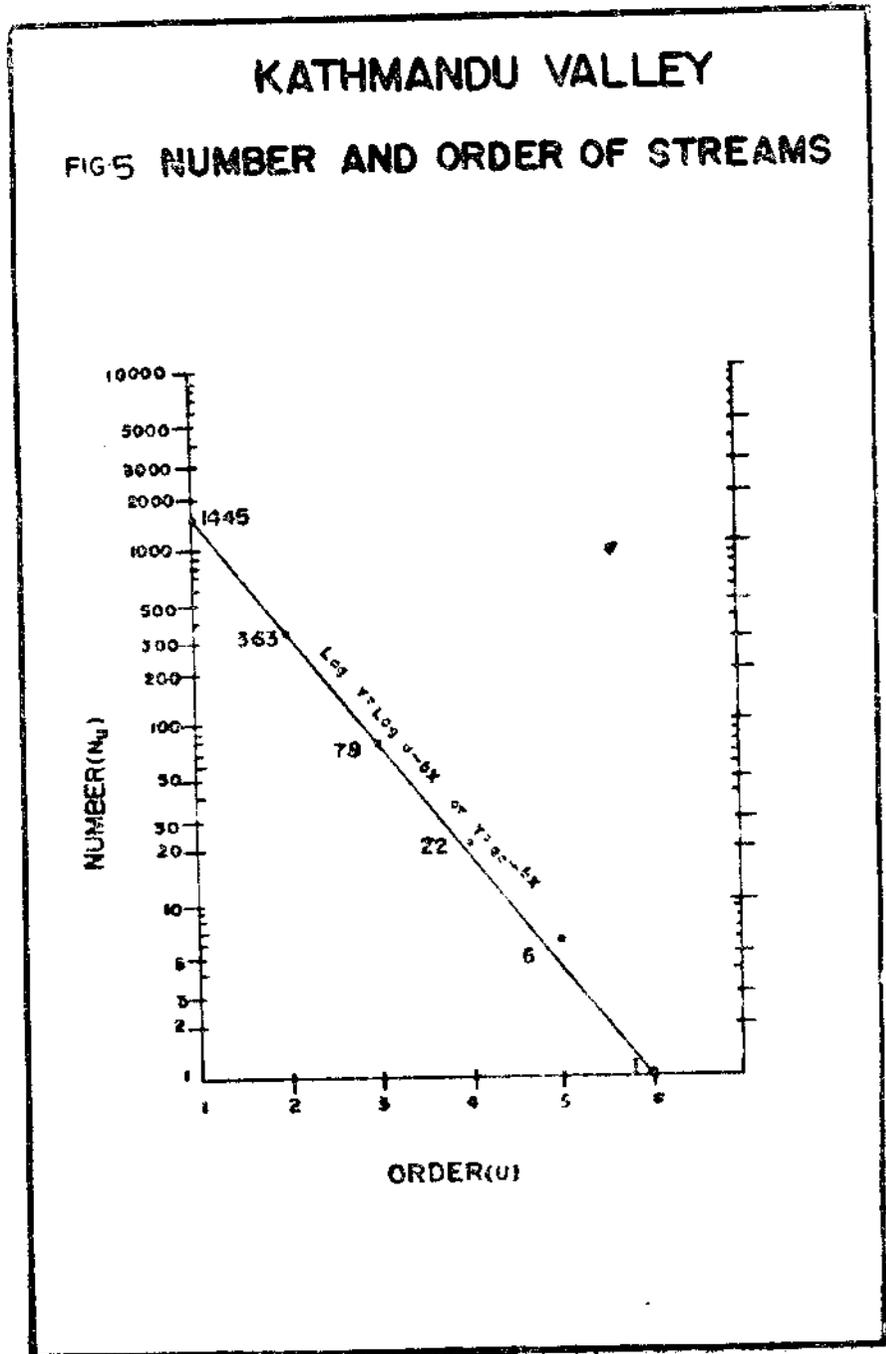


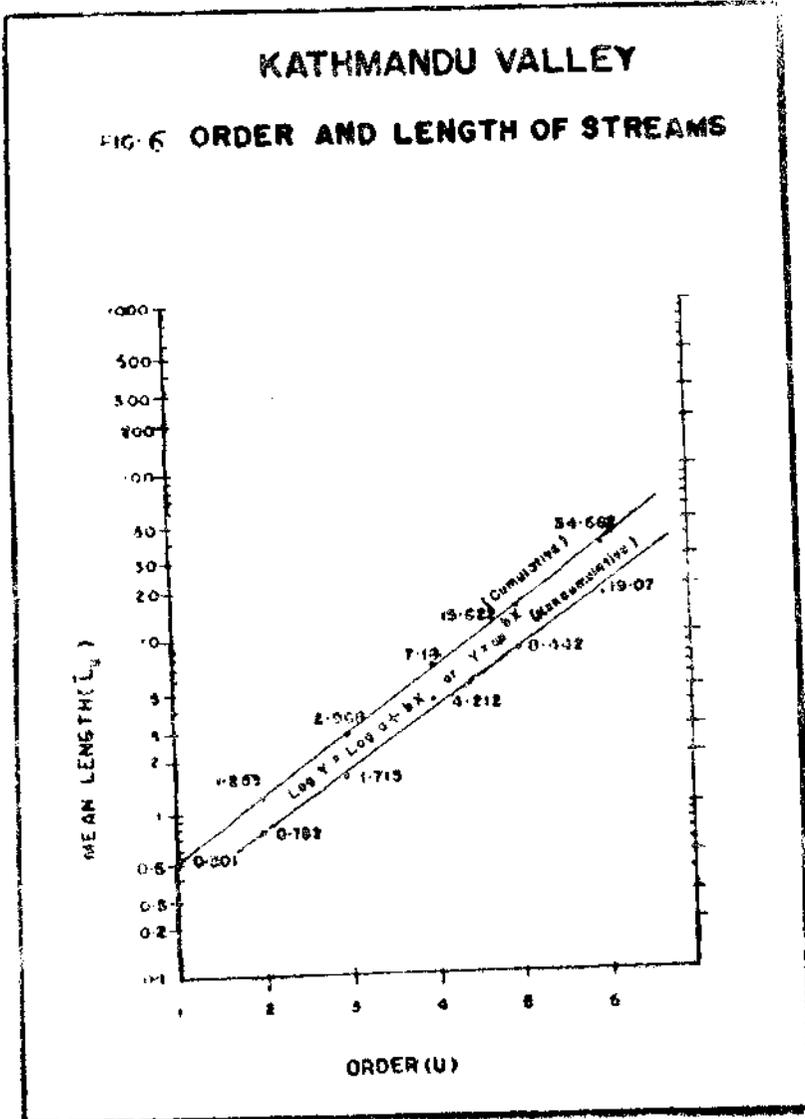
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MAP SOURCE: LAND-USE MAP OF KATHMANDU VALLEY, PUBLISHED BY NATIONAL GEODETIC SURVEY OFFICE, 1961



KATHMANDU





NARYAMANI VALLEY

THE ORDER AND DISENANCE OF STREAMS

