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Influence of topography on some vegetation cover properties

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Abstract

We study the influence of nine local, non-local and combined quantitative topographic characteristics on vegetation cover, altitude and density. The objects under study are four areas of the Rudny Altai. Differentiation of plant properties is shown to depend on relief parameters which control migration and accumulation of water in landscape by gravity. These are landsurface curvatures, catchment area, topographic and stream power indexes. In some cases the phytocoenosis characteristics can have higher correlation with non-local and combined topographic variables than with local ones. This derives from the fact that non-local and combined relief attributes take into account a relative location of an area in a landscape, so they can better determine topographic prerequisites of substance motion. We demonstrate the advisability of the use of digital models and maps of indicated topographic characteristics in plant investigations.

1. Introduction

One of the most important factors–prerequisites of vegetation cover formation and development is relief in parallel with climate, geology, soils and anthropogenic loading. In this connection data on three local quantitative topographic variables namely elevation (h), gradient (G) and aspect (A) (Table 1) are commonly used in vegetation surveying and mapping investigations (Zakharov, 1940; Yaroshenko, 1961; Isachenko, 1965; Burrough et al., 1977; Tom and Miller, 1980; Shasby and Carneggie, 1986; Wu, 1987; Frank, 1988; Leprieur et al., 1988; Paradella et al., 1989). Elevation determines altitudinal zonality of soil and vegetation. Gradient controls velocity and aspect controls direction of flows, insolation, intensity of rain evaporation, snow detention and melting,

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Table 1
Definitions and formulae of topographic variables

Topographic variable, unit	Definition and formula
h, m	Elevation above sea level in a given point of the landsurface
G, °	An angle between a tangent and horizontal planes in a given point of the landsurface (Evans, 1980; Shary, 1991), $G = \mathrm{arctg}\sqrt{p^2 + q^2} \cdot 180/\pi$ [a]
A, °	An angle clockwise from north to a projection of an external normal vector to a horizontal plane in a given point of the landsurface (Evans, 1980; Shary, 1991), $A = \mathrm{arctg}(q/p) \cdot 180/\pi$ [a]
k_v, m^{-1}	A curvature of a normal section of the landsurface by a plane which includes an external normal vector and a gravity acceleration vector in a given point of the landsurface (Evans, 1980; Shary, 1991), $k_v = -(p^2 r + 2pqs + q^2 t)/[(p^2 + q^2)(1 + p^2 + q^2)^{3/2}]$ [a]
k_h, m^{-1}	A curvature of a normal section the landsurface, this normal section is orthogonal to the section with k_v in a given point of the landsurface (Shary, 1991), $k_h = -(q^2 r - 2pqs + p^2 t)/[(p^2 + q^2)(1 + p^2 + q^2)^{1/2}]$ [a]
H, m^{-1}	$H = (k_h + k_v)/2$ (Shary, 1991)
CA, $m^2\, m^{-1}$	A ratio of an area of an exclusive figure, which is formed on the one hand by a contour intercept with a given point of the landsurface and on the other hand by flow lines coming from higher zones of slope to ends of this contour intercept, to an arc length of this intercept (Speight, 1968)
TI	TI = ln(CA/G) (Beven and Kirkby, 1979)
SI	SI = CA·G (Moore et al., 1993)

[a] p, q, r, s, t are partial derivatives of the function $h = f(x, y)$: $p = \partial h/\partial x$, $q = \partial h/\partial y$, $r = \partial^2 h/\partial x^2$, $s = \partial^2 h/\partial x \partial y$, $t = \partial^2 h/\partial y^2$. Moving three by three submatrix

·1 ·2 ·3
·4 ·5 ·6
·7 ·8 ·9

along regular DEM we can estimate values of p, q, r, s, t for a central node of the submatrix by the following formulae (Evans, 1980):

$$p = (-h_1 + h_3 - h_4 + h_6 - h_7 + h_9)/6w$$
$$q = (h_1 + h_2 + h_3 - h_7 - h_8 - h_9)/6w$$
$$r = [(h_1 + h_3 + h_4 + h_6 + h_7 + h_9 - 2(h_2 + h_5 + h_8)]/3w^2$$
$$s = (-h_1 + h_3 + h_7 - h_9)/4w^2$$
$$t = [(h_1 + h_2 + h_3 + h_7 + h_8 + h_9 - 2(h_4 + h_5 + h_6)]/3w^2$$

where h_i is elevation in the ith node of the submatrix, and w is the matrix step. Values of p, q, r, s, t are not calculated along the boundary nodes of a regular DEM.

some soil properties (Zakharov, 1940; Young, 1972; Moore et al., 1993; etc.). G, A and h in many respects determine microclimate (Geiger, 1966). At the same time information on h, G and A can be inadequate for proper mapping and study of vegetation cover.

In particular, the following topographic variables can influence the plant origin and development:

— local topographic characteristics namely horizontal (k_h), vertical (k_v) and mean (H) landsurface curvatures (Young, 1972; Shary, 1991);

— a non-local variable that is specific catchment area (CA) (Speight, 1968);

— combined topographic characteristics namely topographic index (TI) (Beven and Kirkby, 1979) and stream power index (SI) (Moore et al., 1993).

k_h, k_v, H, CA, TI and SI (Table 1) are connected with processes of migration and accumulation of water, mineral and organic substances which are moved along the landsurface and in soil by gravity. k_h is responsible for convergence and k_v for relative deceleration of flows (Kirkby and Chorley, 1967; Shary, 1991). k_h and k_v control soil moisture, pH, thickness of soil profile horizons, organic matter and some other soil properties (Shary et al., 1991; Moore et al., 1993; Bell et al., 1994; etc.). H represents convergence and relative deceleration of flows with equal weights (Shary, 1992). H is nearly in function with soil moisture in different climatic and geomorphic situations (Sinai et al., 1981; Kuryakova et al., 1992).

Local topographic variables can be derived by an analysis of h values in a small neighborhood of each point of the landsurface (Table 1). An analysis of rather big areas of the landsurface is required for derivation of non-local and combined topographic attributes (Table 1). CA, TI and SI take into account the relative location of an area in a landscape, so they can better determine topographic prerequisites of substance motion, such as water (Speight, 1980). CA controls soil moisture (Burt and Butcher, 1985), concentration of natural radionuclides in soil (Martz and De Jong, 1990) and thickness of soil profile horizons (Bell et al., 1994). TI represents a theoretical estimation of flow accumulation and can be used to describe a spatial landscape distribution of areas of surface saturation and soil moisture content (Beven and Kirkby, 1979; Quinn et al., 1991). SI is the measure of the potential erosive power of overland flow (Moore et al., 1993). TI and SI control thickness of soil profile horizons, organic matter, pH, silt and sand content (Moore et al., 1993).

Digital models of k_h, k_v, H, CA, TI and SI are used in geomorphic (Dikau, 1988), hydrological (Quinn et al., 1991, 1995) and soil (Moore et al., 1993) mapping.

Obviously, data cited may lead researchers to the idea that landsurface curvatures, non-local and combined topographic attributes can also control plant distribution and so can be useful in vegetation studies. Nevertheless only some aspects of the influence of k_h, k_v, H, CA and TI on vegetation cover properties, and utilization of these data in plant investigations have been discussed in literature. Thus Sinai et al. (1981) showed great dependence of wheat crop on H in Israel. The use of k_h maps allowed one to recognize patterns of some plant community mesocombinations, their ecological dynamic series and to determine some regularities in vegetation cover organization of the Caspian semidesert region (Shadrina, 1987). Frank (1988) pointed out the need to take into account k_h and k_v in mountainous vegetation mapping. However, Peddle and Franklin (1991) noted a minor improvement in the precision of automated interpretation of spectral and radar data by using k_h and k_v in investigating the Newfoundland vegetation. Perhaps this fact indicates less sensitivity of boreal and subboreal vegetation to variations of landsurface curvature as compared with soils (Florinsky et al., 1994).

Moore et al. (1988) discussed the usefulness of non-local topographic variables for forecasting the vegetation species distribution in arid landscapes. Band et al. (1993) demonstrated the value of using TOPMODEL (a distributed hydrological model which utilizes TI (Beven and Kirkby, 1979; Quinn et al., 1991)) in investigation of forest canopy net photosynthesis and total evapotranspiration.

The aims of this paper are the study and comparative analysis of the influence of a wide range of quantitative topographic variables on some vegetation cover properties.

2. Study sites

The objects under study are four areas of size 4 by 4 km in the territory of Rudny Altai (the East-Kazakhstan Region, Kazakhstan) (Fig. 1). This terrain has middle and low-mountain relief on Paleozoic limestones, granite varieties and clayey schists. Subterranean waters lie at depths of 1–12 m in valleys and at depths of 20–50 m beneath mountain slopes. The area is characterized by an extreme continental climate: January average temperature is − 16°C; July average temperature is 18°C, and precipita-

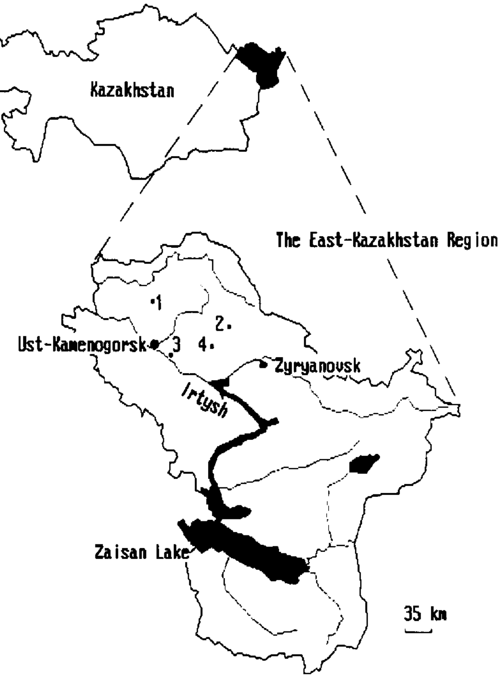

Fig. 1. Geographical location of the study sites: (1) the Sekisovka area (latitudes 50°19′50″N–50°21′50″N and longitudes 82°37′00″E–82°40′15″E), (2) the Berezovka area (latitudes 50°07′10″N–50°09′10″N and longitudes 83°52′45″E–83°56′00″E), (3) the Ust-Feklistka area (latitudes 49°52′40″N–49°54′40″N and longitudes 82°50′00″E–82°53′15″E), (4) the Chistopolka area (latitudes 49°55′20″N–49°57′20″N and longitudes 83°26′00″E–83°29′15″E).

tion is 500–2000 mm per year. Winds are the northwest and the southeast, altitudinal climate zonality is typical. Dark and light chestnut soils are dominant to 400 m altitude and chernozems from 400 to 700 m altitude, with mountain grey forest and sod podzolic soils from 800 to 2000 m altitude. Vegetation cover (Table 2) is also characterized by altitudinal zonality (Fedorovich and Nazarevsky, 1969).

Within the Sekisovka area (Fig. 2a) there are northwestern, submeridian and northeastern azimuth spurs of the Ulbinsky Range which border on steppes. The area is developed. Flood-plain, steppe and forest-steppe phytocoenosises prevail (Table 2).

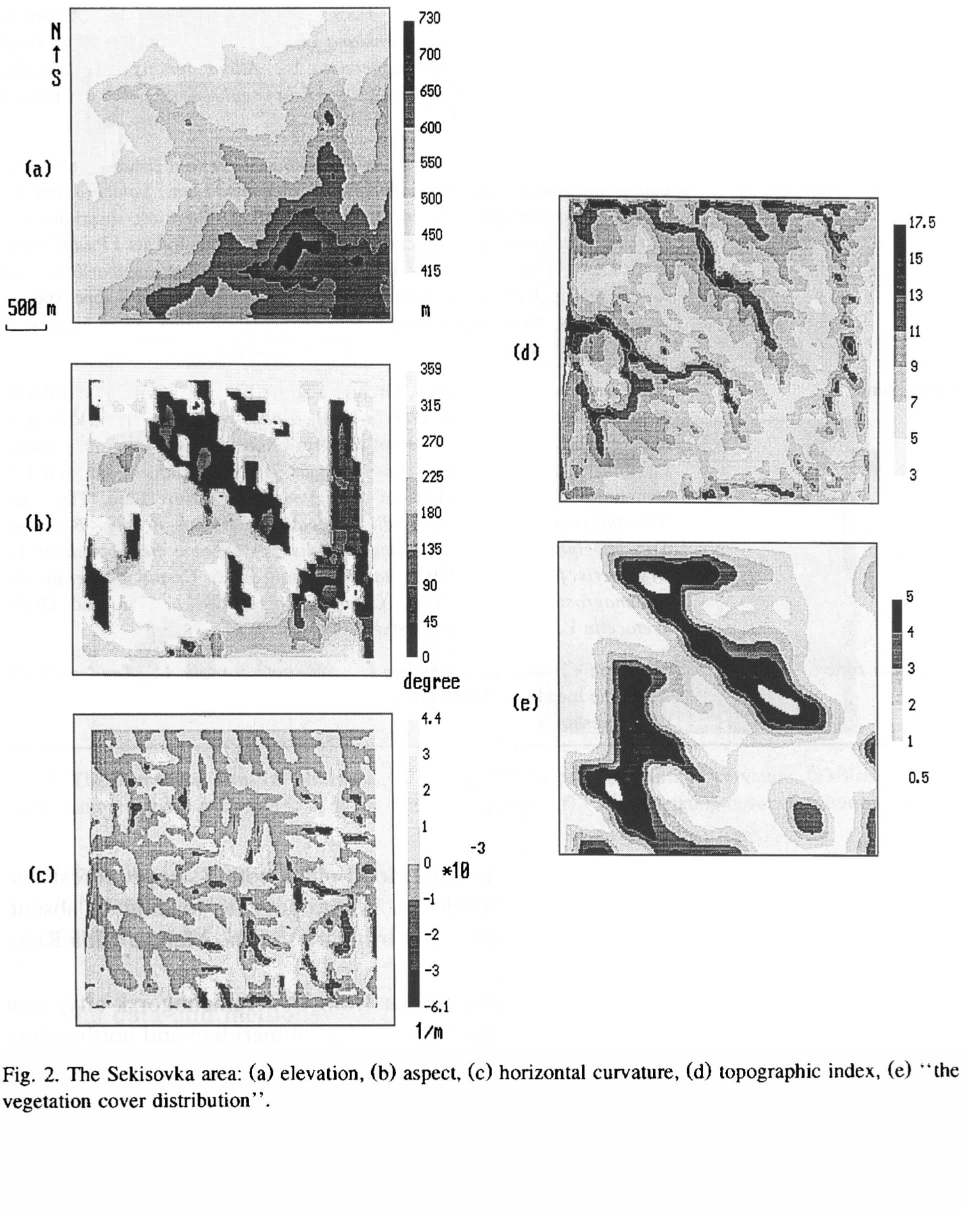

Fig. 2. The Sekisovka area: (a) elevation, (b) aspect, (c) horizontal curvature, (d) topographic index, (e) "the vegetation cover distribution".

Table 2
Vegetation of the study sites (Kozhara and Komshin, 1993)

Flood-plains	There are sedge and reed societies in areas with stagnation moisture and basin coastal parts. Mesophytic, forb and cereal meadows (*Dactylis glomerata* L., *Poa angustifolia* L., *Trifolium pratense* L., *Medicago* L.) are developed by herding and mowing.
Steppe zone	There are *Spiraea hypericifolia* L., *Caragana frutex* L., *Rosa spinosissima* L. in shrubby steppe. Shrub stage has the height of about 0.6–1.5 m, sometimes it forms a continuous cover. It can be sparse and absent due to herding, mowing and other anthropogenic factors and with stony soil formation increasing. Large soddy feather-grass and fescue steppes (*Stipa capillata* L., *Festuca sulcata* Hack., *Koeleria cristata* L., *Artemisia austriaca* Jacq., *Artemisia Schrenkiana* Ledb.) are developing in shrub stage place. Steppe meadows (*Stipa pennata* L., *Allium nutans* L., *Pulsatilla pratensis* L., *Iris ruthenica* Ker.-Gaw., *Filipendula ulmaria* L.) are formed on more developed soils.
Forest-steppe zone	There are *Rosa spinosissima* L. and *Rhamnus* L. within shrub stage in dry balkas and watersheds. Rosariums, *Padus racemosa* Lam., *Lonicera tatarica* L. and *Viburnum opulus* L. in more moist balkas. There are rosariums and *Caragana arborescens* Lam. on convex slopes. Low forests (*Padus racemosa* Lam., *Populus tremula* L., *Salix alba* L., *Sorbus aucuparia* L.) are located along balkas and springs. There are meadow and steppe species within grass stage in rosariums and elements of taiga wide grasses in mesophilous shrubs.
Forest zone	There are chern mixed aspen, birch and silver fir forests with a well-developed undergrowth (*Sorbus sibirica* Hedl., *Padus racemosa* Lam., *Viburnum opulus* L.). The shrub stage is not uniform (*Ribes rubrum* L., *Rubus idaeus* L., *Spiraea media* Schmidt, *Rosa majalis* Herrm., *Lonicera tatarica* L.), sometimes there are thickets of *Caragana arborescens* Lam. There are *Alfredia carnua* L., *Brachypodium silvaticum* Huds., *Bromus Benekenii* Trin., *Delphinium* L., *Aconitum borealis* L., *Cirsium heterophyllum* L., *Dryopteris filix mas* Shott., *Stachys silvatica* L., *Crepis glomerata* L., *Calamagrostis purpurea* Trin., *Calamagrostis obtuscata* Trin. and *Oxalis acetocella* L. within the grass stage.
Subalpine zone	There are *Cirsium heterophyllum* L., *Aconitum borealis* L., *Aquilegia* L. in subalpine meadows. There are *Larix sibirica* and *Pinus sibirica* in subalpine light forests.

The Berezovka area (Fig. 3a) is a depression. Flood-plain, forest-steppe, forest and subalpine plant societies are developed (Table 2). Anthropogenic loading is absent. There are upper reaches of the Stanovaya River and tributaries of the Malaya Ulba River here.

The Ust-Feklistka area (Fig. 4a) is located not far from Ust-Kamenogorsk city, near the Irtysh River but is poorly accessible. It includes border submeridian and northeastern azimuth ranges of the Central Altai, some small tributaries of the Irtysh River. Flood-plain, steppe, and forest-steppe landscape zone phytocoenosises prevail (Table 2).

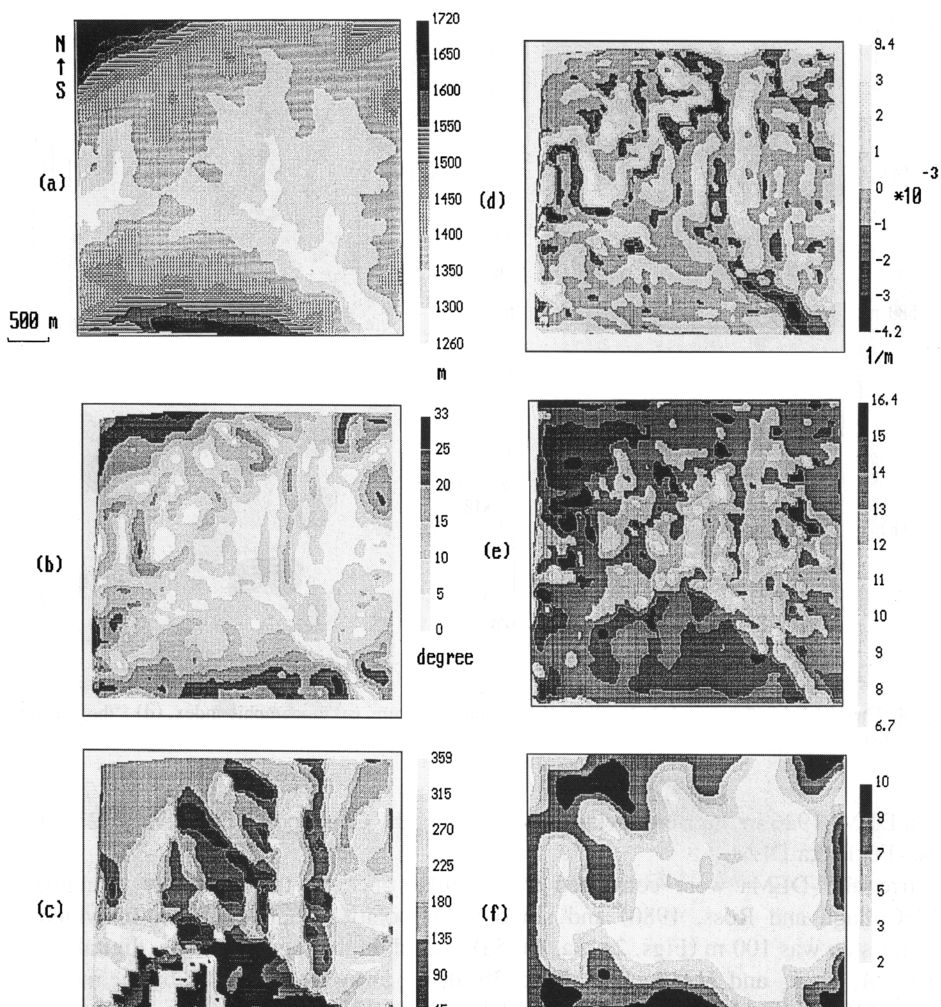

Fig. 3. The Berezovka area: (a) elevation, (b) gradient, (c) aspect, (d) vertical curvature, (e) stream power index (natural logarithmic scale is used for clear SI mapping), (f) "the vegetation cover distribution".

Within the Chistopolka area (Fig. 5a) there are foothill northeastern azimuth ranges and tributaries of the Myakotikha River. Flood-plain, steppe, forest-steppe and forest vegetations are developed (Table 2).

3. Initial data and methods

Initial data on relief were digital models of h (DEMs) obtained by digitizing the contours of 1 : 50 000 scale topographic maps. There are 1619 points in the Sekisovka

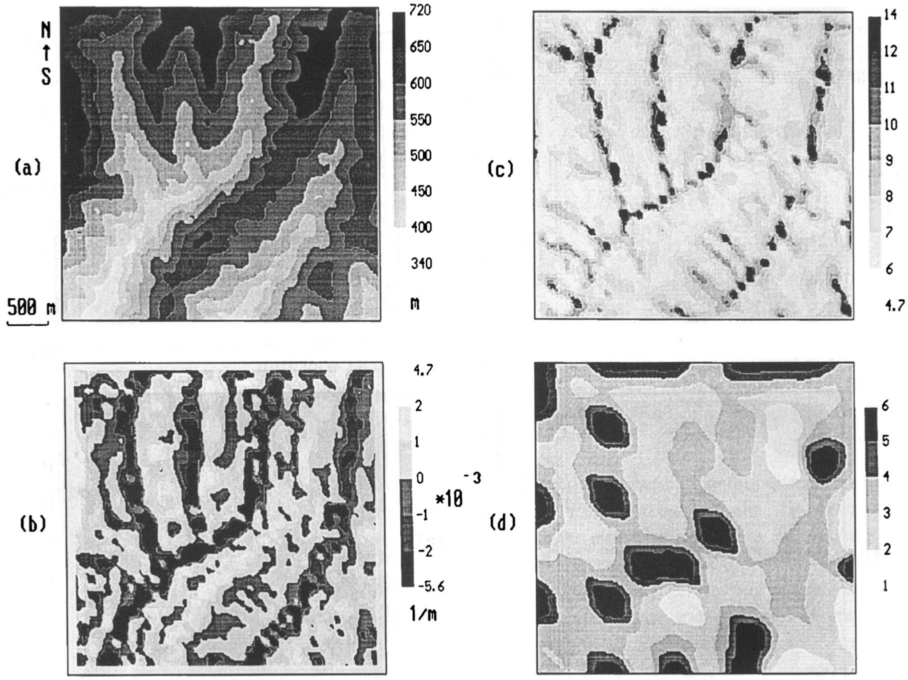

Fig. 4. The Ust-Feklistka area: (a) elevation, (b) vertical curvature, (c) topographic index, (d) "the vegetation cover distribution".

area DEM, 1926 in the Berezovka DEM, 1881 in the Chistopolka DEM, and 1217 in the Ust–Feklistka DEM.

Irregular DEMs were converted into regular ones by the Delauney triangulation (McCullagh and Ross, 1980) and smooth interpolation (Schut, 1976), in which the matrix step was 100 m (Figs. 2a, 3a, 4a, 5a). Based on the regular DEMs, digital models of G, A, k_h, k_v and H (i.e., Figs. 2b, c, 3b–d, 4b, 5b) were calculated by the method of Evans (1980), (Table 1), and digital models of CA, TI and SI (i.e., Figs. 2d, 3e, 4c, 5c, d) were calculated by the method of Quinn et al. (1991).

Initial data on vegetation were (a) field description and classification of the plant cover obtained by the Ecological Survey of the East-Kazakhstan Region, (b) 1 : 50 000 scale topographic maps, and (c) aerial scenes in the visual range. On the basis of these data a list of vegetation cover types was produced. The typification was carried out without taking into account topographic positions of plant patterns. The vegetation cover types distinguished were ranked according to criteria of plant average height and density (Table 3). The vegetation rank scale obtained (Table 3) is independent of the topographic variation in space. This independence is an essential condition for a correct statistical analysis of relationships between topography and vegetation.

Using the rank scale of vegetation cover (Table 3) digital models of "the vegetation cover distribution" (VEG) were compiled by processing topographic map data. The matrix step of 400 m was applied (Figs. 2e, 3f, 4d, 5e). This matrix step on the whole

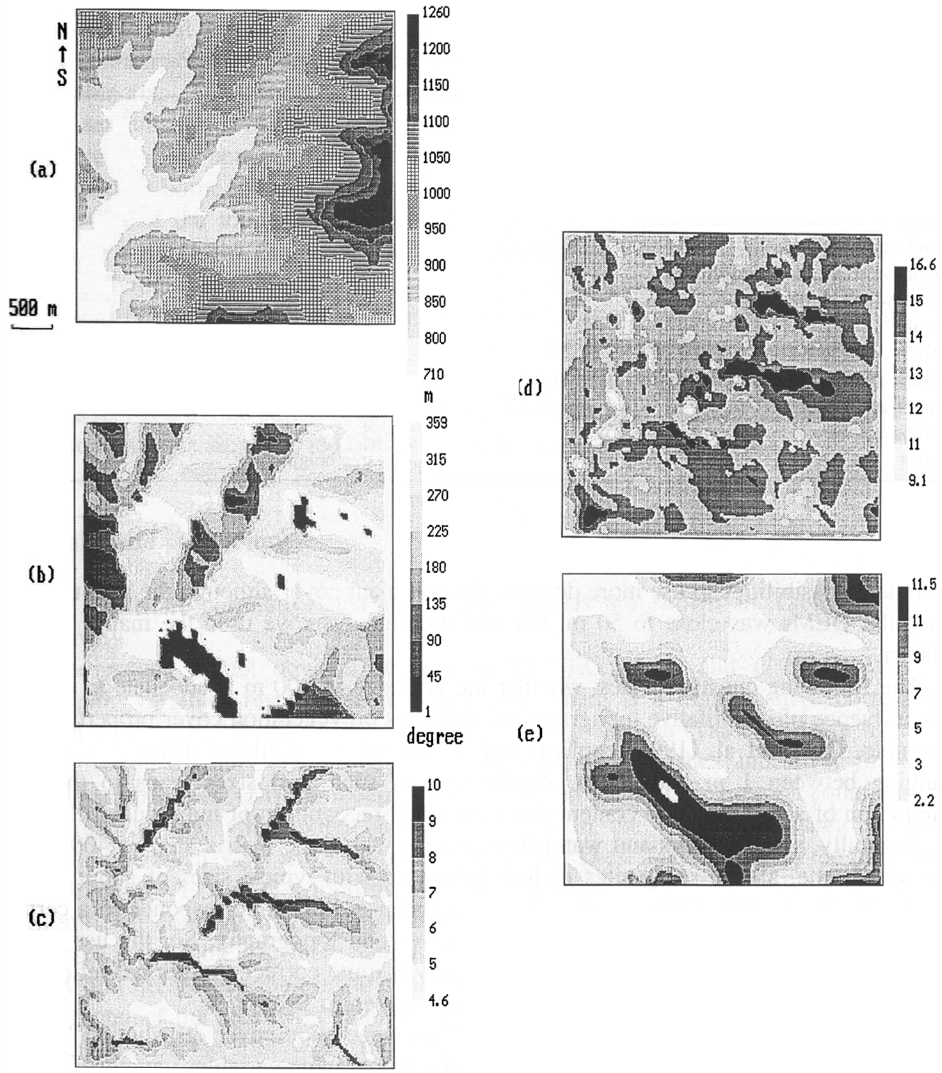

Fig. 5. The Chistopolka area: (a) elevation, (b) aspect, (c) catchment area (natural logarithmic scale is used for clear CA mapping), (d) stream power index (natural logarithmic scale is used for clear SI mapping), (e) "the vegetation cover distribution".

relates to vegetation cover resolution of 1 : 50 000 scale topographic maps. To improve the digital models of VEG, aerial scenes and field plant descriptions were used.

Combined analysis of topographic, vegetation and other ground data with different precision and resolution may lead to unrealistic results in some cases (Lidov, 1949). In spite of the development of remote sensing and geographical information system techniques the problem still stands (Hutchinson, 1982). Unfortunately, we had no

Table 3
Rank scale of vegetation cover

Vegetation cover type	Rank
Field	0.5
Steppe	1
Meadow	2
Light forest and meadow	2.2
Light forest, dead wood and meadow	2.4
Shrubs and steppe	2.5
Light forest, meadow and shrubs	2.6
Meadow and shrubs	2.7
Shrubs	3
Shrubs, light forest and steppe	3.2
Shrubs and light forest	4
Shrubs and saplings	4.9
Shrubs and trees	5
Forest	tree height/2

technical possibilities to use more detailed data on plant cover although the resolution of irregular DEMs was close to 50 m. For statistical analysis we used the matrix step of 400 m.

The following question arises: whether the grid size of 400 m is adequate to explore the influence of quantitative topographical attributes on vegetation cover properties. For example, Quinn et al. (1995) confirm that TI has to be calculated using matrix steps ranging between 1 m and 50 m. Application of such grid sizes leads to the best prediction of a soil moisture content due to detailed recognition of individual hillslopes.

Naturally, small valleys and watersheds are lost using the matrix step of 400 m. At the same time, all the study sites include hillslopes with typical sizes of about 400 m (Figs. 2a, 3a, 4a, 5a). Consequently, the matrix step of 400 m corresponds to a certain scale (hierarchical level) of both vegetation cover and topography. So, the use of the indicated grid size within the frames of our study is quite correct. Additional reflections on functions of study scales and matrix steps are given in Section 4.

To estimate the topographic influence on "the vegetation cover distribution" linear correlative analysis of matrices of VEG and nine topographic variables namely h, G, A, k_h, k_v, H, CA, TI, SI was carried out for each study site. To describe the dependence of VEG on relief the "best" combination of topographic variables was chosen by the stepwise linear regression (Aivazyan et al., 1985). A 48-point sample was used for the Sekisovka area, a 54-point sample for the Berezovka area, a 57-point sample for the Ust-Feklistka area, and a 59-point sample for the Chistopolka area. Sample step was 400 m. Border effects were eliminated. Moreover visual comparative analysis of maps of VEG and topographic attributes (in particular, Figs. 2–5) was used.

VEG is a ranked variable so rank correlative analysis is more suitable to estimate the influence of topographic characteristics on "the vegetation cover distribution" (Aivazyan et al., 1985). However, to realize this procedure quantitative predictors (topographic variables) should be ranked. Solution of this problem is subjective, ambiguous and can lead to accidental errors in matrices of rank topographic variables. (VEG matrices already contain accidental errors which arise due to errors of (a) plant representation on topographic maps, (b) scene interpretation, and (c) vegetation cover type ranking). These can be reasons for artifacts. To decrease the possibility of their appearance linear correlative analysis between rank and quantitative variables was carried out.

It should be borne in mind that linear correlative analysis is only the first step in the investigation of the topographic influence on plant properties, because these relationships have a nonlinear character. Moreover, distributions of topographic variables are slightly different from normal law (Evans, 1980), so it is more correct to work not with coefficients but with indices of correlation (Aivazyan et al., 1985). However, the use of such statistical approaches is outside the scope of the present study.

Irregular DEM interpolation, calculation of topographic variables and mapping (Figs. 2–5) are realized by the software LANDLORD 2.0 (Florinsky et al., 1995). Correlative and regression analysis were carried out by the software STATGRAPHICS 2.6.

4. Results and discussion

The results of correlative and regression analysis are shown in Tables 4 and 5 respectively.

These results reflect obvious dependence of VEG on A and G which are the topographic variables responsible for insolation. There is a high positive correlation between VEG (Fig. 3f) and G (Fig. 3b) in the Berezovka area (Table 4). Here meadow plants grow in a gently sloping depression bottom, while bushes and silver fir forest grow on steep slopes. G is the independent variable in the VEG regression equations for the Berezovka and Chistopolka areas (Table 5). In the Chistopolka area a linear correlation between VEG and G is absent (Table 4). These facts testify to the nonlinear dependence of VEG on G within the Chistopolka area.

Significant correlations between VEG and A are found in all the areas except the Sekisovka area (Table 4), where natural vegetation cover is partially disturbed by human activity and fires. Nevertheless the dependence of VEG on A exists on the range slopes in the center of the area (Fig. 2b,e). On the northeast slopes there are bushes and light forests, while on the southwest slopes there is steppe. However, in other zones of this area there is no dependence of VEG on A, therefore on the whole the correlation between these parameters is absent in the Sekisovka area. In the south of the Berezovka area on the north and northeast slopes, and in the north of this area on the southeast slopes there are silver fir forests. In the east of the Berezovka area on the west, east and southwest slopes there are meadows and bushes (Fig. 3c,f). The influence of A on VEG in the Ust-Feklistka area is not significant. In the Chistopolka area VEG (Fig. 5e) depends in many respects on A (Fig. 5b) (Tables 4 and 5). Here shrubby steppes are situated on the southeast slopes, while silver fir and aspen forests are situated in the northwest and northeast ones.

Significant correlation between VEG and h is found in the Sekisovka, Berezovka and Ust-Feklistka areas (Table 4). h is the independent variable in the VEG regression equations for the Berezovka and Ust-Feklistka areas (Table 5). In principle, this can be

Table 4
Point and interval estimates of pairwise coefficients of correlation between "the vegetation cover distribution" and topographic variables

Topographic variables	Correlation coefficient (in brackets is significance level) and 95% confidence interval of the correlation coefficient			
	Sekisovka	Berezovka	Ust-Feklistka	Chistopolka
h	−0.36 (0.01) −0.58 to −0.10	0.68 (0.00) 0.48 to 0.80	−0.53 (0.00) −0.72 to −0.30	−0.10 (0.45) −0.38 to 0.18
G	−0.10 (0.48) −0.38 to 0.18	0.70 (0.00) 0.52 to 0.83	−0.01 (0.95) −0.30 to 0.27	0.00 (0.98) −0.31 to 0.29
A	−0.15 (0.32) −0.42 to 0.14	−0.40 (0.00) −0.62 to −0.14	0.22 (0.10) −0.06 to 0.48	0.54 (0.00) 0.30 to 0.72
k_h	−0.38 (0.01) −0.60 to −0.11	0.35 (0.01) 0.08 to 0.58	−0.26 (0.05) −0.50 to 0.03	0.00 (0.99) −0.31 to 0.29
k_v	−0.28 (0.06) −0.51 to 0.01	−0.40 (0.00) −0.62 to −0.14	−0.50 (0.00) −0.69 to −0.26	−0.11 (0.39) −0.39 to 0.17
H	−0.43 (0.00) −0.64 to −0.19	−0.04 (0.75) −0.32 to 0.24	−0.46 (0.00) −0.66 to −0.20	−0.06 (0.64) −0.33 to 0.22
CA	0.35 (0.06) 0.06 to 0.59	−0.31 (0.03) −0.53 to −0.06	0.46 (0.00) 0.21 to 0.64	0.24 (0.06) −0.02 to 0.48
TI	0.51 (0.00) 0.28 to 0.70	−0.40 (0.00) −0.62 to −0.14	0.49 (0.00) 0.24 to 0.68	0.13 (0.33) −0.16 to 0.40
SI	−0.11 (0.47) −0.38 to 0.18	0.61 (0.00) 0.40 to 0.78	−0.21 (0.11) −0.47 to 0.08	−0.07 (0.58) −0.34 to 0.22

connected with the altitudinal zonality of plants in mountain regions. The biggest absolute correlation coefficient is found for the Berezovka area where human loading is practically absent. The positive correlation is due to the predominance of flood-plain vegetation in the depression bottom. With increasing elevation bushes and light forests start to appear on the slopes and change to silver fir forest (Fig. 3a,f). In the Ust-Feklistka area aspen groves prevail in valleys, while shrubby steppes are typical of sun-burnt watersheds (Fig. 4a,d). Therefore the correlation between VEG and h is negative here (Table 4). In the Sekisovka area the correlation coefficient between VEG and h is negative too (Table 4). However, this is valid mainly for the west and the south of the area. Here at altitudes around 700 m there is steppe, while on the west and northwest slopes (altitudes about 450–500 m) there are bushes (Fig. 2a,e). At the same time, the northeast slopes in the center of the area exhibit reverse dependence. Notice, that this "reverse dependence" is just natural for the Sekisovka area. It is situated on the border between steppes and mountains and should normally be characterized by positive correlation between h and VEG. However, this is the developed area, where

Table 5
Parameters of regression equations describing the dependence of "the vegetation cover distribution" on topographic variables

Study sites	Independent variables	Coefficients	Significance levels	95% confidence intervals	R^2
Sekisovka	TI	0.46	0.00	0.23 to 0.69	
	Constant	−1.91	0.08	−4.06 to 0.24	
					0.26
Berezovka	h	0.02	0.00	0.01 to 0.03	
	G	0.32	0.00	0.17 to 0.48	
	k_v	−1742.11	0.02	−3287.82 to −196.39	
	Constant	−26.82	0.00	−39.18 to −14.46	
					0.68
Ust–Feklistka	h	−0.007	0.00	−0.01 to −0.005	
	Constant	7.55	0.00	5.63 to 9.47	
					0.27
Chistopolka	A	0.03	0.00	0.02 to 0.04	
	G	−0.26	0.01	−0.45 to −0.07	
	Constant	0.56	0.64	−1.79 to 2.91	
					0.37

high human activity (i.e., burning of forests in agricultural purposes) has led to such big changes in the vegetation cover that the correlation coefficient actually reflects these alterations.

Note, however, that due to relatively insignificant h amplitude (200–500 m) the altitudinal zonality of plants should not be much expressed in the study sites. Here differentiation of phytocoenosis properties can exhibit a greater dependence on differences in soil moisture. Such differences are in many respects controlled by landsurface curvatures, non-local and combined topographic variables (see Introduction). Rather a high correlation between VEG and h (Table 4) is probably the result of the dependence of vegetation cover on CA: h is taken into account in CA calculation in a hidden form (Speight, 1968; Quinn et al., 1991).

Indeed, VEG is in good correlation with H, k_h, k_v, CA and TI in almost all the areas (Table 4). k_v is the independent variable in the VEG regression equation of the Berezovka area. TI is the variable in the equation of the Sekisovka area (Table 5). In the Ust-Feklistka area, in moist valleys (H, k_h and k_v have negative values, CA and TI have high values), there are mainly aspen groves, while on watersheds (H, k_h and k_v have positive values, CA and TI have low values) there are shrubby steppes (Fig. 4b–d). In the Sekisovka area bushes and light forests prevail in more moist zones, while steppes predominate on watersheds (Fig. 2c–e). In the Berezovka area the more moist depression bottom possesses flood plain vegetation, while dry watersheds and slopes have bushes and silver fir forests. Here the most clear-cut is the correlation between VEG

(Fig. 3f) and CA, k_v (Fig. 3d) and TI. In the south and the northwest of the area silver fir forests grow in the zones with low values of CA and TI. In the depression (high values of CA and TI) meadow plants are situated. In the Chistopolka area correlation between VEG and CA is not high, and between VEG and TI is not found (Table 4). However, visual analysis of these maps (i.e., Fig. 5c,e) shows that some of the aspen and silver fir forests grow in zones characterized by high values of CA and TI.

Significance dependencies of VEG on SI are found within two areas. In the Berezovka area this dependence is described by the high correlation coefficient (Table 4) and can be recognized by a visual analysis of SI and VEG maps (Fig. 3e,f). Meadow plants are situated in zones with low and mean values of SI (potential erosion is low), while patterns of silver fir forests grow in zones with high values of SI (potential erosion is high). In the Chistopolka area a numerical correlation between VEG and SI is absent (Table 4). However, patterns of shrubs are on the whole situated in zones with mean and low values of SI. At the same time, some patterns of aspen and silver fir forests correspond to high values of SI (Fig. 5d,e). These results can indicate some relationships between vegetation properties and erosion classes of landscape.

The VEG regression equations (Table 5) explain from 26% to 68% of the variability of measured values of "vegetation cover distribution". It is unlikely we can obtain better values of R^2 because we took into account only the topographic factor of plant cover development. Factors of microclimate, geology, soil and anthropogenic loading were not taken into consideration. Moore et al. (1993) have obtained similar results for the topographic control of soil cover properties.

The results obtained show that in vegetation studies one should not restrict oneself to only three quantitative relief characteristics namely h, G and A. In some cases (especially at small h amplitude) it is just the landsurface curvatures, non-local and combined topographic variables that influence significantly the phytocoenosis properties. Notice that using k_h, k_v, H, CA and TI for soil moisture estimation is more theoretically justified than utilization of "moisture mask" (Warner et al., 1991) or "topographic moisture gradient" (White et al., 1995). It is obvious that the topographic control of vegetation properties is realized differently in different terrains (Figs. 2–5; Tables 4 and 5). For example, in arid regions plant properties can significantly depend on flow convergence intensity which is controlled by k_h, while in boreal regions it can depend on insolation controlled by G and A. Thus only after realizing the test studies is the correct use of topographic data possible for forecasting vegetation properties (Tom and Miller, 1980; Moore et al., 1988; Paradella et al., 1989) or for vegetation mapping (Shadrina, 1987). Obviously, topographic attributes can be utilized not only in uncombined form, but can also be included into some mixed models, as for instance TI was used in investigation of forest canopy net photosynthesis and total evapotranspiration (Band et al., 1993).

Clearly not all the vegetation cover properties depend on the topographic parameters to the same extent. The numerical results of our study (Tables 4 and 5) enable one to estimate *the trends* of the topographic influence on the vegetation cover and to make a certain approximation of real dependencies. In changing the study scale and the biogeocoenosis hierarchical level the character of these dependencies can also change. As landscape and its components, particularly vegetation, have to be viewed in their hierarchical context (i.e., De Boer, 1992), it is necessary to use ranks of study scales and matrix steps. Unfortunately, we were restricted in the choice of both the plant cover properties to be analyzed and the matrix step due to the character and resolution of initial vegetation data. We stress the importance of the proper choice of the matrix step. For example, if the typical size of relief elements which control vegetation properties differs significantly from the matrix step chosen this control can hardly be identified. Unfortunately, the optimal scale rank for investigations of the topographic influence on vegetation is unknown. This problem can be solved only by an expert estimation. So any solution can include elements of subjectivism. A similar problem exists also in soil studies (Moore et al., 1993).

The results obtained (Table 4) shows that in some cases the vegetation properties can depend more on CA, TI and SI than on the local topographic variables. This derives from the fact that non-local and combined relief attributes take into account the relative location of an area in a landscape, so they can better determine topographic prerequisites of substance motion. This regularity was earlier found for the soil cover (Speight, 1980; Moore et al., 1993; etc.). This is not to say that the local topographic variables can be neglected. Local and non-local topographic variables are connected with denudation processes at different hierarchical levels. So the character of relationships between these two groups of relief attributes and landscape properties depends on the study scale, matrix step (Anderson and Burt, 1980) and terrain type. Therefore the discussion of the dominance of a certain topographic variable groups in the origin and development of landscape components (Speight, 1980; Anderson and Burt, 1980) seems to be of little value. These variables complement each other. Note that the use of TI, SI and some other combinations of local and non-local characteristics is something of a compromise of the two scientific approaches.

Obviously, the dependence of phytocoenosis properties on topographic variables can be more clear-cut in regions (a) with contrast relief and (b) where properties of other factors–prerequisites of vegetation cover origin and development change relatively little. This is particularly the case for geology and climate but is not especially true of soils. Soil properties also depend on topographic variables and "transfer" this dependence to vegetation cover.

The dependence of plant properties on topography (and other natural factors of phytocoenosis origin) is on the whole smaller within developed areas or within areas that suffer from occasional loading (i.e., fire) than within virgin areas. Probably, the traces of the influence of landsurface curvatures, non-local and combined topographic attributes may survive longer due to high sensitivity of vegetation to soil moisture differences. Therefore to estimate extent destruction of natural plant cover we can probably analyze correlation coefficients between vegetation and relief characteristics corresponding to disturbed and test areas of the same landscape type. The restoration dynamics of the vegetation cover can probably be estimated by a comparative analysis of correlation coefficients obtained for several years.

Data on quantitative topographic variables can be useful in plant investigation not only due to direct the influence of relief on phytocoenosis properties. For example, in k_h and k_v maps (Figs. 2c, 3d, 4b) lineaments and parts of ring structures are well recognized. At the same time, these structures are not on the whole recognized in h

maps (Figs. 2a, 3a, 4a). This is quite natural because just k_h and k_v quantitatively determine topographic indicators of lineaments and ring structures (Florinsky, 1992). The structures recognized are probably connected with faults and some other geological structures which influence soil and vegetation cover properties (Vinogradov, 1955; Kovda, 1973; Kuryakova and Florinsky, 1991). Unfortunately, the character and resolution of geological and vegetation data used have not allowed us to study the influence of geological organization on the plant cover properties.

We have to mention the other local topographic variable namely total accumulation curvature (K_a). This is a product of k_h and k_v (Shary, 1992). Combined employment of K_a and H allows us (a) to forecast zones of denudation, transit and accumulation of flows (i.e., water, salts, other dissolved and solid substances) and (b) to estimate an intensity of accumulation processes (Florinsky, 1995). K_a negative values correspond to flow transit zones, K_a positive values with H negative values correspond to flow accumulation zones, while K_a positive values with H positive values correspond to flow denudation zones. Obviously, this information can be useful in plant investigations. Moreover, combined employment of K_a and H digital models can be applied to recognition of faults intersection zones (Florinsky, 1993). Concentration of water, salts and microelements can be abnormally high there due to vertical migration of deep hydrothermal solutions and gases and outcropping of artesian mineralized waters (Florinsky, 1995). These geological factors can also influence plant cover properties, so utilization of K_a can be useful in vegetation studies. However, the estimation of the efficiency of K_a employment in plant investigations is outside the scope of the present study.

5. Conclusions

1. The comparative analysis of the influence of nine local, non-local and combined topographic variables on some vegetation cover properties is carried out.

2. Differentiation of plant properties depends on relief parameters, namely landsurface curvatures, CA, TI and SI which control in many respects the conditions of water migration and accumulation in landscape by gravity.

3. In some cases the phytocoenosis characteristics can have a higher correlation with non-local and combined topographic variables than with local ones. This derives from the fact that CA, TI and SI take into account a relative location of an area in a landscape, so they can better determine topographic prerequisites of substance motion.

4. It is worthwhile using digital models and maps of k_h, k_v, CA, TI and SI in plant investigation. Particularly it can be useful for:

— better understanding of relationships between landscape components;

— improving vegetation surveying and mapping;

— more correct modelling and forecasting the vegetation cover properties in natural and anthropogenic landscapes;

— estimating the destruction and restoration dynamics of the vegetation cover;

— analyzing the geological organization influence on phytocoenosis properties.

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