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Hierarchical Grouping of Sub-Watersheds in Bhama Basin for Soil Conservation Planning, a GIS Approach

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Abstract

Prioritization of watersheds helps in taking up soil conservation measures on priority basis. Identification of erosion-prone areas within sub-watersheds helps determine our priority to evolve appropriate soil conservation management strategy. A GIS-Remote Sensing based integrated modeling approach utilizing terrain, climatic and landuse parameters controlling soil erosion in a watershed is the effective means of practical assessment of soil erosion hazard. Composite Erosion Index (CEI) based on landuse changes in their areal extent, slope magnitude and rainfall erosivity on sub-watershed basis for Bhama watershed, a part of Bhima basin is developed for qualitative assessment of soil erodibility of the landscape.

Introduction

It is well accepted that environment and development are interlinked and that certain types of economic development produce negative impacts on the environment and primary productivity. These problems are often ignored as the need for immediate economic benefit blinds us to their impact on the environment. The degradation of the environment is basically attributed to increasing biotic pressure on the fragile ecosystem in the absence of adequate investment and appropriate management practices to augment and conserve the land and water resources. For this, watershed, a natural geohydrological unit of land is adopted for management of basic natural resources; soil and water. A watershed is the natural integrator of processes such as precipitation, runoff, erosion, sediment discharge and deposition as they relate to input and output in an open hydrological system. Land use changes cause havoc with these watershed functions. Denuded watersheds have given rise to higher flood peaks in the rainy season, while during the dry season they have low discharge potential. Erosion processes increase with the thinning of vegetal covers thus threatening the productivity of cropland and the existence of costly reservoirs. Protective measures need to be adopted for watersheds to reduce erosion rates, siltation and for the application of proper practices to increase and stabilize crop production. Against this backdrop, the present study attempts by applying remote sensing and Geographic Information System (GIS) technologies to prioritize sub-watersheds in the upper Bhama basin, Pune district, Maharashtra

State (Figure 1) on the basis of their vulnerability to soil erosion for soil conservation planning.

Data and Methodology

Environmental indices viz., rainfall erosivity, slope and temporal changes in landuse / landcover relating to the vulnerability of sub-watersheds (SW) in Bhama basin to soil erosion have been computed by using the following data and methodology.

Timely and reliable information is essential for effective land use assessment and management. Remote sensing due to inherent repetitive synoptic data coverage and excellent spatial, spectral and temporal qualities is best suited for monitoring land use in its spatio-temporal variability. The study makes use of conventional topographical maps (47 F/9 on 1:50000 scale) as well as remotely sensed data in digital format obtained from National Remote Sensing Agency (NRSA), Hyderabad as given below.

No	Scale	Path/Row	Sat-ID	Sensor	Product Date
1	1:50000	030/055	IRS 1A	LISS II	Oct 23, 1988
2	1:50000	030/055	IRS 1B	LISS II	Jan 12, 1998

The above data was supported by ground information gathered during several field visits to the study area. From the SOI topographical map boundary, drainage and contour maps were prepared. Slope of the land is an important determinant of magnitude of soil erosion and the quantum of sheet and gully erosion is closely related to the slope characteristics. Slope map is prepared by using Miller method as given below;

$$\tan\theta = (Y-Z)/D$$

where θ = slope in degrees, Y = height of the highest point in meters, Z = height of

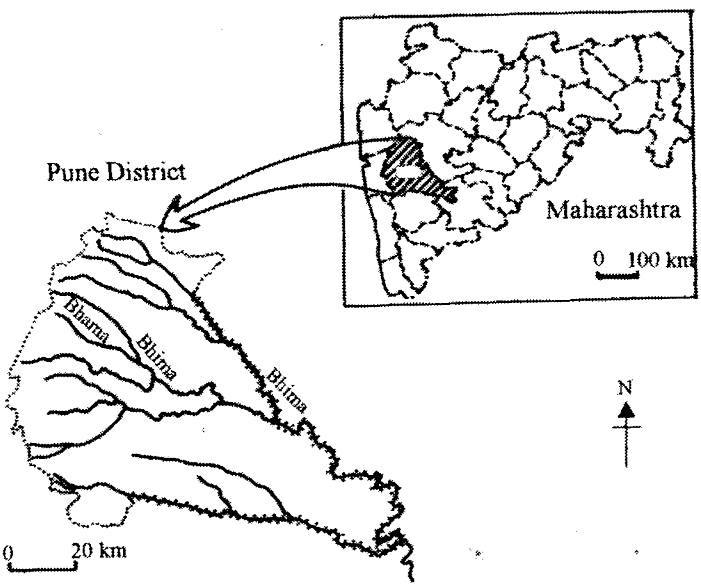

Figure 1: Location map

the lowest point in metres and D = distance between highest and lowest points in metres. The entire basin area was divided into 1 km grid units and in each unit tan q in percentage is worked out and isolines of maximum slope are drawn.

Daily rainfall data for 10 consecutive years from 1986-1996 for 7 stations within the area were obtained from the Irrigation Department, Government of Maharashtra. Thiessen polygon method was used to transform point rainfall data to areal rainfall data for 7 rain gauge stations in the area in which basin area was subdivided into polygonal subareas taking rain gauge locations as centres. The annual average rainfall values based on 1986-96 were processed using an empirical equation given by Singh et al. (1981);

$$Y = 79 + 0.363x$$

where, y = average annual erosion index and x = average annual rainfall (mm). The equation derived from several field studies conducted in varying climatic environments in India takes into account kinetic energy of the storm and 30 minute intensity of rainfall and provides erosivity index for the given annual rainfall of a place.

A Window based Geographic Information System (GIS) software IDRISI version 4.0 is used to perform the digital image analysis (DIP) of the Bhama basin. The term DIP refers to the use of computer to manipulate image data stored in digital format. By applying mathematical transformation to the Digital Numbers (DN represent intensity of reflected light in the visible, infrared or other wavelengths.), IDRISI can enhance image data to highlight and extract subtle information that would be otherwise impossible using traditional manual interpretation techniques.

Satellite data of 1988 and 1998 were band-interleaved-by line (BIL) format for four bands. When viewed each band image appeared dark with a poor contrast and the human eye would not be able to discriminate the details. Hence we applied contrast stretching using a linear contrast stretch to modify the dynamic range of the image to suit the response of the human eye. By combining the stretched bands False Colour Composite (FCC) was created in which red colour was assigned to infrared, green was assigned to red and blue to green bands hence it appeared as false colour showing vegetation in red colour. Drainage and road maps of Bhama basin prepared from toposheet were scanned in bitmap format and later converted into image format in IDRISI. After selecting the co-ordinates of locations known as ground control points (GCPs) the drainage and road maps were resampled with the geocoded FCC. The vector files were created by onscreen digitization of roads and drainage and were overlaid on the FCC. In the field, on this FCC and also the toposheet, homogeneous and fairly large sites (called training sites) for all land use and land cover classes were marked.

Figure 2 indicates the methodology of supervised classification adopted in this study to generate classified image of the Bhama basin. It included the following steps: I) Locating well-distributed and adequate number (at least 25) of representative samples of each land use and land cover type in the image. II) Checking the overlaps and intersections in DN ranges, i.e. separability of each cover type to maintain

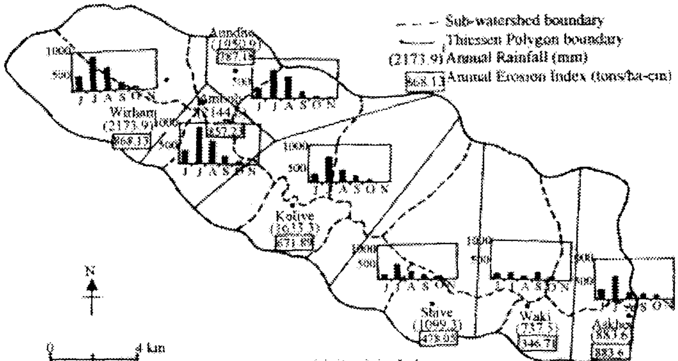

Figure 2: Rainfall Erosivity Index

the accuracy and homogeneity of training sample sets. III) Using Maximum Likelihood Classifier, the entire region is classified. This classifier evaluates the probability that a given pixel will belong to a category and classifies the pixel to the category with the highest probability of membership. IV) The classified image was checked in the field for assessment of accuracy of classification. The process was reiterated till it offered more than 85% accuracy in land use/ land cover pattern. The image of 1998 was classified into following seven categories: evergreen forest, deciduous forest, scrub, pasture, single cropped, double cropped, cliff and wastelands. The image of 1988 was also classified using the same procedure mentioned above. In GIS area under all the categories were measured for both the temporal data sets for the basin as a whole as well as for the 12 sub-watersheds.

Scanning, geocoding and onscreen digitization processes were repeated in GIS for the sub-watershed, slope and rainfall erosivity index maps, and areas under each of slope and erosivity index classes were measured according to sub-watersheds.

Weights ranging from 1 to 5 increasing with the proneness of the area to soil erosion were assigned for the rainfall erosivity, slope and seven land use classes. As the area of SWs varies from 849 to 3374 ha, the weights were converted to per hectare basis as follows:

$$V_{ij} = (x_{ij} / X_j) * Wi$$

where, V_{ij} = vulnerability quotient for ith class in j^{th} sub-watershed, W_i = weight for the i^{th} class, x_{ij} = change in area for i^{th} class in j^{th} sub-watershed (ha) for land use and area under ith class for slope and rainfall erosivity index and X_j = area of j^{th} sub-watershed (ha). The Composite Erosion Index (CEI) for the j^{th} sub-watershed was obtained by adding V_{ij} values for all attribute classes. Based on the CEI, twelve sub-watersheds were grouped hierarchically into one of the three classes.

Results and Discussion

Setting of the upper Bhama basin: Geographically the Bhama basin (area ~19000 ha) is a part of Bhima basin; lithologically it belongs to the Deccan Trap region and geomorphologically it is characterized by a polycyclic landscape. The western part of the basin is rugged comprising of the Sahyadri ranges with many peaks rising above 1000 metres. Variation in altitude from source to mouth is 1000 to 640 metres and landform features range from escarpment, mid-slope, scree slope to pediment slope. River terrace is almost absent. Pediment slopes are dissected by tributary valleys giving a basin and flat-topped interfluve topography. Average annual rainfall increases from east (884 mm) to west (2174 mm) and is marked by unimodal distribution with July maximum. The region receives most of the rainfall during the southwest monsoon season therefore Bhama is a seasonal river.

Most of the area is under the cover of black cotton soil of varying depth, developed from basalt rocks. Very shallow (<7.5 cm), shallow (7.5-25 cm), medium deep (25-50 cm), deep (50-100 cm) and very deep (>100 cm) soils roughly correspond to scree and mid-slope, pediment and river channels respectively. In response to changing slope, rainfall and soil natural vegetation of the region varies from dense open forest to scrub and pastures. Rocky surfaces of escarpments are devoid of vegetation cover.

Environmental Indices: Rainfall erosivity-Erosivity of rainfall is a crucial parameter that determines erosion proneness of a SW. The index estimates erosive force of rainfall on soil in tons ha-1-cm. Maximum rainfall erosivity is found in the source SWs - 868 tons ha-1-cm decreasing towards the mouth of Bhama river - 347 tons ha-1-cm (Figure 2). Area weighted rainfall erosivity index for each SW was calculated.

Effect of slope: It is the well-established fact that if the slope increases, the erosion rate also increases. Left-bank region has slope <10%; interfluvial mesa-like areas of tributaries are steep >20% with flat tops, and ridge slopes are very steep, their slope ranging from 20 to 40% (Figure 3). Ridge to valley gradient on the right bank is steeper than that on the left bank. Area weighted slope index for each SW was calculated.

Landuse/Land cover classes: Interpreting the colour scheme, signs and symbols used in the toposheets, five broad classes like forest, scrub, pasture, crop and barren land were identified and a preliminary land use map was prepared. During the field visit additional classes like cliff, single and double cropped areas, current fallow, dense and open forests and wastelands were marked on the base map. The study area thus exhibited 9 cover categories viz., cliff/escarpment, dense forest, open forest, scrub, pasture, single-cropped, double-cropped, current fallow and wasteland.

Dense forests are observed on the higher slope of the ridges, open forests on the middle slope. Scrub areas relate to degraded forest areas with <10% tree cover, ~60% scrub and ~30% grass cover are growing on the pediment slopes. The post-monsoon season sorghum is referred to as a single crop in this study, as the field is kept fallow during the monsoon season and sorghum is planted using the stored soil moisture. Paddy fields largely grown on terraces along the monsoonal tributary streams in the foothills of the upper reaches of Bhama river are also used for wheat cultivation in the post-monsoon season, and hence are taken as double cropped areas. Current fallow refers to the ploughed but uncultivated field for the cur-

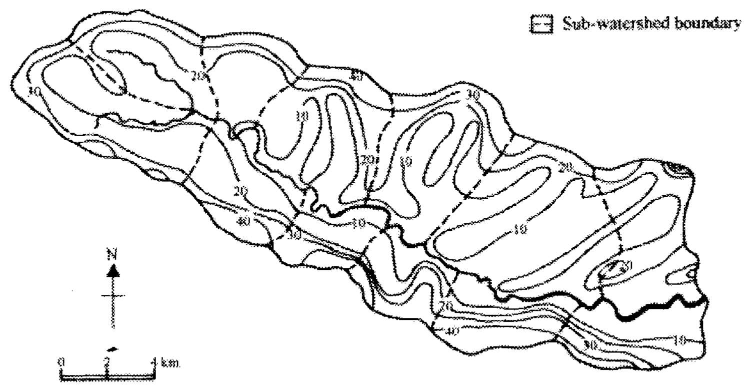

Figure 3: Slope Map (%)

rent year. Pastures are the natural grassy areas, described in the Census Handbook as culturable waste were found on the scree slopes and pediment. They become green in the rainy season; after cessation of rains they turn yellow-brown with an approaching summer. Two types of wastelands where biomass is almost nil are exposed stony waste on pediments in downstream direction in the upper part and severely eroded channels (ravines and gullies) in the lower part of Bhama basin.

Digital image analysis: Geocoded digital data for 1988 and 1998 obtained from IRS satellites in geocoded format for toposheet no. 47F/9 have been processed in IDRISI. After contrast stretch of green, red and infrared bands FCCs were prepared. Using various elements of image interpretation like size, shape, pattern, texture, association etc. visual interpretation was carried out. In FCC vegetation appears red, water appears deep blue and black arches in the ridge zone indicate cliff or escarpments while red colour along the streams confined narrow valley fills represent agricultural fields. Based on the understanding of association between gray level intensity and land cover types obtained from ground truth we created training sites for each land use category and classified image of 1998 was obtained. This classified image (Figure 5) was again verified for locations and extensions of various land cover classes by the ground truth data. The procedure was repeated till at least 85% accuracy in land use/land cover pattern was noted. By using the same spectral signatures 1988 image was also classified.

Temporal change in landuse/landcover: Tables 1 and 2 denote areas (%) under different land use/land cover classes calculated in GIS according to Bhama basin as a whole and sub-watersheds.

Over the decade, in Bhama basin area of dense and open forests have decreased by 5% and 2% respectively while that of scrubland has increased by 2.5%. The latter change is due to felling of trees in relatively more accessible open forest areas where regrowth is often in the form of short, sparse trees predominantly mixed with shrubs and bushes. With the increasing cattle population and unrestricted grazing activities, pasture areas (which usually are common property resources - CPRs of a village) have degraded from 22% to 10%. Total cropped areas (single+double+current fallow) increased from 35% to 50% indicating intensification of agriculture in the basin. Decreasing vegetal cover in the ridge zones enhances runoff and soil loss under the humid hilly conditions resulting into gully formation. The study brought out 3.5% increase in area under wastelands during the decade under consideration. Such a changed scenario has revealed the increase in cliff areas due to the occurrences of landslide.

Areas under various landuse / landcover categories according to sub-watersheds are depicted in Table 1&2. Areas under single crop, double crop, fallow and wastelands have increased. An exception forms SW 6 and 7 near the mouth of Bhama river where the area under wasteland has decreased by some 15%. Large areas from these SWs have been evacuated for dam related construction works which are not discriminated from the rest of the cover classes. This has resulted into a large anamolous reporting of reduction of wasteland in those SWs. However, in SW 8 and 9 restoration of some 5% of ravenous wasteland has been noted which can be attributed to the implementation of various soil conservation practices like nalla bunding by fabricated shutters, stone bunds across the pediment slopes and afforestation in these areas.

Temporal change in area (in hectares) was divided equally in to five parts. The assignment of weights for the five categories of each class was based on their contribution to the erosion processes in making the SWs vulnerable for loss of soil; this relationship is indicated in the table given below. On the basis of weights and change in areas of landuse/landcover, area weighted index indicating vulnerability of the given SWs to soil erosion was computed. (Table 3)

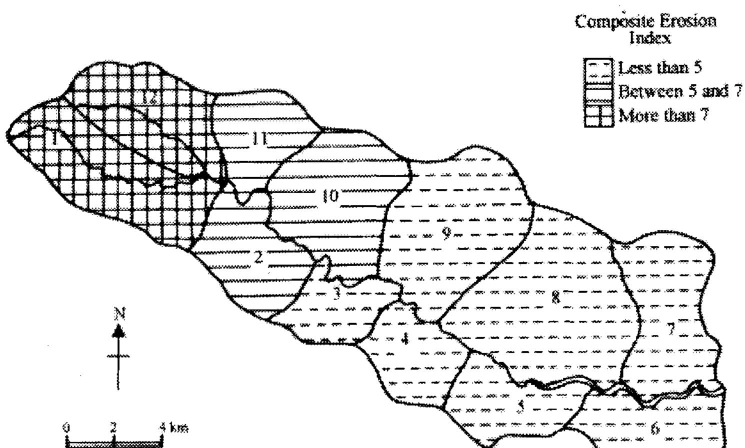

Figure 4: Eco-zones of Bhama watershed

Table 1 **Area under landuse/ landcover (%) - 1988**

Sub-Ws	Cliff	Dense forest	Open forest	Scrub	Pasture	Single Crop	Double Crop	Current Fallow	Waste Land
1	3.0	5.2	9.0	2.6	0.7	10.4	2.5	30.2	37.7
1	6.1	13.5	9.4	0.1	37.9	1.1	0.3	9.7	20.7
2	0.9	5.7	9.9	0.8	38.0	2.6	0.8	23.1	18.4
3	1.3	10.0	13.6	0.6	23.5	1.7	0.8	27.5	15.5
4	0.5	6.3	10.6	1.8	28.4	2.2	1.5	23.0	18.9
5	0.9	8.1	8.4	1.6	37.6	2.6	1.6	20.5	16.5
6	0.5	11.3	3.6	0.8	23.9	0.8	0.9	19.4	37.2
7	0.1	10.7	1.5	0.1	27.7	0.05	0.2	21.7	37.7
8	0.2	7.8	3.4	0.8	36.3	0.2	0.3	24.7	24.4
9	0.3	3.8	4.3	2.8	39.9	1.2	1.9	25.3	19.1
10	0.4	2.4	3.2	1.7	41.5	1.6	1.1	29.9	18.4
11	0.05	6.2	6.6	0.9	38.6	3.1	1.8	26.5	17.8
12	0.1	12.5	16.9	0.9	33.0	3.3	1.4	16.8	14.2
Total	**0.4**	**9.3**	**6.5**	**6.2**	**22.2**	**4.0**	**0.9**	**30.7**	**19.7**

Table 2 **Area under landuse / landcover (%) - 1998**

Sub-Ws	Cliff	Dense forest	Open forest	Scrub	Pasture	Single Crop	Double Crop	Current Fallow	Waste Land
1	3.0	5.2	9.0	2.6	0.7	10.4	2.5	30.2	37.7
2	2.0	1.9	5.1	4.0	5.2	18.5	4.5	31.9	26.4
3	2.5	2.2	6.1	5.9	2.2	15.2	3.8	31.5	26.9
4	2.8	2.5	1.7	9.5	6.8	19.9	3.8	38.6	19.6
5	6.2	3.3	1.2	5.0	5.6	10.3	3.0	33.8	32.6
6	1.0	9.4	0.1	13.4	8.3	8.5	0.9	38.4	20.8
7	0.8	8.6	0.01	12.5	6.4	8.5	1.7	40.0	19.5
8	0.2	5.0	0.03	12.5	14.4	9.1	2.0	36.5	18.8
9	0.4	1.9	0.1	13.3	20.5	16.8	2.7	30.9	13.6
10	1.2	0.8	0.2	4.5	16.0	24.1	4.0	25.1	22.8
11	0.5	1.0	0.2	5.4	10.5	20.8	0.1	26.1	26.6
12	1.1	3.8	5.4	10.2	2.2	18.7	7.5	27.9	23.9
Total	**1.5**	**4.0**	**4.2**	**8.9**	**9.7**	**14.5**	**3.3**	**32.6**	**23.2**

Eco-zones

Table 4 shows the integrated as well as specific indices derived for slope, rainfall erosivity and landuse categories on per hectare basis for 12 sub-watersheds in Bhama basin. Based on Composite Erosion Index, SWs are classified and prioritized into 3 eco-zones (Figure 4), which are the clusters of SWs, having common environmental characteristics. Such an exercise would help us to design an action plan for management of land resources to minimize risk of the given region to soil erosion.

The results of classification and prioritization are given below:

Priority class	CEI	Sub-watersheds
P1	> 8	1, 12
P2	6 - 8	2, 10, 11
P3	< 6	3, 4, 5, 6, 7, 8, 9

Sub-watersheds in Priority 1 (P1) cluster exhibit intense rainfall erosivity, steepness and reduction in dense forests while those in Priority 2 (P2) cluster face in addition to the above factors reduction in pastures also. Sub-watersheds 3 to 9 are in the sequence of lower priority for the management of their land resources. They are situated in the lower reaches of Bhama basin and are characterized by extensive scrub growth resulting from destruction of trees and grass cover on the lower slopes and pediment due to developmental activities like roads, dam site, workshop and colonies etc. The out-migration to the cities from these SWs has resulted in widespread fallowing of croplands, which is reflected in the large area-weighted index for fallow.

Table 3 **Relationship of change in area in various classes versus vulnerability to soil erosion**

Classes	Nature of relationship	
	Direct	Inverse
Dense forest		*
Open forest		*
Scrub	*	
Single-cropped	*	
Double-cropped		*
Current fallow	*	
Pasture (grassed area)		*
Wasteland	*	

Recommendations

Considering area-weighted index values for erosion proneness of the various parameters indicated in Table 4, recommendations to control soil loss have been outlined (Table 5).

A - Plantation in the upper slopes;

B - Plantation in the lower slopes;

C - Gully plugging by stone and/or live bunds;

D - Protection to CPRs and

E - Mulching of single cropped areas.

Priority 1 (SWs 1 and 12) should be adopted by the GOs and/or NGOs for implementation of recommended measures so that beneficial impact would infiltrate downstream eventually.

Table 4**Environmental Indices**

SW	Dense forest	Open forest	Scrub	Past-ture	Single Crop	Double Crop	Current Fallow	Waster Land	R`fall Fallow	Erosive Slope	CEI
1	0.41	0.01	0.02	1.49	0.18	0.09	1.03	0.85	3.9	2.2	10.2
2	0.11	0.14	0.03	1.31	0.47	0.11	0.26	0.24	2.6	1.7	7.0
3	0.23	0.23	0.05	0.07	0.27	0.12	0.04	0.23	2.1	1.8	5.1
4	0.08	0.27	0.15	0.43	0.32	0.09	0.47	0.01	1.9	2.0	5.7
5	0.16	0.22	0.03	0.96	0.06	0.07	0.4	0.64	1.3	2.0	5.8
6	0.12	0.07	0.38	0.31	0.07	0.005	0.76	0.16	0.8	1.6	4.2
7	0.04	0.01	0.62	0.64	0.12	0.06	0.91	0.18	0.7	1.1	4.4
8	0.11	0.14	0.59	1.09	0.11	0.05	0.59	0.06	1.0	1.0	4.7
9	0.04	0.17	0.53	0.78	0.57	0.04	0.17	0.05	2.0	1.4	5.7
10	0.03	0.09	0.06	1.02	1.08	0.09	0.1	0.09	2.6	1.4	6.5
11	0.16	0.19	0.04	0.56	0.35	0.16	0.005	0.18	2.9	1.7	6.2
12	0.44	0.57	0.28	0.92	0.46	0.06	0.33	0.29	4.1	2.1	9.6

Table 5 **Recommended Strategy**

SWs	Practices				
	A	B	C	D	E
1	*		*	*	*
2			*	*	
3	*	*	*		
4		*		*	
5		*		*	
6		*			*
7		*		*	*
8		*		*	*
9			*	*	*
10			*	*	*
11			*	*	*
12	*	*	*	*	*

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