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Mapping Environmental Health: Choice of Data Organisation and Colour Schemes

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Abstract: *The term 'health' to denote wellness or well-being e.g. its use for 'economic health' with respect to communities in a spatial entity was first used by Thompson J. H. et al. in case of New York State. The other such usage are 'health of oceans', 'financial health', 'ecological health' or 'health of ecosystem'. The present paper, in an effort to add a more holistic scope to the term health, attempts to extend the term's sphere of connotation to include environment too and use it to denote the different states of environment's wellness. The paper aims to find a data organisation which is compatible with environment health data sets and select a classification routine which matches this organisation. In addition, an attempt is being made lay down a map design approach, particularly in the area of symbolisation related to colour choices. The variables or indicators of environmental health are grouped into indicators related to (1) environmental systems (2) environmental stresses and (3) human vulnerability. Indicators in the different groups can be combined, by a suitable statistical routine, into an index which could function as a numerical or digital measure that expresses the state of the health of environment. Environmental health status data have a divergent spatial structure. Data in such structures diverges in ascending negative and positive values from a critical or normal value in geospace. This data mapped through cartographically and perceptually organised dimensions of colours provide the most effective way of apprehending information from data visualisations. Selection of organised and ordered paths across multidimensional colour models such as Munsell which result in creating logical progressions of colour have been selected and are suggested to map this kind of data.*
Key Words*: *Diverging Data, Diverging Colour Schemes, Environmental Health, Environmental Stresses, Human Vulnerability,

I. Introduction

In academic usage, other than medical sciences, the term 'health' is used to denote wellness or well-being e.g. its use for 'economic health' (Thompson J. H. et al. 1962 [1]) with respect to communities in a spatial entity. The other such usage are 'health of oceans', 'financial health', 'ecological health' or 'health of ecosystems'. Similarly the present paper, in an effort to add a more holistic scope to the term health, attempts to extend the term's sphere of connotation to include environment too and use it to denote the different states of environment's wellness.

WHO uses the term in its rather restricted medical denotation where Environmental Health is defined by them as: 'Environmental health addresses all the physical, chemical, and biological factors external to a person, and all the related factors impacting behaviours. It encompasses the assessment and control of those environmental factors that can potentially affect health. It is targeted towards preventing disease and creating health-supportive environments. This definition excludes behaviour not related to environment, as well as behaviour related to the social and cultural environment, and genetics.'

However, WHO in their other literatures while referring to a state of environment, in its conversion as an adjective from noun as healthy, uses it to mean a clean environment. In its wider connotation the term is also used to signify 'a flourishing condition or well-being'.

Park (1980 [2]) defines environment as an aggregate of all conditions which surround man in a given area in geospace and a point in time. This aggregation, in the current context, includes all the elements, processes, living and non living things together with their interrelationships around a living organism which bear upon its life.

This aggregate i.e. the environment of any organism is made up of two components, living and non-living. The living component is known as **biotic** and includes the organisms themselves, i.e. human beings, plants, animals, and other living organisms, their food and their interactions. The second component is the non-living, known as **abiotic** which includes such items as sunlight, soil, air, water, land, climate etc. The term environment, in its widely understood meaning thus refers to 'the complex of climatic, edaphic (soil-based), and biotic factors that act upon an organism or an ecologic community.

The concept of environmental health is formulated here as a state of environmental system which is in the condition of being well, is clean, is free from any kind of possible damage, degradations and stress and has a stability that is sustainable. In addition, this paper puts forward that a healthy environment has an ability to maintain its structural components, and has a vigorous functional dynamism over time which is resilient to conditions of degradation, external and internal stresses and human vulnerability. This concept is measurable and can be reckoned in terms of a group of variables or indicators that denote the state of wellness, damage and degradation together with stresses and stability, and human vulnerability.

The emergence of awareness about environmental degradation and environmental stresses with a focus on environmental wellness or health which seeks to answers the what-where and how much questions lead to the efforts for the identification of systems and processes related to or responsible for the adverse environmental conditions. The answers necessitate collection, management, and organisation of data sets in suitable categories and their mapping on required scales. Effective and efficient symbolisation and mapping of such data sets was a big problem with achromatic maps in analogue map production environment. Solutions using line and dot patterns for the required types of data organisations did not prove very effective and efficient functionally because of certain limitations of line and dot patterns vis-à-vis visual information processing.

Rising incomes in developing nations, dominance of capitalist market economy and a wider acceptance of consumerism has led to increasing industrialisation, and high rate of resource exploitation in developing economies as well growth in consumption with concomitant increase in energy consumption and greater exploitation of resources. These events in turn have created problems of environmental degradation, resource depletion leading to different types of environmental stresses and degradation.

The information era has brought with it a growing awareness of these problems. Associated with it is the availability of huge amounts of data related with different aspects of environmental problems and the capability for efficient storage and management of such data. Data visualisation is required for efforts towards understanding levels of degradation of environmental systems, environmental stresses, risks and impact assessment in terms of human vulnerability. Need of data visualisation of such data extends to environmental management in efforts towards amelioration and alleviation of worsening conditions of environmental health. Such data visualisations require analysis of data into suitable organisations and their transformation into presentational formats. Since most of data related to such problems have spatial dimensions their presentational transformation has to be in the form of thematic maps.

Maps that represent geospace by space in a two dimensional graphic formats best present the spatial variations of environmental health. These maps at the same time also function as a medium of communication and storage of this information and help in answering questions of what, where and how much. In addition these maps can help in visualising patterns in the environment health distribution and spatial relationships between patterns. In GIS supported situations these maps can also function as an interface to the geospatial data from which the maps were produced and can maintain meaningful information access for data exploration.

Most of the earlier problems faced in the symbolisation and mapping of such data organisations with an achromatic medium in manually produced maps are no more in existence with the personalisation of computers with the advent of powerful desk tops with more than 8 bit colour monitors. Added to this is the availability of 'Windows' compatible and user friendly graphics, mapping and GIS software with map production subsystems. Another development was in the area of peripherals which made available affordable colour printers as well scanners for input of cartographic data. These technological advancements did away with most of the symbolisation and mapping problems of data sets organised in this manner. But with the easy production of such maps in colour on personal computers the mapping of such data organisations brought in problems of a different nature in terms of both functional efficiency and aesthetic considerations

II. Objectives

This paper aims to find data organisations which are compatible with environmental health data sets and select classification routines which match this organisation. In addition, an attempt will be made to lay down a map design approach, particularly in the area of symbolisation related to colour choices, which will result in the production of an effective and efficient map leading to its high degree of usability in related geospatial operations and decision making particularly in planning healthier environments and reduce degradation in a sustainable manner.

III. Environmental Health Data

The recognised variables or indicators of environmental health can be grouped into indicators related to (1) environmental systems (2) environmental stresses and (3) human vulnerability. Indicators in the different groups can be combined, by a suitable statistical routine, into indices which could function as numerical or digital measures that express the state of the health of environment over different locations/areas in geospace at various points or lengths of time.

The indicator scores of environmental health data may be presented as standard normal percentiles of variables, ranging from a theoretical low of 0 to a theoretical high of 100. In other cases the indicator scores of environmental health can also be presented as averages of the constituent variable values. These variables can be divided in three groups. The variables that can measure environmental health in this manner are shown in table1.

Table: 1 Environment health indicators in their respective groups

Environmental Systems	Environmental Stresses	Human Vulnerability
1. Air Quality	1. Air Pollution Reduction	1. Natural Resource Management Status
2. Biodiversity	2. Ecosystem Stresses Reduction	2. Environment Related Health Risks
3. Land Quality	3. Population Pressure Reduction	3. Basic Human Sustenance Status
4. Water Quality	4. Reduction in Green House Gases Emission	4. Natural Disaster Vulnerability
5. Forested Area	5. Waste Treatment and Reduction	
	6. Water Stress Reduction	

3.1 Data Structure

Environmental health status data have a divergent spatial structure. Data in such structures diverges in ascending negative and positive values from a critical or normal value in geospace showing departures towards healthier and unhealthier states. Data that have a divergent spatial structure are often met in geospatial studies and investigations. Brewer (1997 [3]) has cited examples of early research literature that have used such data structures published in 1990s in *Annals of the Association of American Geographers*, *The Professional Geographer* and *Cartography and Geographic Information Systems*, as an example that represent instance of such data structures. Some of these examples can be seen in indices of inequality in economic development and human welfare (Holloway and Pandit 1992 [4]) and in Eyton's (1991[5]) work on accelerating versus decelerating increases in mobile-home residency. These examples also include data structures that are inherently diverging such as male to female ratios among daily commuters to cities and positive and negative residuals from regression analyses.

3.2 Data Organisation

These spatial structures are best suited to a divergent data organization. Such organizations use classification routines that diverge from a central value in the direction of both negative and positive maxima or in other words, where two monotonically increasing size classes of two negative and positive values are put together about a shared mid value point. These monotonically increasing size classes are generally arranged in an arithmetic series. In certain cases these classes can be determined by Jenks (1977 [6]) optimization method also described as the Jenks' natural breaks classification method. Three classification standards can be used for obtaining diverging class interval schemes:

1. Use of an exogenous system of class intervals (Evans 1977 [7]) where a predefined mid value is the score for healthy environment as determined by experts in the field based on the conditions in a particular spatial unit and class sizes on both negative and positive sides are fixed in relation to some meaningful threshold values relevant to different wellness conditions of environmental health.
2. Using Z scores and mean as midpoint where class size is decided in terms of both positive and negative Z scores.
3. Using modal value of the distribution of environmental health index values and equally dividing distance between highest negative index values and positive index values from the modal index value i.e. $x_i - m$ where m is the modal value and x is any value in the distribution of the environmental health indexes.

IV. Symbolisation: Colour Schemes

Creating compatibility between organizations of data being mapped cartographically and the perceptually organised dimensions of colours is the most effective way of apprehending information from data visualisations (Brewer and MacEachren et al. 1997 [8]). Selection of organised and ordered paths across multidimensional colour models such as Munsell and CIELAB result in creating logical progressions of colours for this purpose. These progressions take a diverging form in which two opposites start from a neutral point of a selected value and diverge towards their maxima at both the negative and positive ends. Using a Munsell colour model and putting an accent on a mid or critical value following different colour schemes can be obtained. Brewer (1997 [2]) describes the decision of choosing such colour schemes, in such cases, in the words:

"The choice … … to use a diverging scheme …….. hinges on whether the cartographer wishes to emphasize both extremes in a distribution and whether there is a critical point within the distribution that the cartographer also wishes to emphasize with light colors. This critical value may be zero, the mean, the median …… or otherwise relevant to the data mapped."

4.1 Considerations of Aesthetic Aspects of Colour Schemes: Harmony

Colour theory recognizes harmony as the most important aspect of colour choice, which produces the aesthetic quality in any colour arrangement. The other two aspects relate to balance and contrast in such arrangements which act to supplement the harmony and the aesthetic quality. Harmony, in the context of colour, is defined as a varied arrangement of colours which point to some kind of interrelationships. These relations might be based on the individual colour dimensions of hue, value and chroma and their different combinations. Colour harmony creates a sense of logical structure or order and unity that produces a pleasing visual experience or a sensation of beauty (Albers, 1975 [9]); Munsell 1991[10]; Luke 1996[11]).

The aesthetic aspects of colour, recognised in the manner of Karssen (1980 [12]), are also regarded as forming another set of possible functional properties of the overall map design (Wood, 1993 [13]). Such functional properties relate to the visual processing of information and emotional influences on motivation in map use. Motivation in map use relates to degree of interest aroused in a map or a lack of it. The human mind tends to reject a chaotic unbalanced visual experience, which cannot be organized. In case of the visual processing of information their possible effects can be seen in the guidance of selective attention and allocation of attentional resources at a higher level of such processing.

Colour harmony in practice can be achieved by using complementary, analogous and monochrome arrangements, which are based on the interrelations of the two other colour dimensions of value and chroma. Complementary colours are those, which are directly opposite to each other on a horizontal cross-section of any colour solid or on any colour wheel. In addition to this some other types of complementary pairs are obtained. Split-complementary are those hues that lie on either side of a hue complement while Tetradic split-complements represent two pairs of split-complementary hues. Analogous colours can be identified in those hues, which are closely related in terms of colour families or are related by their positions on the colour wheel. Harmony in monochrome is created by manipulation of the levels of either value or chroma (Chevreul, 1981[14]; Chijiiwa 1987[15]; Sawahata, 2000[16])

4.1.1 Harmonious Colour Schemes

The first colour scheme in this series is based on analogous hues. The last two schemes are made by complementary and split complementary hues.

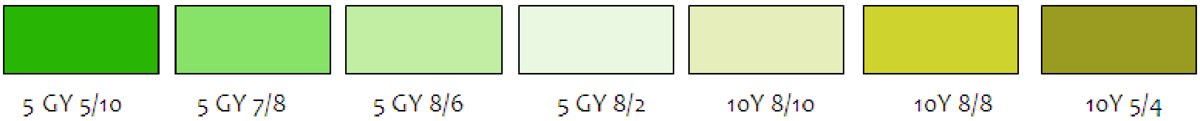

Figure 1 Selection of Analogous Hues: A combination of 5GY and 10Y

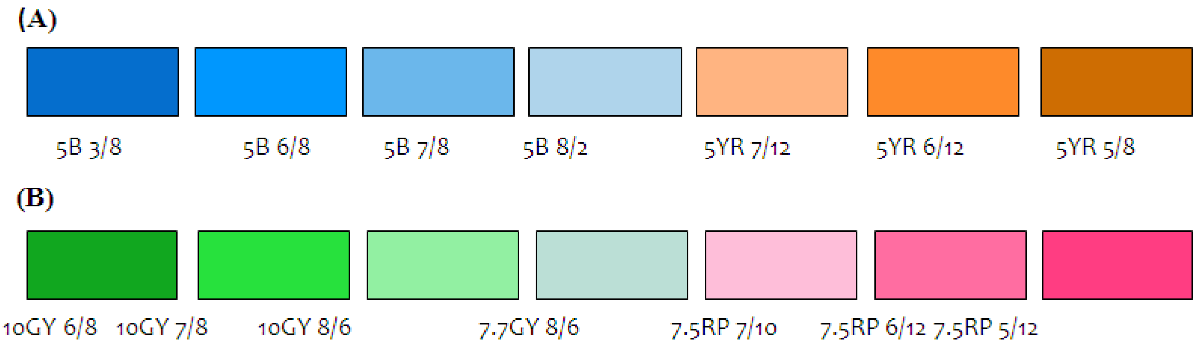

Figure 2 Selection from Harmonious Hues: A. Complementary Hues B. Split Complementary Hues (One Hue only)

4.2 Colour Schemes Derived from Spectral and Partial Spectral Hue Sequence

The spectral sequence consists of the hues evoked by the wavelengths of visible spectrum constituting spectral progression. This hue progression varies in wavelengths from about 390 to 700 nm. In terms of frequency, this corresponds to a band in the vicinity of 430–790 THz. The hues of this progression tend to be strongly saturated. These strong saturation levels vary from hue to hue. These hues at the same time vary greatly on the dimension of value too (Arnheim, 1969: 329 [17]). These hues in this sequence lie between violet and red. An approximation of these spectral hues described as 'pigment echo of spectral sequence' in the words of Albert Munsell (1991:22 [10]) is obtained by replacement of violet by the extra-spectral hu- purple. When located in Munsell colour space, the sequence represents a movement in the three dimensional segment of limited vertical extent in which the path described by such a movement tilts towards hues of comparatively longer wave-lengths making one end of the progression darker and the other comparatively lighter. The hues lying in such sequence follow a semi circular path in an anticlockwise direction and are located at irregular distances from the neutral gray axis at their maximum chromatic purity. A diverging colour scheme is formed from this progression by dividing the spectrum in two parts around a greenish grey of high value which divides this progression in short and long wavelength components. The choice of hues is based, to the extent possible, on the colour association in the context of states of environmental health. Another colour scheme in this progression is made by spectral hues excluding Indigo hue from the spectral sequence. The use of these colour schemes is advocated strongly by Ware (1988 [18]) and Brewer (1997 [3]).

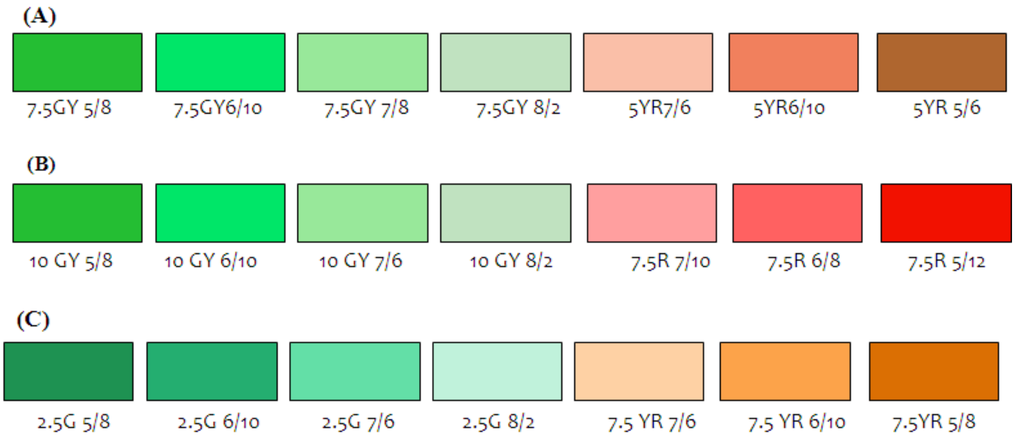

Figure 3. Selections from Spectral Hues A. Selections from Spectral Colours: A. combination of 7.5GY and 5YR, B. Combination of 10 GY and 7.5 R, C. Combination of 2.5 G and 7.55YR

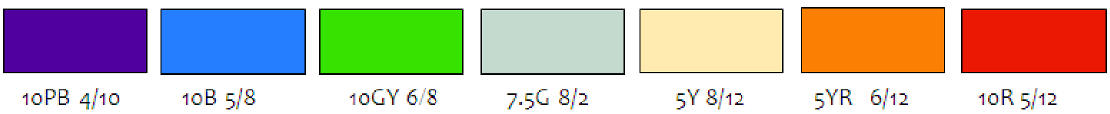

Figure. 4 Spectral Hues

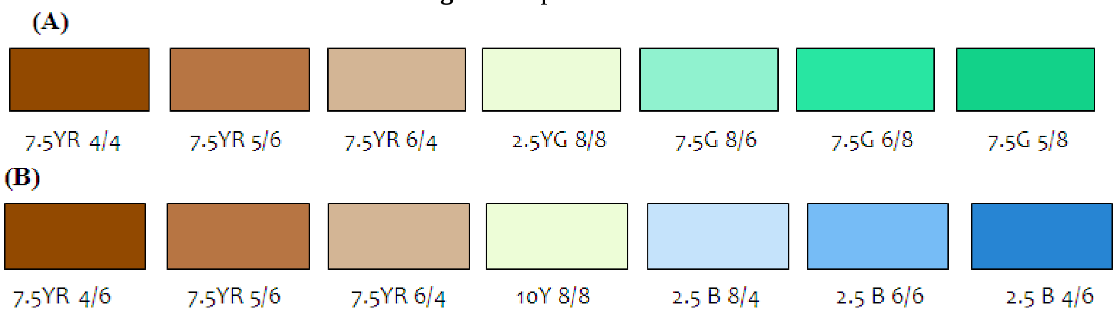

Figure 4. Partial Spectral Colour Schemes with value and chroma changes: A. Progression without Red, B. Progression without Green

4.2 Monochrome Value-Chroma Sequences

This type of ordered monochrome series is produced by the combinations of chroma and value when the dimension of the two hues being used is held constant. Such sequences are obtained by combining successively higher or lighter values with similarly ordered low or weaker chromas. The sequences formed in this way vary from a combination of high or dark values with high proportion of pure chromatic colour to a low or light value with a low proportion of chromatic content. Munsell had chosen to describe such combinations by the term 'saturation' (Luke, 1996: 9 [11]). This combination can also be taken to form another graphic variable. These sequences represent a diagonal movement in a vertical constant hue plane. Any selection in the sequence takes a path that starts and follows the diagonal from a point close to the neutral gray axis in lower value levels. It sometimes tends to bend inwards from the diagonal in the higher value levels at the end of the path in some of the hues.

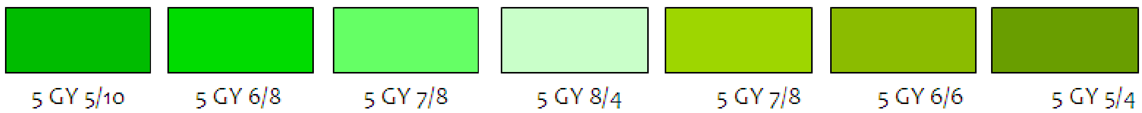

Figure 5 Monochrome scheme of 10 GY with Value and Chroma changes

The visual relationships in these sequences are based on the ordered gradations of both value and chroma to meet the functional requirement of their use. The synchronous and ordered differences in combination are used for characterisation of magnitude intervals and their order in the referent contents.

4.3 Colour Associations and Meanings

Colour in itself is a medium of expression using its own vocabulary. The meaning can be changed completely, simply by changing the chroma or value of a hue**.** Human being's culture and their personal past experiences have a bearing on how they spontaneously react to a particular colour to a large extent. However explaining these reactions is not actually that simple. Currently neuroscientists both in medical sciences and psychology are finding that humans by their inbuilt neural mechanisms are made to respond in highly similar ways to colour stimulus. These findings suggest that it is, to a certain extent, possible to agree on certain traits in such reactions across culture and experiences. When selecting colour schemes, for a given purpose, it is prudent to keep in mind the effect that it might be creating.

Generally it can be taken that some of the colour reactions to a certain extent will have a certain kind of meaning and associated reaction. Red is alerting, excites vision and indicates danger. Birren (1961[19]) associates blood, fire, danger, rage, and fierceness to red. Blue, as noted by Birren (1961 [19]), is commonly associated with some of the adjectives like cold, and sober. Most people associate blue with security and safety. The American Heritage Dictionary of the English Language, (Fourth Edition) defines security as freedom from risk or danger and safety. Blue is also taken as serene, blissful quite and heavenly. Green is taken as natural, and as natural is associated with better. Green is ranked second with purple in preference by all people regardless of age or gender. Purple is supposed to uplift, calm the mind and nerves, and offers a sense of spirituality in terms of closeness to nature. The colour purple connotes luxury, wealth, and sophistication also. Birren further notes that purple has a historically close association with dignity –the quality of being worthy of esteem or respect, degree of excellence, grandeur of bearing or appearance. Purple is ranked second in preference with green after blue. Yellow is seen to correlate to associations like exciting, jovial, cheerful, peaceful, youthfulness in high chromas and mid values. It is ranked on these associations at the second place among the hues: red, purple, yellow-red, green, blue, and white respectively in Birren's study (1961 [19]). Brown is low chroma Yellow-Red which is a close relative of red and yellow. In low chroma it is seen as desolate and bleak and is associated with absence of green when it is a time of falling leaves in the seasons that come between winters and summers. The absence of green in surroundings usually elicits strong negative association. In case of the second dimension of colour-value, its middle ranges show the strength and freshness, while the decreasing or low chroma stand for bleak, drab and desolate while reverse appears true for higher chromas.

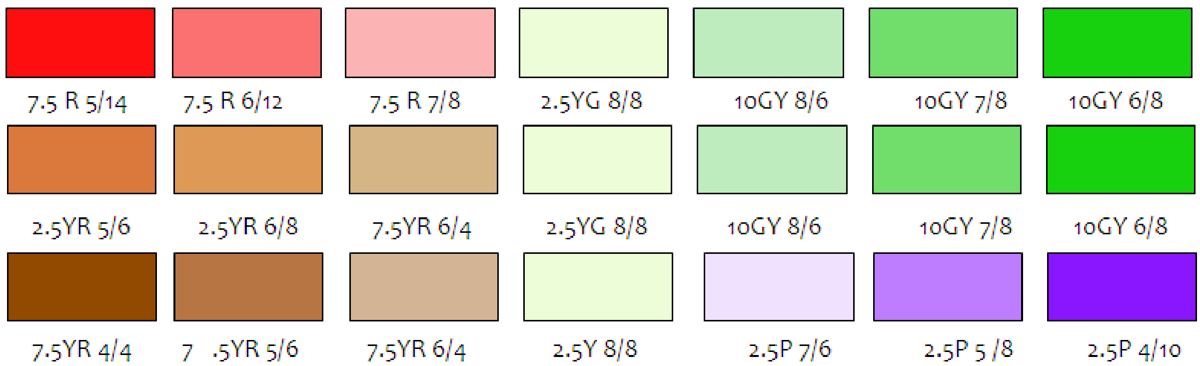

Figure 6. Graded Diverging Colour Schemes based on combination of hues using colour meaning considerations and colour associations. The required effect in colour schemes has been given by the use of colour value and chroma in addition to hues.

V. Conclusions

The suggested colour schemes have their bases in some authoritative studies and experimental studies. It is hoped that these will prove helpful to cartographers geographers and other professional who work on and use GIS systems in their work (Brewer 1997 [3]), (John

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